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Effets des stimulations sensorielles par vibrations des muscles du cou sur les perturbations posturales secondaires aux troubles de la représentation spatiale

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Table des abréviations

AVC	Accident Vasculaire Cérébral
BBS	Berg Balance Scale
FNM	Fuseau Neuromusculaire
HAS	Haute Autorité de Santé
IRMf	Imagerie par Résonance Magnétique fonctionnelle
LBA	Longitudinal Body Axis
MI	Cortex Moteur Primaire
NMV	Neck Muscle Vibration
OTG	Organe de Golgi
PASS	Postural Assessment Scale for Stroke
SI	Cortex Somatique Primaire
SII	Cortex Somatique Secondaire
SSA	Subjective Straight Ahead
SSV	Subjective Visual Vertical
VH	Verticale Haptique
VP	Verticale Posturale
VV	Verticale Visuelle

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Avant-Propos

L'être humain est caractérisé par sa position érigée, c'est un « bipède » qui se définit par une position debout en appui sur ses 2 pieds (Paillard, 2016). Cette posture peut être perturbée, notamment, dans les suites d'un accident vasculaire cérébral (AVC). L'AVC est un problème majeur de santé publique. En effet, selon la Haute Autorité de Santé, on en dénombre en France chaque année 130 000 nouveaux cas. L'AVC est responsable de 40 000 décès par an, représentant la 3ème cause de mortalité et la 1ère cause de handicap d'origine non traumatique ("HAS - Juin 2012). D'autre part, la fréquence des AVC étant liée à l'âge, le vieillissement de la population laisse présager un accroissement du nombre de personnes atteintes dans les années à venir ("HAS - Mars 2007). De plus, en France, cette maladie génère un coût socio-économique important estimé à 8,7 milliards d'euros en 2007 (De Pouvourville, 2016). Une des causes de handicap chez le patient victime d'un AVC sont les perturbations posturales (Pérennou et al., 2014). Ces perturbations posturales provoquent un plus grand risque de chute et sont source d'une perte d'autonomie pour le patient (Mansfield et al., 2015). Selon les données de la littérature, le taux de chute annuel des patients victimes d'un AVC s'élève entre 10 à 45% de la population post-AVC (Kim & Kim, 2014; Pérennou et al., 2005a, 2005b; Teasell et al., 2002; Weerdesteyn, 2008). Ces chutes sont plus fréquentes dans la population AVC comparativement à une population saine du même âge avec notamment plus de récidives (Weerdesteyn et al., 2008). Elles sont source de multiples conséquences physiques telles que des fractures, essentiellement localisées au niveau de la hanche, du côté parétique, à l'origine de conséquences accrues pour ces patients avec moins de chance de récupération de mobilité et un taux de mortalité après chirurgie plus important comparé à une population du même âge (Weerdesteyn et al., 2008). En dehors des conséquences physiques, il est nécessaire de prendre en compte également les conséquences psychosociales secondaires à ces chutes. En effet, 80% des patients AVC chuteurs développent une peur de tomber provoquant chez 44% de ces patients une diminution des activités et ainsi progressivement une perte d'autonomie (Diagne et al., 2013; Kim & Kim, 2014). Ces patients présentent un risque accru d'isolement social du fait de leur peur de chuter, accentué par l'inquiétude de leur aidant. Cet isolement social n'est que néfaste car il accélère le déconditionnement physique et augmente ainsi le risque de chute. Ainsi la rééducation des troubles de l'équilibre est l'un des objectifs majeurs de la rééducation après un AVC.

Les perturbations posturales en position debout après un AVC sont fréquemment caractérisées par une asymétrie d'appui qui se traduit par un déficit d'appui sur le membre parétique associé à une augmentation des oscillations posturales (Genthon et al., 2008; De Haart et al., 2004; Pérennou, 2005; Pérennou et al., 1996; Rode et al., 1997). L'asymétrie d'appui est corrélée à un moins bon équilibre (Bonan et al., 2017; Corriveau et al., 2004; Mansfield et al., 2012; Peters et al., 2014), à un niveau plus élevé de dépendance fonctionnelle et à une durée d'hospitalisation plus longue (Sackley, 1990). A ce jour, les causes de l'asymétrie d'appui restent encore débattues.

Ce travail de thèse a pour but, dans un premier temps d'améliorer la compréhension des mécanismes impliqués dans l'asymétrie d'appui suite à d'un accident vasculaire cérébral; et dans un second temps, d'étudier l'efficacité d'une approche par stimulations proprioceptives par vibration des muscles du cou sur la correction de cette asymétrie d'appui. Ce manuscrit se présente sous la forme d'une thèse d'articles, organisée en 3 parties ; la 1ère partie correspond à une introduction générale, la 2ème partie recense mes contributions scientifiques et se divise en deux chapitres. Le premier chapitre porte sur l'asymétrie d'appui post AVC, et comporte une revue systématique rapportant les relations entre l'asymétrie et les caractéristiques de l'hémiplégie, l'équilibre et la marche (*Article 1 soumis)* et un deuxième article qui vise à approfondir la relation entre l'asymétrie d'appui et les troubles de la représentation spatiale (*Article 2 publié*). Le second chapitre est basé sur l'utilisation d'une approche de rééducation que sont les vibrations des muscles du cou visant à améliorer spécifiquement les troubles de l'équilibre secondaires à des perturbations de la représentation spatiale. Ce chapitre comprend un premier article synthétisant les données de la littérature sur les effets des vibrations des muscles du cou, sur l'équilibre et la représentation spatiale (*Article 3 publié)* et le 2ème d'une étude expérimentale testant l'efficacité des vibrations répétées sur l'asymétrie posturale *(Article 4 soumis*). Enfin la 3ème et dernière partie est une discussion générale.

Partie 1 : Introduction générale

1. Les mécanismes posturaux

Le contrôle de la posture s'appuie sur l'intégration des informations sensorielles que sont les informations visuelles, vestibulaires et somesthésiques qui s'élaborent dans différents référentiels spatiaux afin que le sujet puisse élaborer une ou des représentations de son corps dans l'espace (Barra et al. 2010; Bonan et al. 2013; Galati et al. 2010; Lestienne and Gurfinkel, 1988; Saj et al. 2014). Le contrôle postural se conçoit selon une double composante ; une composante d'orientation et de stabilisation (ou équilibre) posturale (Amblard, 1998; Barra et al., 2010; Halligan et al., 2003; Horak and Macpherson, 2011;Massion, 1994; Pérennou et al., 1996; Rousseaux et al., 2014). Le premier objectif est d'assurer l'orientation du corps dans l'espace qui consiste à la fois pour le sujet à organiser ses différents segments corporels les uns par rapport aux autres en fonction de l'environnement qui l'entoure mais également à orienter les objets de son environnement par rapport à lui-même. Le second objectif est d'assurer une stabilité posturale qui est défini comme étant « *la capacité à maintenir la projection de la verticale passant par le centre de gravité à l'intérieur de la surface d'appui au sol* » (Paillard, 2016) La surface d'appui au sol constitue le polygone de sustentation dans lequel le sujet va osciller dans la limite de sa stabilité et éviter un risque de chute. Afin d'obtenir cette stabilité, deux conditions sont nécessaires ; la résultante des forces appliquées, à savoir les forces externes (gravité) et internes émanant du corps, doit être nulle ainsi que le moment des forces (Massion 1994 ; Paillard, 2016) Ces deux impératifs que sont la stabilisation et l'orientation posturale bien qu'indépendants (Paillard, 2016) sont nécessaires au maintien de cette posture afin que le sujet puisse interagir dans son environnement.

Dans les suites de l'AVC, cette posture va être perturbée notamment dans sa composante d'orientation. Ces perturbations posturales peuvent être caractérisées en position debout par différents comportements asymétriques tels que la latéropulsion, caractérisée par une inclinaison du côté hémiplégique (Dai et al., 2018; Pérennou et al., 2008; Roller, 2004) qui peut aller jusqu'à une résistance à la correction de cette posture (Karnath, 2007; Karnath et al., 2000; Karnath & Broetz, 2003; Paci et al., 2009; Pérennou et al., 2002) et par une asymétrie d'appui qui se traduit par un déficit d'appui sur le membre parétique associé à une augmentation des oscillations posturales (de Haart et al., 2004; Genthon et al., 2008a; Pérennou et al., 1996; Pérennou, 2005; Rode et al., 1997). Nous nous sommes plus particulièrement penchés sur la compréhension de l'asymétrie d'appui dans ce travail de thèse.

A ce jour, les mécanismes sous tendant l'asymétrie d'appui après un AVC ne sont pas parfaitement compris. En dehors des déficits sensitifs, moteurs et d'hyperactivité réflexe du tonus musculaire (Barra et al., 2009; Genthon et al., 2008b; Sackley, 1990; Singer et al., 2013), les troubles de la représentation du corps dans l'espace participeraient également à cette perturbation posturale (Bonan et al., 2006a; Pérennou et al., 1999, 2014; Rode et al., 1997). L'élaboration de la représentation spatiale s'appuie sur l'intégration des informations visuelles, vestibulaires et somesthésiques dans différents types de référentiels spatiaux permettant la construction mentale des représentations des différentes parties du corps les unes par rapport aux autres et de celles-ci par rapport à l'environnement (Barra et al., 2010; Bonan et al., 2013; Galati et al., 2010; Isableu & Vuillerme, 2016; Saj et al., 2014). Ces représentations sans cesse actualisées en fonction de l'évolution des interactions du sujet avec son environnement (Paillard, 2016) permettraient d'organiser le contrôle postural de façon anticipée ou en réaction aux perturbations de l'environnement en tenant compte de l'interaction des différents segments (géométrie, masse) entre eux (Isableu & Vuillerme, 2016; Pérennou et al., 1996).

2. Les informations sensorielles

2.1 Les informations visuelles

Les informations sensorielles sont ainsi nécessaires à l'élaboration mentale de la représentation du corps dans l'espace. Les informations visuelles issues de l'organe œil et plus spécifiquement de la rétine participent au contrôle postural notamment dans l'orientation du corps dans son environnement (Paulus et al., 1984 ; Dupui, 2016). La rétine se divise en deux zones à l'origine de deux mécanismes bien distincts l'un de l'autre. La fovéa que constitue la partie centrale de la rétine, composée de cônes, est sensible aux variations de luminosité et de couleurs (Vibert, 2011). Cette partie centrale de la rétine permet d'identifier de façon précise les objets permettant de les caractériser (Vibert, 2011). Elle est impliquée dans le contrôle postural lors de la détection des informations de hautes fréquences afin d'assurer une action de stabilisation (Amblard, 1998). Au contraire, la partie périphérique de la rétine, constituée de bâtonnets, fournit des informations relatives au mouvement (Dupui, 2016). Cette zone de la rétine est impliquée dans le maintien postural lors de la détection des informations de basses fréquences participant à l'orientation du corps (Amblard, 1998). Ces informations visuelles fournies par le système visuel participent à l'élaboration du sens de la verticalité (Piscicelli & Pérennou, 2016). Des informations d'ordre proprioceptives sont également apportées par l'appareil visuel via les muscles oculomoteurs qui renseignent sur l'orientation du regard (Dupui, 2016; Isableu & Vuillerme, 2016).

Les informations visuelles recueillies par la rétine vont ensuite être transmises via les voies optiques jusqu'au cortex visuel (Amblard, 1998; Bullier, 1989; Dupui, 2016). Les informations parviennent de façon rapide via la voie dorsale vers l'aire pariétale et plus particulièrement dans la partie occipito pariétale du cortex (Bullier, 1989) impliquée dans la vision périphérique et la position des objets dans l'environnement (Bullier, 1989). Elles transitent de façon plus lente via la voie ventrale en direction du cortex inféro-temporal permettant la reconnaissance des objets (Bullier, 1989; Vibert, 2011).

2.2 Les informations vestibulaires

Concernant les informations vestibulaires, les récepteurs vestibulaires fournissent, notamment, des informations sur la position de la tête et son orientation par rapport à la gravité (Perrin et al., 2016; Sakka &Vitte, 2004; Vibert, 2011). Les canaux semi-circulaires sont au nombre de trois et disposés selon les trois plans de l'espace (Perrin et al., 2016; Sakka

& Vitte, 2004; Vibert, 2011). Constitués de cellules ciliées, ils permettent de détecter les accélérations angulaires de la tête. L'utricule et le saccule, nappés d'une membrane otoconiale elle-même constituée de microcristaux de calcium appelés les otolites, permettent de détecter des accélérations linéaires et fournissent ainsi des informations sur la position de la tête par rapport à la gravité (Perrin et al., 2016; Sakka & Vitte, 2004; Vibert, 2011).

Les informations vestibulaires vont transiter via le nerf vestibulaire pour rejoindre les quatre noyaux vestibulaires situés au niveau du tronc cérébral (Perrin et al., 2016; Sakka &Vitte, 2004; Vibert, 2011). Parmi les voies partant de ces noyaux vestibulaires, les voies vestibulo-oculaires participent à la stabilisation du regard en fonction des mouvements de la tête. Les voies vestibulo-spinales se projettent au niveau de la moelle épinière. Ces voies agissent sur le tonus des muscles posturaux et participent au maintien de la tête, du tronc et des membres inférieurs en luttant contre la gravité (Brandt, 1991; Dichgans & Diener, 1989; Perrin et al., 2016). D'autres projections ont été mises en évidence, notamment en direction du cervelet, via les voies vestibulo-cérébelleuses impliquées dans la coordination des mouvements (Sakka & Vitte, 2004), et du thalamus qui fait le relai vers le cortex. Les données de la littérature s'accordent pour souligner que, ni les expérimentations animales ni l'application de stimulations sensorielles n'ont révélé l'existence d'un véritable cortex vestibulaire spécialement individualisé. Elles confirment cependant l'existence de multiples projections corticales, notamment, dans les aires insulaires, pariétales (somato-sensoriel), frontales, temporales et cingulaires (Lopez et al., 2005; Sakka &Vitte, 2004).

2.3 Les informations somesthésiques

Les informations somesthésiques participent au contrôle postural en fournissant des informations relatives à la position du corps et, notamment, de l'agencement des différents segments corporels les uns par rapport aux autres (Boyas, 2016; Isableu & Vuillerme, 2016). Ces informations sont constituées des voies extéroceptives (la sensibilité du toucher via les récepteurs cutanés), des voies proprioceptives (position et mouvement du corps via les récepteurs musculaires, tendineux et articulaires) et des voies intéroceptives (sensibilité interne liée aux informations viscérales) (Vibert, 2011). Les informations proprioceptives sont fournies par des récepteurs appelés « propriocepteurs » que constituent les faisceaux neuromusculaires (FNM). L'ensemble des muscles du corps sont composés de FNM, notamment, au niveau des mains et du cou où la densité de ces propriocepteurs est la plus importante (Boyas, 2016; Dupui, 2016). Par l'intermédiaire des fibres afférentes présentes dans le FNM (fibres type Ia et II), les FNM renseignent sur l'état de longueur du muscle (fibres Ia et II) et sur ses variations (fibres Ia) (Boyas, 2016; Vibert, 2011). Lorsqu'ils sont localisés au niveau des muscles posturaux, les FNM participent au maintien du tonus musculaire postural par des boucles médullaires dont la plus connue est le réflexe myotatique et permettent ainsi de lutter contre la gravité (Boyas, 2016; Dupui, 2016). Leur forte densité dans l'ensemble du corps, ainsi que leur grande sensibilité, soulignent leur rôle déterminant dans le contrôle postural comparé aux autres propriocepteurs.

Situés au niveau de la jonction myotendineuse, les organes de Golgi (OTG) sont également impliqués dans la proprioception. Via les fibres afférentes (Ib), ils renseignent sur l'état de tension musculaire active (Boyas, 2016) et ont un rôle protectionniste du muscle par l'intermédiaire du réflexe myotatique inverse (Boyas, 2016) Parallèlement, les propriocepteurs articulaires tels que les corpuscules de Ruffini, Pacini et ceux de Golgi- Mazzoni participent à un moindre niveau au contrôle postural en fournissant des informations sur l'état de tension et de compression des différentes articulations, surtout pour des positions extrêmes (Boyas, 2016; Vibert, 2011). Concernant les récepteurs cutanés, il existe quatre types que sont les disques de Merkel, les corpuscules de Meissner, les corpuscules de Ruffini et ceux de Pacini dont la densité et la répartition sont variables en fonction des zones de la peau (Boyas, 2016). Ces récepteurs, notamment ceux localisés au niveau de la sole plantaire (Janin, 2016) renseignent sur l'état de tension et de compression de la peau lors du mouvement (Boyas, 2016; Janin, 2016) et participent au maintien postural.

Les informations somesthésiques vont transiter via les voies ascendantes ; la voie lemniscale regroupe surtout les informations tactiles et proprioceptives tandis que la voie extra-lemniscale concentre les informations sur la douleur et la température et à un moindre degré les informations proprioceptives (Vibert, 2011). De ce fait, seule la voie lemniscale sera développée dans la suite de ce travail. Parallèlement à cette voie lemniscale, la voie cérébro-spinale transmet des informations somesthésiques directement au niveau du cervelet. Toutefois, les informations qui transitent par cette voie cérébro-spinale ne sont pas d'ordre conscient comparées aux informations transmisses via les autres voies (Boyas, 2016; Vibert, 2011). La voie lemniscale va transiter via le bulbe où s'effectue la décussation puis rejoint le thalamus contro-latéral au niveau du noyau ventral postérieur (Vibert, 2011). De ce noyau ventral postérieur, des projections se font dans le tronc cérébral vers plusieurs aires corticales dont principalement le cortex somatique primaire (SI) qui correspond au gyrus post-central du lobe pariétal et aux aires de 1, 2, 3a et 3b de Brodman (Vibert, 2011). De cette aire corticale sont envoyées plusieurs connexions, notamment en direction de l'aire somatique secondaire (SII), du cortex moteur en particulier primaire (M1) ainsi qu'en direction des aires controlatérales via le corps calleux et d'aires sous corticales (Vibert, 2011).

Le contrôle postural s'appuie ainsi sur ces différentes entrées sensorielles. Celles-ci fournissent de façon redondante une multitude d'informations sensorielles (Isableu &Vuillerme, 2016) dans l'objectif du maintien postural. Cette redondance des informations sensorielles présente l'intérêt de fournir des informations complémentaires de chaque entrée sensorielle prise indépendamment afin de les croiser entre elles (Fourneau, 2012; Isableu & Vuillerme, 2016). La pondération de chaque entrée sensorielle, à savoir leur contribution dans le maintien postural, a une certaine variabilité interindividuelle (Fourneau, 2012; Isableu & Vuillerme, 2016). Toutefois, en cas de discordance entre deux entrées sensorielles, notamment entre les visuelles et les vestibulaires, l'entrée visuelle serait privilégiée au détriment de l'entrée vestibulaire afin de stabiliser le regard, en particulier dans les suites d'un AVC (Bonan et al., 2004, 2006; Perrin et al., 2016).

3. Les référentiels spatiaux

Afin de maintenir sa posture et pouvoir se mouvoir, le sujet va élaborer une ou des représentations de son corps à partir des informations sensorielles vues précédemment et qui vont être intégrées dans différents référentiels spatiaux tels que le référentiel gravitaire, égocentrique et allocentrique.

Le référentiel gravitaire, également décrit sous le terme de référentiel géocentré (Isableu & Vuillerme, 2016; Lopez et al., 2005), est issu de la force gravitationnelle le rendant absolu et constant (Isableu & Vuillerme, 2016; Lopez et al., 2005; Mouchnino, 2016). Le système vestibulaire joue un rôle primordial dans l'élaboration de ce référentiel via les otolites (Berthoz, 1997; Bringoux et al., 2007). Toutefois, les informations visuelles ainsi que somesthésiques, fournies notamment par les gravicepteurs viscéraux (présents autour des reins et gros vaisseaux), les fibres Ia et Ib, sont également impliquées (Bringoux et al., 2003; Piscicelli &Pérennou, 2016).

Le référentiel égocentrique décrit comme étant « *centré sur le corps* » prend comme référence le corps à partir duquel l'environnement est codé (Committeri et al., 2007; Galati et al., 2010; Jeannerod & Biguer, 1989; Saj et al., 2014). Ce référentiel est caractérisé par l'intégration des informations relatives aux objets présents dans l'environnement par rapport au sujet lui-même (Colombo, 2017; Galati et al., 2010; Isableu & Vuillerme, 2016; Saj et al., 2014). Bien que l'ensemble des informations sensorielles participent à la construction de ce référentiel, ce sont les informations somesthésiques qui seraient le plus impliquées dans cette élaboration et notamment les informations provenant du tronc et de la tête (Barra et al., 2009, 2007; Isableu & Vuillerme,2016).

Le référentiel allocentrique (ou exocentré) se distingue du référentiel égocentrique de par l'intégration des informations relatives des objets présents au sein de l'environnement les uns par rapport aux autres, indépendamment de la position du sujet (Colombo et al., 2017; Galati et al., 2010; Isableu & Vuillerme, 2016; Saj et al., 2014). L'élaboration de ce référentiel est basée sur l'intégration de l'ensemble des informations sensorielles mais plus particulièrement sur les informations visuelles (Isableu & Vuillerme, 2016).

Ces trois référentiels, par l'intermédiaire de l'intégration des informations sensorielles permettent l'élaboration d'une ou plusieurs représentations simultanées du corps dans l'espace. L'utilisation de ces représentations codées selon différents référentiels (gravitaire, égocentrique et allocentrique) est très changeante en fonction de la tâche en cours et de l'environnement avec toutefois une variabilité inter-individuelle (Isableu & Vuillerme, 2016). Dans un objectif d'orientation et de stabilisation du corps, il est difficile de définir quels sont les référentiels sélectionnés et leur pondération (Isableu & Vuillerme, 2016). Afin de comprendre les mécanismes sous tendant les troubles posturaux, nous avons choisi de sélectionner des biomarqueurs des troubles de la représentation spatiale se référant à ces différents types de référentiels spatiaux : à travers la perception du droit devant, de l'axe longitudinal et de la verticale.

4. Les biomarqueurs de l'évaluation de la représentation du corps dans l'espace

Afin d'appréhender et d'évaluer la représentation du corps dans l'espace, plusieurs biomarqueurs de la cognition spatiale sont proposés dans la littérature : la perception du droit devant par le biomarqueur Subjective Straight Ahead (SSA), la perception de l'axe longitudinal via le biomarqueur Longitudinal Body Axis (LBA) qui sont considérés comme des biomarqueurs égocentriques puis la perception de la verticale via les biomarqueurs Verticale Visuelle (VV), Verticale Haptique (VH) ou Verticale Posturale (VP) qui sont considérés comme des biomarqueurs allocentrés. Ces biomarqueurs de la représention spatiale peuvent être mesurés selon différentes modalités ; visuelle, corporelle ou haptique.

La mesure du « droit devant ou subjective straight ahead (SSA) » (Chokron, 2003; Hugues et al., 2015; Jeannerod & Biguer, 1989; Kuhn et al., 2010; Rousseaux et al., 2014) peut se mesurer selon deux modalités différentes : haptique ou visuelle. La modalité haptique consiste à demander au sujet, en position assise et en l'absence de vision, avec sa main de pointer « droit devant » de manière à diviser l'espace en deux parties (Figure 1) (Chokron, 2003; Hugues et al., 2015; Jeannerod & Biguer, 1989; Rousseaux et al., 2014). Dans le cadre de la modalité visuelle, également réalisée dans le noir, un point lumineux est projeté dans différentes positions face au sujet, celui-ci doit informer verbalement l'examinateur de la façon d'ajuster la position du point jusqu'à ce qu'il se trouve dans la position droit devant (Kuhn et al., 2010). Ce biomarqueur s'appuie sur l'ensemble des entrées sensorielles mais plus spécifiquement sur les informations somesthésiques (Jeannerod & Biguer, 1989; Saj et al., 2008). L'évaluation de ce biomarqueur réalisée sous Imagerie Résonnance Magnétique (IRM) fonctionnel a montré des activations des deux hémisphères cérébraux mais une prédominance à droite avec en particulier le réseau frontotemporal qui comprend, notamment, les régions pariétales postérieures, le lobule pariétal inférieur (autour de la jonction temporo-pariétale) et, dans une moindre mesure, le cortex prémoteur latéral et postérieur, le gyrus frontal inférieur droit et le cortex prémoteur interne (Galati et al., 2001, 2000; Rousseaux et al., 2014, 2013; Saj et al., 2014a).

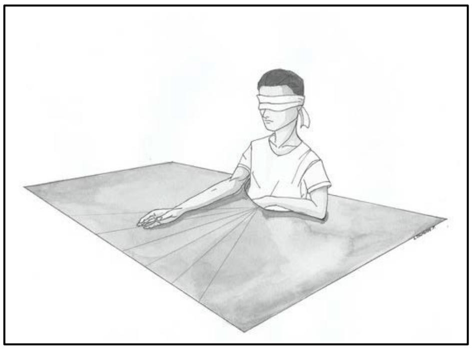

Figure 1 : Mesure de la perception du droit devant ou subjective straight ahead (SSA)

La mesure de la perception de l'axe longitudinal (ou longitudinal body axis (LBA)) (Figure 2) (Barra et al., 2007; Hugues et al., 2015; Luyat et al., 1997) étant réalisée dans une chambre noire ; le sujet en position allongée doit indiquer lorsqu'une baguette fluorescente est alignée avec l'axe médian de son corps. Cette évaluation réalisée en position allongée, les informations vestibulaires sont abolies au profit des informations somesthésiques (Barra et al., 2007; Lopez & Blanke, 2010; Luyat et al., 1997). La réalisation de cette tâche activerait principalement le réseau frontopariétal de l'hémisphère droit (Galati et al., 2010, 2000; Moulinet et al., 2016).

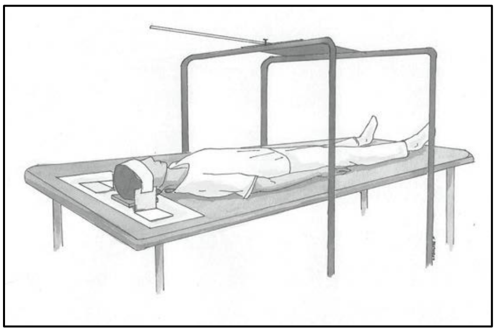

Figure 2 : Mesure de la perception de l'axe longitudinal ou longitudinal body axis (LBA)

La perception de la verticale peut s'effectuer selon différentes modalités ; visuelle, haptique, posturale (Pérennou et al., 2014; Piscicelli & Pérennou, 2016). En modalité visuelle, cette mesure consiste à demander à un sujet assis dans le noir, d'orienter verticalement une baguette lumineuse (Figure 3) (Bonan et al., 2006a; Pérennou et al., 2014; Piscicelli & Pérennou, 2016, 2017). Du fait de sa simplicité d'évaluation et du faible coût du matériel nécessaire (Piscicelli & Pérennou, 2016), cette modalité d'évaluation de la représentation de la verticale est couramment utilisée tant sur le plan de la recherche qu'en clinique. Cette modalité évalue essentiellement la contribution de l'entrée vestibulaire. En effet, l'entrée visuelle est abolie par le choix de placer le sujet dans le noir supprimant tout indice visuel (Piscicelli & Pérennou, 2016). De plus, la baguette lumineuse peut être déplacée directement par l'examinateur, de ce fait l'entrée proprioceptive haptique n'est pas mise à contribution.

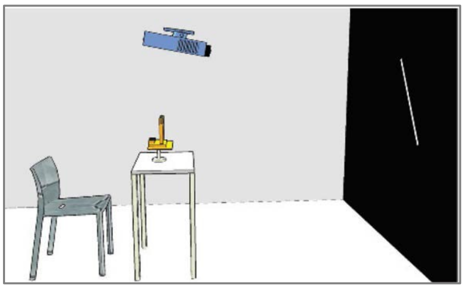

Figure 3 : Mesure de la perception de la verticale en modalité visuelle (subjective visual vertical SVV)(Bonan et al., 2007; Piscicelli & Pérennou, 2017).

Lorsque la baguette lumineuse est déplacée directement par le sujet, on parle alors de verticale haptique (VH). Si cette modalité d'évaluation est moins répandue (Piscicelli & Pérennou, 2016), elle présente l'intérêt d'évaluer, en plus des informations vestibulaires, la contribution des informations somesthésiques lors de la stimulation de la baguette lumineuse (Piscicelli & Pérennou, 2016). Ainsi, mise à part l'information visuelle, cette modalité permet d'évaluer la contribution des autres informations à la construction de la perception de la verticale (Pérennou et al., 2014; Piscicelli & Pérennou, 2016).

En modalité posturale, la perception de la verticale peut être appréhendée par différents dispositifs ; les chaises motorisées (Karnath et al., 2000), le simulateur de vol (Bergmann et al., 2014), la « *wheel paradigm* » (Pérennou et al., 2008). Parmi ces différents dispositifs, la *wheel paradigm* est la plus utilisée en routine clinique (Piscicelli &Pérennou, 2016). En absence de vision, le sujet assis, tête, tronc et membres inférieurs maintenus dans la roue doit indiquer lorsqu'il perçoit son corps comme étant vertical (Pérennou et al., 2014, 2008; Piscicelli & Pérennou, 2016). Cette roue présente l'intérêt d'évaluer la perception de la verticale dans sa modalité posturale à fois dans le plan frontal (Figure 4) et sagittal (Barbieri et al., 2008) et d'évaluer la contribution des informations somesthésiques graviceptives (Pérennou et al., 2014, 2008; Piscicelli & Pérennou, 2016).

Figure 4 : Mesure de la perception de la verticale posturale par la « wheel paradigm » (Pérennou et al., 2008).

L'évaluation de ce biomarqueur de la perception de la verticale activerait essentiellement deux régions cérébrales que sont le thalamus postérolatéral (Dieterich & Brandt, 1993; Pérennou et al., 2014) et le cortex pariéto-insulaire (Baier et al., 2012; Brandt, 1994; Pérennou et al., 2014). Une activation plus postérieure a également été mise en évidence (Lopez et al., 2011; Rousseaux et al., 2015, 2013). Toutefois, la modalité de mesure visuelle, haptique ou posturale pourrait expliquer cette variabilité des zones (Rousseaux et al., 2015).

Nos travaux s'appuieront sur ces trois biomarqueurs que sont le LBA, SSA et SVV afin d'appréhender la perception de la représentation spatiale dans différents référentiels.

5. Les perturbations posturales liées à un trouble de la représentation spatiale

Les patients ayant présenté un AVC droit sont plus souvent déficitaires en terme d'équilibre que ceux présentant une lésion au niveau de l'hémisphère gauche. Ce désavantage est connu en position assise (Saito et al., 2013) et en position debout (Bonan et al., 2017; Jasińska K., 2015; Lopes et al., 2015; Pérennou et al., 1999; Rode et al., 1997). Ainsi (Bohannon et al., 1986) qui ont suivi un groupe de 105 patients comprenant à la fois des patients AVC droit et gauche, ont constaté une impossibilité de tenir assis de façon indépendante chez 32% des patients avec une lésion droite contre 5% des patients cérébrolésés gauches. Il faut noter que la persistance de ce trouble en position assise est de mauvais pronostic pour l'acquisition des transferts, de la position debout et de la marche (Amusat, 2009; Bohannon et al., 1986; Genthon et al., 2007). En position debout, le constat est le même avec un *« désavantage postural en cas de lésion droite »* (Pérennou et al., 1999). (Rode et al., 1997) ont évalué l'équilibre de 15 patients AVC droit contre 15 patients AVC gauche mettant en évidence une majoration des troubles posturaux dans le groupe AVC droit. Ce résultat est régulièrement confirmé (Bonan et al., 2017; Jasińska, 2015; Lopes et al., 2015).

L'hémisphère droit jouerait un rôle prépondérant sur l'élaboration de la représentation du corps dans l'espace (Barra et al., 2010; Bonan et al., 2013; Halligan et al., 2003; Lopez et al., 2005; Rousseaux et al., 2014) ; il constitue l'hémisphère de la cognition spatiale (Barra et al., 2010; Bonan et al., 2015; Halligan et al., 2003; Rousseaux et al., 2014). L'hémisphère droit est impliqué dans la négligence spatiale (Halligan et al., 2003; Karnath & Rorden, 2012) et dans d'autres troubles de la cognition spatiale (Barra et al., 2010; Bonan et al., 2013; Halligan et al., 2003; Lopez et al., 2005; Rousseaux et al., 2014). Son implication dans la représentation du corps dans l'espace se manifeste par une perturbation plus importante de la représentation spatiale appréhendée par les biomarqueurs que sont la mesure de la perception de la verticale, du droit devant et de l'axe longitudinal (Barra et al., 2007; Bonan et al., 2006a, 2006b; Chokron, 2003; Pérennou et al., 2008).

6. Amélioration des troubles de l'équilibre liés à un trouble de la cognition spatiale

Les approches de rééducation actuelle pour la récupération de l'équilibre n'ont pas été spécifiquement conçues pour améliorer les perturbations posturales liées à un trouble de la représentation spatiale. L'approche traditionnelle dite *« Top-Down »* consiste à stimuler la représentation consciente de l'orientation du corps dans l'espace. Cette approche est exigeante et laborieuse (Bonan et al., 2015). Les stimulations sensorielles sont une approche complètement différente. Cette approche dite « *Bottom-up* » présente plusieurs intérêts car elle ne nécessite ni une prise de conscience par le patient de son trouble ni sa participation. Cette approche a montré des résultats bénéfiques dans un trouble de la cognition spatiale bien connu à savoir, la négligence spatiale (Kerkhoff et al., 2006; Rode et al., 1998; Saj et al., 2013). En effet, l'adaptation prismatique induit une amélioration significative de la négligence spatiale et ce à long terme (Frassinetti et al., 2002; Panico et al., 2019; Rode et al., 1998; Rossetti et al., 1998; Serino et al., 2009). La stimulation sensorielle par vibration des muscles du cou a également montré des résultats intéressants dans l'effet à court terme et à long terme, seule ou combinée aux techniques standards de rééducation de l'héminégligence (Johannsen et al., 2003; Schindler et al., 2002). L'hypothèse concernant son utilisation pour l'amélioration des troubles posturaux que nous émettons pour ce travail est que l'application de stimulations sensorielles améliorerait la composante cognitive des perturbations posturales.

Quelques travaux ont été menés concernant l'effet des stimulations sur l'asymétrie d'appui ; ainsi la stimulation de l'entrée vestibulaire par l'application de stimulations calorimétriques ou galvaniques, de l'entrée visuelle par stimulations optocinétiques, modifie l'asymétrie d'appui du patient AVC (Bonan et al., 2015; Rode et al., 1998; Tilikete et al., 2001). En ce qui concerne l'entrée proprioceptive, celle-ci peut être stimulée via l'utilisation de vibrations entrainant à la fois une modification de la posture (Magnusson et al., 2006) et de la représentation spatiale (notamment la perception du droit devant ou subjective straight ahead (SSA)) (Karnath et al., 2002). Ce travail cherchera à comprendre spécifiquement les mécanismes de cette stimulation proprioceptive et d'en évaluer les effets.

7. Les stimulations sensorielles proprioceptives par vibration

La stimulation vibratoire provoque une activation de l'ensemble des mécanorécepteurs, à savoir : cutanés, tendineux et musculaires (cutanés (Mountcastle et al., 1967; Ribot-Ciscar et al., 1989), tendineux (Brown et al., 1967; Burke et al., 1976), musculaires (Roll et al., 1989). Chaque type de mécanorécepteur répond de façon plus ou moins sensible à la stimulation vibratoire. En effet, les mécanorécepteurs phasiques, c'est à dire ceux à adaptation rapide, sont activés de façon préférentielle par la stimulation vibratoire (Mountcastle et al., 1967). Ce phénomène d'activation préférentielle est déjà mis en évidence au stade cutané entre les différents mécanorécepteurs cutanés, en fonction de leur type d'adaptation (Ribot-Ciscar et al., 1989; Vedel & Roll, 1982). Parallèlement, les mécanorécepteurs musculaires et tendineux sont également mis en jeu par la stimulation vibratoire (Brown et al., 1967; Burke et al., 1976; Ribot-Ciscar et al., 1998; Roll et al., 1989). Les afférences issues des organes tendineux de Golgi sont recrutées et déchargent lors de stimulations vibratoires (Brown et al., 1967; Burke et al., 1976), mais ce sont les mécanorécepteurs de type musculaire et, plus spécifiquement, les afférences primaires (fibre Ia) issues des faisceaux neuromusculaires qui sont les plus sensibles et sont les plus fortement activées lors de la stimulation vibratoire (Brown et al., 1967; Ribot-Ciscar et al., 1998; Roll et al., 1989; Roll & Vedel, 1982). L'activation des afférences primaires des FNM s'explique par leur organisation structurelle, enroulées au niveau de la portion équatoriale des fibres intrafusales qui sont très élastiques et donc sensibles à l'étirement alors que les afférences secondaires (fibre II) sont enroulées autour de l'extrémité polaire des fibres, riches en myofibrilles avec un haut degré de viscosité, les rendant moins sensibles à la stimulation vibratoire (Cooper, 1961). Comme développé précédemment (Partie I, informations sensorielles), les informations proprioceptives sont fournies par les récepteurs appelés « propriocepteurs » et, en particulier, par les faisceaux neuromusculaires. De ce fait, la stimulation de ces faisceaux neuromusculaires par stimulation vibratoire présente un intérêt de par leur implication dans le contrôle de la proprioception à un niveau segmentaire ou global de l'équilibre et de la posture (Goodwin et al., 1972). Selon le muscle vibré, l'effet sensoriel peut être focalisé sur l'articulation où le muscle est fixé (Roll et al., 1980) ou plus globalement à distance du muscle vibré, produisant une réaction posturale (Eklund, 1972; Magnusson et al., 2006; Wierzbicka et al., 1998). L'activation de ces mécanorécepteurs musculaires est optimale pour des fréquences de stimulations vibratoires comprises entre 70 et 80 Hz (Roll et al., 1989b; Roll & Vedel, 1982). Nous verrons dans notre revue systématique (*Article 3*) les connaissances issues de la littérature sur les vibrations.

8. Synthèse et Objectifs

Les perturbations posturales peuvent être caractérisées en position debout par différents comportements asymétriques tels que la latéropulsion, le syndrome du pusher et l'asymétrie d'appui. Ce travail de thèse se focalisera sur l'asymétrie d'appui qui se traduit par un déficit d'appui du membre parétique et, en particulier, sur l'implication de trouble de la représentation spatiale sur l'asymétrie d'appui. Puis, ce travail de thèse se proposera d'étudier l'utilisation de stimulations sensorielles proprioceptives par vibration des muscles du cou, une approche dite « bottom-up ».

Les objectifs de ce travail de thèse sont :
1-d'améliorer la compréhension des mécanismes impliqués dans l'asymétrie d'appui suite à d'un accident vasculaire cérébral.
2-d'étudier l'efficacité d'une approche par stimulations proprioceptives par vibration des muscles du cou sur la correction de cette asymétrie d'appui.

Les hypothèse de sont qu'en dehors du déficit moteur et sensitif, les troubles de la représentation spatiale serait impliqué dans les mécanismes d'action de l'asymétrie d'appui et en particulier dans le groupe de patient avec une lésion au niveau de l'hémisphère droit ce qui pourrait expliquer un déficit plus marqué pour ce groupe. Concernant les vibrations des muscles du cou, notre hypothèse est une rééducation de ce déficit d'asymétrie d'appui et en particulier pour le groupe de patient AVC droit du fait de la correction de la part de des troubles de la représentation spatiale

Pour répondre à ces objectifs, cette thèse d'articles s'articulera autour de deux parties ; une première partie constituée d'une revue systématique avec méta-analyse sur l'asymétrie d'appui traitant de son évolution en fonction des stades de l'AVC ainsi que ses relations avec les différents facteurs de l'hémiplégie *(Article 1)* et d'un article traitant de l'implication de la représentation spatiale dans ces troubles posturaux *(Article 2).* Puis une seconde partie constituée d'une revue systématique qui pose la question des effets des stimulations proprioceptives par vibration des muscles du cou (NMV) sur l'asymétrie d'appui et des troubles de la représentation spatiale *(Article 3),* puis d'un article évaluant l'efficacité de séances répétées de vibration des muscles du cou sur des patients AVC en phase chronique *(Article 4).*

Partie 2 : Partie expérimentale

Chapitre 1 : L'asymétrie d'appui

Article 1: Postural asymmetry and hemiplegia post-stroke: a systematic review and meta-analysis; Karim Jamal, Stéphanie Leplaideur, Thomas Lucas, Simon Butet, Mélanie Cogné, Isabelle Bonan.

L'asymétrie d'appui suite à un Accident vasculaire cérébral : revue systématique et méta-analyse.

Les perturbations posturales sont une des conséquences de l'AVC, elles sont à l'origine d'un plus grand risque de chute et induisent une perte d'autonomie pour ces patients (Kim & Kim, 2014; Mansfield et al., 2015). L'asymétrie d'appui suite à un AVC a fait l'objet de plusieurs revues narratives et/ou systématiques sur ce sujet mais les relations entre l'asymétrie d'appui et les facteurs démographiques et de gravité de l'AVC n'ont pas encore été rapportées. De même, à ce jour l'évolution de l'asymétrie d'appui au cours du temps n'a pas été décrite de manière détaillée. Le premier objectif de cette revue est de synthétiser les connaissances sur l'évolution de l'asymétrie d'appui en position assise et debout, puis de mener une méta-analyse sur la relation entre l'asymétrie d'appui et les différentes caractéristiques de l'hémiplégie. Cette revue systématique a été soumise dans le journal *« Annals of Physical and Rehabiliation Medecine ».*

Postural asymmetry and hemiplegia post-stroke: a systematic review and meta-analysis

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Objectives: Postural asymmetry and enhanced postural sway are frequently observed in stroke population during static standing and sitting positions. Our aim was to map out the characteristics of postural asymmetry after a stroke in relation with the characteristics of hemiplegia, balance and gait function. Furthermore, we would synthesize its evolution over time. **Methods:** Following the PRISMA guidelines, a systematic review was performed using the databases MEDLINE, EMBASE, Cochrane library, Web of Science and PEDRO with the key words (Weight Bearing Asymmetry OR Center of Pressure) AND (Stroke) for articles published through to November 2017. **Results:** 195 articles (population n=6068) were included in this systematic review. We highlighted a certain heterogeneity in carrying out assessments and a low quality in studies design with only 55/195 studies with a PEDRO scale score higher than 6/10. The first meta-analysis focusing on postural asymmetry at different stages showed that postural asymmetry was found at an acute stage (33.56% 95%CI[31.56;35.56] weight on the paretic leg) and was still persistent at a chronic stage (42.31% 95CI[41.09;43.54]) with less weight on the hemiplegic side in case of right stroke (42.15% 95%CI[33.69;50.62]) compared to the left brain damage (43.85% 95%CI[40.08; 47.62]). The second meta-analysis focused on postural asymmetry and its relations included 32 articles. Postural asymmetry was moderately related to balance perturbation (Berg Balance Scale (r=0.33, p=0.006)) and spatial cognition (Subjective Visual Vertical (r=0.34, p=0.03)), but not to motor deficit (r=0.24, p=0.4) or hypoesthesia (r=-0.14, p=0.4). **Conclusion:** Postural asymmetry is present at all stages of stroke and possibly related to balance perturbation and spatial cognition. However, this result must be taken with caution because of the variability in the measurement method and the heterogeneity of correlations carried out. Further research should be conducted to confirm our results.

key words
Postural asymmetry, postural sway, stroke, hemiplegia, review

The appendix A, B and C are contained in the Annexe I.

1.Introduction

After a stroke, postural imbalance is an important issue as it is associated with a greater risk of falls, and is also a factor responsible for loss of autonomy [1]. When evaluated by way of a force platform (FP), postural imbalance can be translated by an increase in postural sway along with a postural asymmetry expressed by an asymmetrical weight distribution (weight-bearing asymmetry WBA) on the paretic leg or a shift of the center of pressure (CoP) in the medio-lateral plane (ML) towards the none-paretic side of the body [2-4]. Genthon *et al.* [5] found these two measures; WBA and CoP ML to be highly related (r=0.97; p<0.001) as a shift of CoP of 10 mm in the medio-lateral plane corresponded to a 5% increase of the body weight toward this side. The force platform evaluation is usually integrated into the postural assessment and as the interest of comprehension of the mechanism of postural imbalance has grown, this assessment therefore requires to be described in depth. Besides few reviews on the subject [6-8], the evolution of postural asymmetry after stroke still remains uncertain. Additionally, to our knowledge, the question of the relation between postural asymmetry and the characteristics of hemiplegia, balance and the gait function still stand unanswered. The objectives of this review are 1) to describe methods used for assessing postural asymmetry, 2) to describe postural asymmetry and postural sway after a stroke in the literature and 3) to map out the different factors related to postural asymmetry and postural sway.

2.Method

2.1 Eligibility criteria

This review followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) guidelines [9] and was registered on the international prospective register of systematic reviews PROSPERO (CRD42018083338). Only subjects over 18 years of age with a diagnosis of stroke were considered in this review. Patients with an orthopaedic, a rheumatologic history, a visual history, and/or a neurological disorder associated with a stroke diagnosis were permitted within a limitation not to exceed 30% of the population for the purpose of this review. In addition, studies were also considered eligible, if they implicated an assessment of postural asymmetry in static seated and/or standing positions at rest. All studies focusing on assessment of postural asymmetry during walking or transfer were excluded. Accordingly, the primary outcome(s) were the postural asymmetry, namely: WBA expressed in percentage of body weight on the paretic side; or shifting of COP (mean position of the CoP in the medio-lateral plane expressed in mm) whatever the delay since stroke. The secondary outcome was the CoP instability expressed by surface (mm2), velocity (mm/s). Finally the correlation between postural asymmetry and demographic data and characteristics of stroke (age, delay post-stroke, side of stroke, neglect, spasticity, hypoesthesia, motor deficit, spatial cognition (subjective visual vertical (SVV), subjective straight ahead (SSA), longitudinal body axis (LBA)) balance or gait function) were conducted via a meta-analysis. We also carefully mapped out the methods used for assessing postural asymmetry.

2.2 Search strategy and data extraction

This systematic search was performed on a selected literature using the databases MEDLINE, EMBASE, the Cochrane Central Register of Controlled Trials (CENTRAL), PEDRO and Web of Science. A hand search was also carried out for the unpublished studies on Google Scholar, ClinicalTrials.gov and EUCTR. The key words used in the search were ((weight bearing asymmetry) OR (center of pressure)) AND ((stroke) OR (hemiplegia)). All designs of studies were considered, with the exception of reviews and meta-analysis. Lastly, only studies published in either French or English up to November 2017 were integrated in this review of literature.

After having eliminated all the duplications, an independent eligibility examination for the remaining studies was performed by two researchers (KJ and TL) based on the titles and the abstracts. In the event of a divergence between them over the acceptability of any particular study, the disparity was than subsequently resolved by way of a discussion with two other reviewers (SL and IB). The data extraction was assessed independently by two reviewers (KJ and TL) for the selected studies for inclusion, and here again; for any divergence arising, this was resolved through discussions with two other reviewers (SL and IB). In consequence, for each eligible study, valid information was extracted on the basis of the following criteria: a) the characteristics of the study: authors, year and type of design; b) the characteristics of the trial participants: age, number of subjects included in the analysis and data of analysis (time since stroke, side of the paresis); c) the type of intervention: the position of assessment of postural asymmetry i.e. seated or upright position; d) the outcome measures, as mentioned above e) a description of the methods used for assessing postural asymmetry from the included studies was provided, i.e the brand, feet condition, sitting/standing position, duration and eyes condition were noted.

2.3 Risk of bias (quality) assessment

In order to evaluate methodological quality, randomized controlled trials and cross-over trials were assessed using the PEDRO scale [10]. This scale is based on 11 items scored out of 10: namely, eligibility criteria, randomization, concealed allocation, blinding (subjects, therapists, and assessors), follow-up, intention-to-treat analysis, between-group comparisons, point estimates and variability [11,12]. This scale gives a classification of quality with different cut-off score possibilities whereby 9 to 10 is considered as excellent; 6 to 8 as good; 4 to 5 as fair; and < 4 as poor quality. Whilst for other studies, such as observational studies; these were assessed by using the JBI Critical Appraisal Checklist for Case Series [13].This scale is also based on 10 items; criteria for inclusion, the condition measured, valid methods, consecutive inclusion of participants, complete inclusion of participants, reporting of the demographics of the participants, reporting of clinical information of the participants, outcomes conditions, reporting of the presenting site(s)/clinic(s) of demographic information, and statistical analysis condition.

2.4 Strategy for data synthesis

As regards the strategy for the data synthesis, to describe postural asymmetry and postural sway after a stroke in the literature and to map out the different factors related to postural asymmetry and postural sway, a random effects model to pool was used with the different parameters of posturography depending on the post-stroke delay and the lesion side (question 2) and a second one for question 3 on the different correlations observed between postural asymmetry with the following outcomes: delay post-stroke, age, side of stroke, neglect, spasticity, motricity, spatial cognition (SVV, SSA, LBA) balance or gait assessment. As only WBA on the paretic leg was considered in the meta-analysis, the sign of the relation was reversed when the authors used the result of non-paretic side. This method was also conducted for CoP. As WBA and CoP were found to be related, these data were pooled together. Summary posturography parameters and correlation coefficient measures were displayed with 95% confidence intervals, and heterogeneity was assessed using the I^2 statistic and Cochran's Q test.

3.Results

This systematic research identified 15432 references of which 39 references were added thereafter by way of a hand search process. Consequently, only 1345 articles met the eligibility criteria and were requested for full-text evaluation with at the end, only 195 articles ultimately included in this review (Fig. 1). These articles have been published between 1983 up to 2017 (Appendix A). A total of 85(43%) studies related to randomized control trials design were incorporated with a median quality on PEDRO scale of 5.8/10 [min=3/10; max=8/10] (Appendix B) and 110(56%) other types of design (JBI Critical Appraisal Checklist for Case Series: 6.6/10 [min=3/10; max=10/10]) (Appendix B). Of the 85 studies related to randomized control trials design or cross-over trials, only 55(28% out of 195) articles were rated as good (PEDRO >6/10) whereas none was found to be excellent.

Concerning the participants, a total of 6068 [min=1;max=359] were included (table 1). Although some articles provided information on the lesion side; a total of 2465 right brain damage (RBD) and 2591 left brain damage (LBD) participated in these studies (table 1). The average age for patients who had a stroke was 60.5 years [min=40; max=75] with a delay post-stroke of 105.3 weeks [min=2; max=677]. Only 32 stroke survivors were in the acute phase meaning before the 14_{th} after the stroke, 2562 in the sub-acute phase (between day 14 and 6 months post-stroke) and 3226 at a chronic stage (after 6 months post-stroke) [14,15] (table 1)

As regards the assessment methodology for postural asymmetry, 181 (92%) of the studies were carried out in the standing position, while 7 were conducted in the sitting position, 2 in both sitting and standing position and the rest did not provide information on the position status. Most of the studies were performed with opened eyes 93(47%); 76(39%) with both eyes open and closed, while only 2(1%) with closed eyes. 24 articles (12%) did not apprise on the eyes condition. For those studies which draw special attention to the feet position and more precisely the feet interval, the distance was either 10cm, 17cm, or 20cm, Most studies when the information was provided were performed barefoot (39(20%)). 20(10%) authors used the brand Good Balance system® (*Metitur, Jyväskylä, Finland*) while 15(7%) opted for BIORescue® (*RM Ingenierie, Rodes, France*) and the remaining 13(6%) choose Wii Balance Board® (*Nintendo, Kyoto, Japan*). 22 (11%) of the studies did not indicate the force platform brand employed. Regarding the average duration of the assessment, an average of 37sec [0.05; 300] was obtained but 41(21%) studies did not indicate the measure duration. Concerning the number of repetitions, most of the authors performed the evaluation only once. For those who repeated the test, they submitted their results as an average for 3 evaluations.

By pooling in the first meta-analysis, all the articles in the standing position with eyes opened the mean WBA was 41.45% with eyes open (95%CI [40.69; 42.21] I_2= 99.5% [99.5%; 99.6%] p=0)(table 2). Focusing on the delay post-stroke, WBA in acute stage was 33.56 % (95%CI [31.56; 35.56] I_2= 99.9% [99.9%; 99.9%] p=0; (2 articles) 40.86 % in sub-acute stage (95%CI [38.76; 42.95] I_2= 93.2% [91.1%; 94.8%] p<0.0001(23 articles)) and 42.31%(95CI [41.09; 43.54] I_2= 94.9% [93.9%; 95.7%] p<0.0001 (35 articles) at chronic stage (table 3). Additional data on postural sway are explained in table (table 2 and table 3). Regarding the side lesion (table 2), 11 articles provided a difference between right and left brain damage on WBA OE with (Appendix A) (RBD n=86; LBD n=108) respectively 42.15 % (95%CI [33.69; 50.62] I_2 = 93.4% [87.6%; 96.5%] p<0.0001) and 43.85% (95%CI [40.08; 47.62] I_2 = 87.4% [73.1%; 94.1%] p <0.0001). These results were confirmed with the CoP ML which highlights a shift towards the right side for RBD 15.02 mm (95%CI [-7.37; 37.42] I_2 = 97.7% [96.4%; 98.6%] p<0.0001) and towards the left side for LBD -2.06 mm (95%CI [-20.32; 16.18] I_2 = 97.0% [95.0%; 98.2%] p<0.0001)

Out of the 195 articles reviewed, 32 articles (n=1042) had performed correlations and therefore were included in the second meta-analysis (Appendix C). Among these 32 articles, a total of 85 correlations were extracted, 35(41%) correlations were found with only one reference and therefore no random effects model could be used. All results are presented in Appendix C. This meta-analysis revealed the absence of the relation between postural asymmetry and delay post-stroke (r=-0.02 95%CI[-0.6291; 0.6001] p=0.9; I_2=90.0% [63.4%; 97.3%] (2 articles)), age (r=0.12 95%CI[-0.0808; 0.3184] p=0.2) (1 article)), hypoesthesia (r=-0.14 95%CI [-0.4785; 0.2314] p=0.4; I_2= 81.3% [56.5%; 91.9%] (3 articles)), motor deficit (r=0.24 95%CI[-0.3699; 0.7106] p=0.4; I_2= 89.5% [71.6%; 96.1%]) (3 articles)) (Fig. 2). Significant correlations were found between postural asymmetry and spasticity (r=-0.29 95%CI[-0.4370; -0.1442] p=0.0002; I_2= 0.0% (2 articles)), neglect (r= -0.37 95%CI[-0.5273; -0.1975] p<0.0001; I_2= 0.0% [0.0%; 85.4%] (3 articles) and spatial cognition; SVV (r= 0.34 95%CI[0.0330; 0.5917] p=0.03; I_2= 32.5% [0.0%; 93.0%] (3 articles)) (Fig. 3), LBA r=0.41 95%CI [0.1556; 0.6260] p=0.002; I_2= 0.0% (2 articles)). When considering the relationship between postural asymmetry and balance function, a correlation was found with Postural Assessment Scale for Stroke (PASS) (r=0.51 95%CI[0.1126; 0.7667] p=0.01 (1 article)) and Berg Balance Scale (BBS) (r= 0.33 95%CI[0.0980; 0.5288] p=0.006; I_2= 41.5% [0.0%; 75.4%] (7 articles)) (Fig. 4), whereas no correlation was found with 10m walk (r= 0.38 95%CI [-0.1737; 0.7556] p=0.1; I_2= 81.8% [22.8%; 95.7%] (article 2)) and Timed Up and Go (TUG) (r= 0.27 95%CI [-0.2705; 0.6850] p=0.3; I_2= 89.9% [77.0%; 95.6%] (4 articles)). Relating to the correlations with postural sway, significant correlations were found between CoP Velocity and motor deficit (r= -0.36 95%CI [-0.6251; -0.0225] p=0.03; I_2 = 21.3% [0.0%; 91.8%] (3 articles)) and BBS (r= -0.38 95%CI [-0.5886; -0.1267] p=0.004; I_2 = 59.3% [6.3%; 82.3%] (7 articles)).

4.Discussion

This present review found stroke patients with postural asymmetry and postural sway at different delay post-stroke. Indeed, weight bearing asymmetry was found in early stage after stroke and still persistent at a chronic stage. However, only two studies focused on stroke patients at an acute stage whereas most of the others were at a chronic stage, this could be explained by the fact that stroke patients may not have yet acquired the sitting position or even the standing position at this stage of the stroke. Interestingly this meta-analysis included a sufficient numbers of articles (195) but a large heterogeneity in the results were noticed. This heterogeneity could be due to the variability in the method of assessment of postural asymmetry. Besides these observations, our results are in accordance with several longitudinal studies, postural asymmetry is less important at distance and this probably with an improvement during the first months [16-19] but stroke patients could still be found with postural asymmetry at a chronic stage [20-22]. For those 11 studies which provided the difference of postural asymmetry between patients with RBD and LBD, when pooling the data, this showed a difference between these two groups with less weight on the paretic leg for RBD patients independently of the position, namely sitting or standing [23-27]. Today this question of difference of postural asymmetry between patients with RBD and LBD is still discussed [25, 28-30]. Therefore, this meta-analysis is a step forward on the inequality between these two groups regarding postural asymmetry for the benefit of the patients with LBD, and this possibly due to the disorders of spatial cognition found in the patients with RBD [31-34]. The low numbers of studies and their quality suggests the need for further studies to confirm our results.

The second meta-analysis revealed an important number of correlations carried out between postural asymmetry/postural sway and the characteristics of hemiplegia, and this, despite the few articles extracted. Thus, as a result, many correlations were only found by a single study which does not allow us to make a decisive conclusion.

Surprisingly, postural asymmetry was not related to motor deficit (r=0.2 p=0.4 (3 articles)) nor to sensory deficit (r=-0.14 p=0.4 (5 articles) but there was a relation with postural instability (motor deficit r=-0.3 p=0.03 (3 articles)). On the contrary, a relation was found with spatial cognition parameters (LBA r=0.41 p=0.002 (2 articles) and SVV r=0.34 p=0.03 (3 articles)). Notwithstanding the low numbers of articles (3), a low heterogeneity was revealed by the meta-analysis between these articles. To add, postural asymmetry was also found to be related to another spatial disorders; i.e neglect (r=-0.34 p<0.0001 3 articles). Therefore, this reinforces the assumption that postural asymmetry is almost partly due to spatial cognition disorders [10-12].This conclusion is also in accordance with our previous results on the difference in postural asymmetry between RBD and LBD patients as the right brain is involved in the mechanism of spatial cognition [35,36]. Interestingly, the meta-analysis revealed a relation between motor deficit and CoP displacement velocity rather than with postural asymmetry. This result is not so surprising as the involvement of the muscles in the mechanism of postural velocity has already been shown [37,38]. Indeed, fatigue muscle increased velocity [37]. Therefore we can suggest due to this result that motor deficit is more involved in the mechanism of postural sway than postural asymmetry. This meta-analysis also revealed, from only two articles but with low heterogeneity, that spasticity is another parameter related to postural asymmetry (r=-0.29 p<0.0002). No study was found taking in consideration the relation between spasticity and postural sway. A possible explanation of this relation could be that spasticity and in particular that of the gastrocnemii in that case, affects the muscle balance involved in maintaining postural balance [39-41]. Interestingly, WBA was also found to be related to balance perturbation. The more the postural asymmetry is, the more impaired is postural balance. Indeed, besides only one article which focused on this relation between PASS and WBA, 7 articles were pooled in the meta-analysis highlighting a constant relation between WBA and BBS (r=0.33 p=0.006). Postural asymmetry could be compensatory for patients with poor balance as claimed by several authors [8,42]. To add, BBS was also found to be related with postural sway (r=-0.38 p=0.004 7 articles). However, aside from this relationship, we have to note that the cause-and-effect relationship has yet to be proven to confirm this statement. Postural imbalance could also be the consequence of postural asymmetry. Nonetheless, this draws special attention to the interest in rehabilitation when taking the postural asymmetry into account.

Most certainly this review highlights the low quality of the studies, based on this subject, as less than half of these studies were randomized control trials and only 1/3 of them were considered as good quality. Further, this research equally revealed a certain heterogeneity in the manner in which the postural asymmetry and postural sway were assessed. As regards to the choice of the force platform, a multitude of platforms were used. With only one exception when one platform was compared to a dual platform allowing to evaluate the percentage of weight on each limb and the calculation of the CoP under each foot directly [43]. Moreover, some authors did not provide adequate information on the method and omitted the brand of the force platform employed, 12% ignored to mention the eyes conditions and 35% disregarded information concerning the foot position. It is worthy to note, variability in feet placement has been raised in this review, as it has been observed in healthy subjects [44] and in stroke patients that foot placement could influence the results of the postural sway [45].Therefore, for further studies, we recommend a better quality of postural measurement by asking authors to provide the brand name of the force platform utilized and to describe the feet condition, sitting/standing position, duration and eyes condition.

There are several limitations to this review, WBA could not always be collected as the raw data was not available and was presented using a specific calculation and therefore could not be included in neither the systematic review nor in the meta-analysis. Further, this review and its meta-analysis highlighted a number of articles focusing on the postural asymmetry and its relation but with a high heterogeneity. Therefore, further research should be carried out to examine these relationships. To add, this review also pointed out the question of heterogeneity, a path to knowledge for future studies, whereby the methodology of evaluation must be clearly described based on these recommendation in the literature; i.e. some authors such as Genthon *et al.* [46] suggested to perform the evaluation with recordings from two separate force plates in order to measure the weight under both feet. Further, based on their study, Mouzat *et al*. [47] suggested a foot spacing of between 15 to 20 cm is an ideal parameter for maintaining an easy. When looking at the angle of the foot position, the literature advices placing the subject in a position of comfort with an angle of 14° between the long axes of the feet, which is based on the work of the authors McIlroy *et al.* [48] who studied a large cohort of 262 healthy subjects and which was confirmed later by Mouzat *et al.* [47]. A recent paper published in 2018 by the Pilkar *et al.* [49] which included both healthy and stroke subjects highlighted that the duration is likewise a measure which influences the displacement of the CoP. and Van der Kooij *et al*. [50] confirmed this by suggesting a duration of around 60 seconds. In case of a shorter duration, authors suggested to average several measures [43,51]. Therefore, we strongly advice authors for their future publications to take these points into consideration and make both this information and the description of their methods available.

5.Conclusion

To conclude, this review revealed long-lasting alterations of postural asymmetry during the post stroke phase even at a chronic stage. By means of a meta-analysis, postural asymmetry was found to be more related to spatial cognition disorders rather than motor or sensitivity disorders and is as such associated to the balance function. However, motor disorders are rather a source of postural instability. That is said, the heterogeneity of the results, does not allow us to draw a reasonable conclusion from the information presented and therefore further studies by selection of identical correlations are needed. We highlighted the aspect heterogeneity and the manner of performing the assessment, suggesting the need of a standardized assessment.

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8.Declaration of conflict of interest

The authors declare that they have no competing interests.

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Table 1 = Description of stroke population out of the 195 articles included. Left Brain Damage (LBD),Numbers (n), Not Available (NA), Right Brain Damage (RBD).

Charateristics Population	Studies (n)	Population (n)	%
Total Population	195	6068	
Side lesion			
**RBD*	160	2465	40
**LBD*	161	2591	42.6
**NA*	30	917	15.1
**Right and Left brain damaged*	6	95	1.56
Gender			
**Male*	173	3415	56.2
**Female*	165	2201	36.2
**NA*	20	452	7.4
Stage of stroke			
**Acute (0-14days)*	2	32	0.5
**Sub-acute (14 days-6months)*	56	2562	42.2
**Chronic (after 6 months)*	125	3226	53.1
**NA*	12	248	4

Table 2 = Posturography (mean) of the stroke population selected in the review (n=195). Center of Pressure (CoP), Closed eyes (CE), Left brain damage (LBD), Numbers (n), Open eyes (OE), Right brain damage (RBD), Surface (Surf), Total (T), Velocity (Vel), Weight bearing asymmetry (WBA)

TOTAL

Posturography parameters	Studies (n)	Population (n)	Results		
		6068	mean [95%IC]	I2 (%)	p Value
**WBA OE (%)*	65	1749	41.45 [40.69; 42.21]	99.5% [99.5%; 99.6%]	0
**WBA EC (%)*	6	148	42.08 [38.31; 45.85]	87.1% [78.8%; 92.1%]	< 0.0001
**WBA T (%)*	5	148	42.15 [40.23; 44.07]	76.4% [54.9%; 87.7%]	< 0.0001
**CoP ML OE (mm)*	59	1756	17.70 [16.37; 19.04]	99.7% [99.6%; 99.7%]	0
**CoP ML EC (mm)*	31	749	25.28 [23.08; 27.48]	99.7% [99.7%; 99.8%]	0
**CoP Surf OE (mm2)*	42	1086	157.20 [139.60; 174.79]	99.8% [99.8%; 99.8%]	0
**CoP Surf EC (mm2)*	28	541	456.09 [363.76; 548.42]	100.0% [100.0%; 100.0%]	0
**CoP VeL OE (mm/s)*	58	1433	17.20 [14.63; 19.77]	99.9% [99.9%; 99.9%]	0
**CoP VeL EC (mm/s)*	30	752	17.09[15.18; 19.01]	98.2% [97.9%; 98.4%]	0

RBD

Posturography parameters	Studies (n)	Population (n)	Results		
	11		mean [95%IC]	I2 (%)	p Value
**WBA OE (%)*	5	86	42.15 [33.69; 50.62]	93.4% [87.6%; 96.5%]	< 0.0001
**WBA EC (%)*	3	44	44.62 [34.80; 54.44]	94.7% [88.0%; 97.7%]	< 0.0001
**WBA T (%)*	1	15	34.00[29.44; 38.55]		
**CoP ML OE (mm)*	5	64	15.02 [-7.37; 37.42]	97.7% [96.4%; 98.6%]	< 0.0001
**CoP ML EC (mm)*	3	35	20.98[14.99; 26.96]	16.0% [0.0%; 91.3%]	0.3
**CoP Surf OE (mm2)*	2	26	512.36[214.67; 810.06]	52.5% [0.0%; 88.1%]	0.14
**CoP Surf EC (mm2)*	1	15	1244.00 [760.20; 1727.79]		
**CoP VeL OE (mm/s)*	2	23	-4.48 [-27.02; 18.05]	98.1% [95.7%; 99.2%]	< 0.0001
**CoP VeL EC (mm/s)*	NA				

LBD

Posturography parameters	Studies (n)	Population (n)	Results		
	11		mean [95%IC]	I2 (%)	p Value
**WBA OE (%)*	5	108	43.85[40.08; 47.62]	87.4% [73.1%; 94.1%]	< 0.0001
**WBA EC (%)*	3	50	44.21 [37.47; 50.96]	88.5% [68.3%; 95.9%]	0.0002
**WBA T (%)*	1	15	39.00 [36.97; 41.02]		
**CoP ML OE (mm)*	5	71	-2.06 [-20.32; 16.18]	97.0% [95.0%; 98.2%]	< 0.0001
**CoP ML EC (mm)*	3	44	-0.35 [-29.81; 29.11]	98.2% [96.8%; 99.0%]	< 0.0001
**CoP Surf OE (mm2)*	2	30	646.58 [152.89; 1140.27]	66.9% [0.0%; 92.5%]	0.0821
**CoP Surf EC (mm2)*	1	16	1393.00[820.20; 1965.79]		
**CoP VeL OE (mm/s)*	2	23	-6.25 [-30.74; 18.24]	97.7% [94.3%; 99.0%]	< 0.0001
**CoP VeL EC (mm/s)*	NA				

Table 3 = Posturography parameters (Mean) depending on the delay post-stroke (acute, sub-acute, chronic). Center of Pressure (CoP), Closed eyes (CE), Numbers (n), Open eyes (OE), Surface (Surf), Total (T), Velocity (Vel), Weight bearing asymmetry (WBA)

Posturography parameters	**Studies (n)**	**Population (n)**	**Results**		
	195	6068	mean [95%IC]	I2 (%)	p Value
Acute Stage *(0-14days)*					
**WBA OE (%)*	2	32	33.56 [31.56; 35.56]	99.9% [99.9%; 99.9%]	0
Sub-Acute stage *(14 days-6months)*	56				
**WBA OE (%)*	23	798	40.86 [38.76; 42.95]	93.2% [91.1%; 94.8%]	< 0.0001
**WBA EC (%)*	2	64	48.73[46.21; 51.25]	33.4% [0.0%; 76.5%]	0.2117
**CoP ML OE (mm)*	17	769	6.73[5.28; 8.17]	98.3% [97.9%; 98.6%]	< 0.0001
**CoP ML EC (mm)*	5	127	8.06[-5.93; 22.07]	98.2% [97.3%; 98.8%]	< 0.0001
**CoP Surf OE (mm2)*	9	317	85.61 [62.46; 108.75]	97.9% [97.3%; 98.4%]	< 0.0001
**CoP Surf EC (mm2)*	5	124	161.23 [99.64; 222.82]	90.0% [82.7%; 94.2%]	< 0.0001
**CoP VeL OE (mm/s)*	10	220	14.86[11.07; 18.65]	97.8% [97.0%; 98.3%]	< 0.0001
**CoP VeL EC (mm/s)*	5	131	13.33 [9.57; 17.10]	92.2% [86.6%; 95.5%]	< 0.0001
Chronic Stage *(after 6 months)*	125				
**WBA OE (%)*	35	860	42.31 [41.09; 43.54]	94.9% [93.9%; 95.7%]	< 0.0001
**WBA EC (%)*	4	84	38.20 [35.52; 40.87]	50.4% [0.0%; 79.0%]	0.0598
**WBA T (%)*	5	148	42.15[40.23; 44.07]	76.4% [54.9%; 87.7%]	< 0.0001
**CoP ML OE (mm)*	38	880	26.27 [24.13; 28.41]	99.7% [99.7%; 99.7%]	0
**CoP ML EC (mm)*	23	543	33.84 [30.95; 36.74]	99.8% [99.8%; 99.8%]	0
**CoP Surf OE (mm2)*	33	769	183.47 [161.50; 205.45]	99.8% [99.8%; 99.9%]	0
**CoP Surf EC (mm2)*	18	417	476.86[372.38; 581.35]	100.0% [100.0%; 100.0%]	0
**CoP VeL OE (mm/s)*	47	1134	17.87 [14.47; 21.27]	99.8% [99.7%; 99.8%]	0
**CoP VeL EC (mm/s)*	24	557	17.42[14.74; 20.11]	98.3% [98.1%; 98.6%]	0

Figure 1: Selection of studies.

PRISMA 2009 Flow Diagram

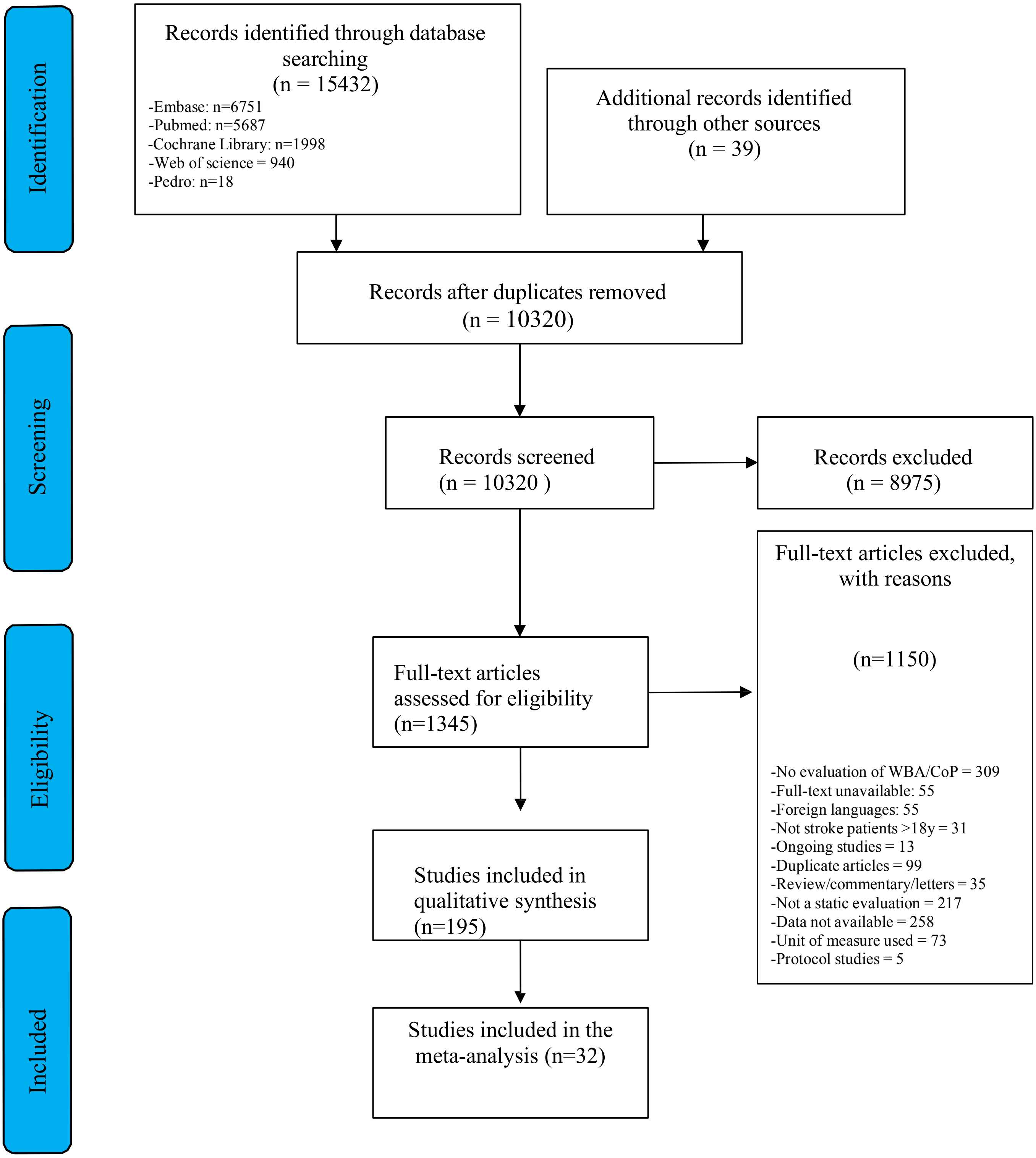


Figure 2 : Meta-analysis of correlation between Postural Asymmetry and motor deficit.

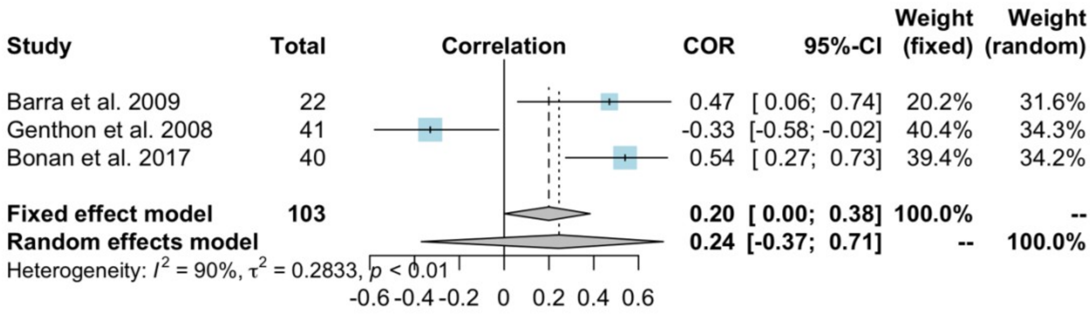


Figure 3 : Meta-analysis of correlation between Postural Asymmetry and spatial representation (subjective visual vertical (SVV)).

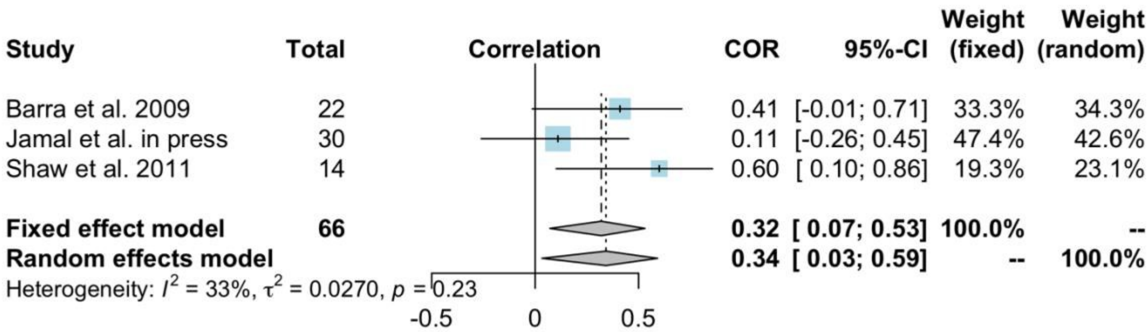
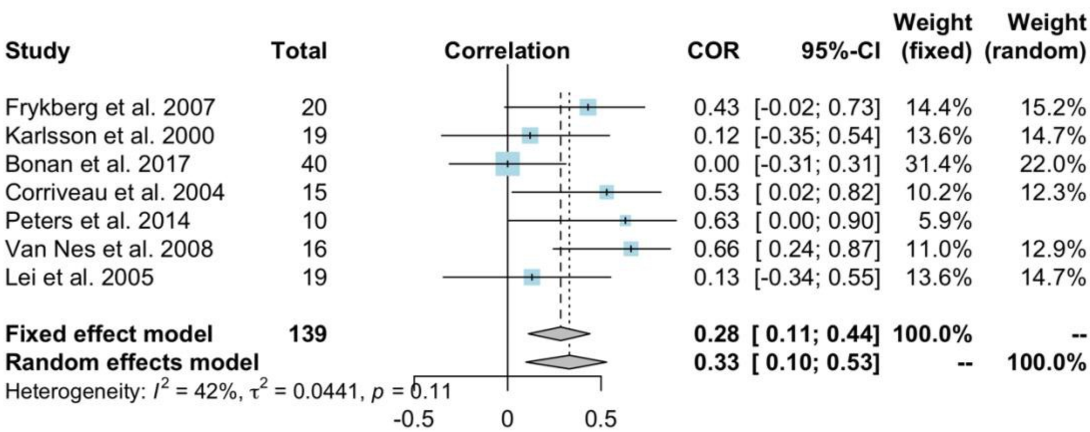


Figure 4 : Meta-analysis of correlation between Postural Asymmetry and functional test (Berg Balance Scale).



Discussion :

L'objectif de cette revue est d'étudier l'évolution de l'asymétrie au cours du temps et d'étudier les différentes relations entre l'asymétrie d'appui et les diverses caractéristiques de l'hémiplégie. Nous avons de plus soigneusement relevé la méthodologie de recueil de l'asymétrie d'appui pour chaque article.

Cette revue systématique inclut 195 articles publiés avant Novembre 2017 et montre une hétérogénéité dans les méthodes d'évaluation de l'asymétrie d'appui, que ce soit sur la durée de mesure ou sur le placement des pieds sur plateforme de force. Parmi les 195 études incluses, seules 7 études ont été réalisées en position assise. Ce faible nombre d'articles évaluant les perturbations posturales en position assise pourrait s'expliquer par le délai des patients inclus dans les études. En effet, les études incluses concernent souvent des patients à un délai subaiguë ou chronique, stades auxquels une majeure partie des patients ont acquis la station assise. De plus, contrairement aux troubles de la posture en position debout qui sont couramment évalués sur plateformes de force en rééducation, les troubles de la posture en position assise bénéficient de peu d'outils de mesure instrumentale en dehors d'échelles de mesure clinique.

Concernant l'évolution du degré d'asymétrie d'appui, une seule étude de qualité modeste suit de façon longitudinale l'asymétrie d'appui (Hyndman et al., 2009). A ce jour, il n'est donc pas possible de connaître avec un bon niveau de preuve l'évolution de l'asymétrie d'appui. Des données d'asymétrie d'appui sont disponibles dans la littérature à différents stades de l'AVC, elles montrent la présence d'une asymétrie d'appui au stade aigue de l'ordre de 33.56% (95%IC[31.56; 35.56]), au stade subaiguë de l'ordre de 40.86% (95%IC [38.76; 42.95]) et en phase chronique de l'ordre de 42.31% (95%IC[41.09; 43.54]). Cependant le niveau de preuve de cette décroissance est modeste en raison du faible nombre d'études, de leur méthodologie hétérogène et de l'hétérogénéité de leurs résultats.

Concernant le rôle de la lésion cérébrale, notre méta-analyse ne montre qu'une légère différence entre les patients AVC droit et gauche avec un déficit plus marqué au dépend du premier groupe. Notre travail d'analyse conforte donc ce résultat attendu sans pour autant l'affirmer avec un niveau de preuve élevé. En effet, l'inégalité mise en évidence par notre méta-analyse reste minime avec une forte hétérogénéité dans l'analyse. Ce résultat pourrait s'expliquer par le faible nombre d'articles (11 articles) inclus ainsi que par le faible nombre de patients au sein de chaque groupe (au total 86 patients AVC droit et 108 patients AVC gauche). Enfin, du fait du faible nombre de patients inclus, il n'a pas été possible d'investiguer si l'évolution de l'asymétrie d'appui au cours du temps dépend du côté de la lésion. Des études longitudinales de grande ampleur seraient utiles pour répondre à cette question de l'évolution.

Au sujet des relations entre l'asymétrie d'appui et les caractéristiques de l'hémiplégie, cette méta-analyse met en évidence une relation significative entre l'asymétrie d'appui et les troubles de la représentation spatiale évalués par la perception de l'axe longitudinal ou Longitudinal Body Axis (LBA $r=0.41$ $p=0.002$) et la perception de la verticale dans sa modalité visuelle ou Subjective Visual Vertical (SVV $r= 0.34$ $p=0.03$). En revanche, aucune relation n'a été retrouvée entre l'asymétrie d'appui et le déficit moteur ($r=0.24$ $p=0.4$) et sensitif ($r=-0.14$ $p=0.4$). Ce constat renforce l'hypothèse d'une implication des troubles de la représentation spatiale dans les mécanismes de ce comportement postural, en particulier en ce qui concerne la perception de la verticale et de l'axe longitudinal. Cependant, en raison du peu d'études inclues et de l'hétérogénéité des résultats, ces conclusions restent à confirmer. Enfin, une relation entre l'asymétrie d'appui et les évaluations de l'équilibre telles que le Berg Balance Scale (BBS) ($r= 0.33$ $p=0.006$) et le Postural Assessment Scale for Stroke (PASS) ($r=0.51$ $p=0.01$) ont été mises en évidence par la méta-analyse. Mais la relation de cause à effet reste à démontrer et à ce jour, les résultats de nos recherches ne permettent pas de savoir si l'asymétrie d'appui est la cause de troubles de l'équilibre ou si à l'inverse l'asymétrie d'appui est un mécanisme compensatoire d'un trouble de l'équilibre.

Article 2: Disturbances of spatial reference frame and postural asymmetry after a chronic stroke; Karim Jamal, Stéphanie Leplaideur, Chloé Rousseau, Lucie Chochina, Annelise Moulinet‐ Raillon, Isabelle Bonan

La relation entre l'asymétrie d'appui et les troubles de la cognition spatiale suite à un Accident vasculaire cérébral.

Dans cet article, nous avons souhaité investiguer à la phase chronique, le résultat de (Barra et al., 2009) qui a montré qu'il existait une relation entre l'asymétrie d'appui et les troubles de la représentation spatiale et plus spécifiquement avec la perception de l'axe longitudinal (Longitudinal Body Axis LBA) et ceci à la phase subaiguë. Il nous a semblé intéressant d'étudier non seulement la relation entre l'asymétrie d'appui et le LBA mais aussi la relation avec d'autres biomarqueurs de la représentation spatiale, à savoir la perception du droit devant (SSA) et de la verticale visuelle (SVV) en phase chronique et en fonction du côté de la lésion cérébrale.

Le premier objectif était d'investiguer si les perturbations de la représentation spatiale perdurent à la phase chronique. Le deuxième objectif était d'étudier la relation entre ces perturbations et l'asymétrie d'appui en fonction du côté de la lésion cérébrale. L'hypothèse était que des perturbations de la représentation spatiale perduraient à la phase chronique et que ces perturbations, en particulier du LBA étaient reliées à l'asymétrie d'appui, notamment chez les patients avec une lésion de l'hémisphère droit. Cet article a fait l'objet d'une publication dans le journal «*Experimental Brain Research »*.

Experimental Brain Research
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RESEARCH ARTICLE

Disturbances of spatial reference frame and postural asymmetry after a chronic stroke

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Abstract
Asymmetrical postural behaviors are frequently observed after a stroke. They are due in part to the sensorimotor deficit, but they could also be related to a disorder of the representation of the body in space. The objective was to determine whether the asymmetrical postural behaviors of chronic stroke patients are related with a disruption of the perception of spatial frame. 30 chronic stroke patients (mean age 60.3 year ± 10, mean delay post-stroke 4.78 year ± 3), 15 patients with right brain damage (RBD) and 15 patients with left brain damage (LBD), and 20 healthy subjects participated in the study. Postural asymmetry was detected by the evaluation of body weight repartition on a force platform (weight body asymmetry) and was related to the longitudinal body axis (LBA) and the subjective straight ahead (SSA) (egocentric space representation) and to the subjective visual vertical (SVV) (allocentric space representation) by a multivariate analysis of variance adjusted with motor function and sensitivity as covariables. Both patients with RBD (35% ± 8) and LBD (39% ± 4) had body weight asymmetry and there was still space misperception at this stage of recovery, especially in the RBD group. WBA was related to LBA when considering both patients with RBD and LBD ($p = 0.03$). However, this relation was dependent on the side of the lesion ($p = 0.0006$) with a stronger relation in the RBD group (0.01). No relation with WBA was found neither with SSA ($p = 0.58$) nor with SVV ($p = 0.47$). This study pointed out a strong relationship between disturbance in the perception of the longitudinal body axis and postural asymmetry in chronic strokes, and especially within the RBD group. Conversely, no other spatial perturbations seemed to be involved in this particular postural behavior.

Keywords Stroke · Postural asymmetry · Egocentric reference frame · Allocentric

Introduction

One of the causes of disability in the patient following a stroke is postural disturbances (Pérennou et al. 2005b), which cause a greater risk of falls and contribute to loss of autonomy (Kim and Kim 2014). Postural control requires integration of vestibular, visual, and somatosensory information which is realized in different spatial reference systems such as allocentric and egocentric reference frames. This allows the patient to develop a perception of his body in

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space, thus maintaining its position and allowing the body to move (Barra et al. 2010; Bonan et al. 2013; Galati et al. 2010; Saj et al. 2014).

Postural imbalance is characterized in upright stance by an increased postural sway and more weight-bearing asymmetry (WBA) on the none-paretic leg (Mansfield et al. 2013; Pérennou 2005). This postural asymmetry is increased in the case of a right side lesion, which could be partly due to a disorder of the body orientation in space (Pérennou et al. 2014). Many researchers agree that the location for the determination of mental representation of the body in space is in the right cerebral hemisphere; the hemisphere which is specialized in spatial cognition (Barra et al. 2010; Bonan et al. 2013; Halligan et al. 2003; Rousseaux et al. 2014). This could explain why patients who have suffered from a right brain damage (RBD) have a lower prognosis in terms of balance and why they take a longer time to acquire a correct balance compared to patients in whom the lesion is located in the left hemisphere (LBD) (Bonan et al. 2007; Pérennou 2005; Rode et al. 1997).

Disorders of representation of body in space can be captured by measuring the perception of allocentric space representation such as vertical misperception and egocentric space representation such as the body midsagittal misperception. The allocentric reference frame involves the perception of space relative to information from the environment and also relative to one to another (Colombo 2017; Galati et al. 2010; Saj et al. 2014) and can be explored by assessing the subjective vertical (SV) (Bonan et al. 2006a, b; Pérennou et al. 2014; Piscicelli and Pérennou 2017; Rousseaux et al. 2013). While, the egocentric reference frame is body centered (Colombo 2017; Galati et al. 2010; Saj et al. 2014) and can be divided into two parts; first, the personal space, which corresponds to the body space and second, the extra-personal space, which refers to the out of body (Chokron et al. 2004; Chokron and Bartolomeo 1998; Committeri et al. 2007; Guariglia and Antonucci 1992; Rousseaux et al. 2014; Ventre-Domine 1984). Consequently, the egocentric space representation can be explored according to the part of space involved either in the extra-personal space representation with the subjective straight ahead (SSA) (Chokron 2003; Hugues et al. 2015; Jeannerod and Biguer 1989; Moulinet et al. 2016; Rousseaux et al. 2014) or the personal space representation with the longitudinal body axis (LBA) (Barra et al. 2009; Hugues et al. 2015; Moulinet et al. 2016).

The disturbance in the perception of vertical subjective after a stroke is the subject of numerous studies and its relationship with postural disorders have been exposed in several studies (Bonan et al. 2006a; Pérennou et al. 2008). This is, however, not the case for the egocentric spatial representation, where the relation with postural disorders was explored in only one study (Barra et al. 2009). Although, Barra et al. highlighted a relation between LBA and postural asymmetry in acute stroke, these authors did not examine its relation with the SSA. Even though SSA is an accepted manner to assess the egocentric extra-personal space representation, (Chokron 2003; Hugues et al. 2015) which is often disturbed after a stroke, to our knowledge no authors have investigated its relation with weight-bearing asymmetry.

Therefore, the first objective of this research was to examine both egocentric and allocentric space representation and weight-bearing asymmetry in chronic stroke patients. The second objective was to study their relations. Hence, the assumption that the bias of both egocentric and allocentric space representation could be explained, at least in part, by the postural asymmetry of patients with right brain damage. Determining a link between disturbance of egocentric or allocentric space representation and the postural asymmetry would, therefore, allow for a better understanding of balance disorders and provide for new approaches for the treatment of such disorders in stroke patients.

Methods

Participants

Stroke patients were recruited from a list of patients who were treated in the Department of the Physical Medicine and Rehabilitation (PMR) "Centre Hospitalier Universitaire (CHU)" of Rennes. The patients were contacted by phone after having confirmed the inclusion criteria and the foremost patients who responded were included in the study. The inclusion criteria incorporated the following two main considerations right or left brain unique sustentoriel damage with a time post-stroke of more than 1 year without any neglect and, hemianopia or pusher syndrome as these disorders are known to modulate both spatial and postural biases (Honoré et al. 2009; Karnath et al. 2000; Pérennou et al. 2014; Richard et al. 2005; Saj et al. 2005, 2006, 2010). Four tests for visuo-spatial neglect were conducted: the bell cancellation test (Rousseaux et al. 2001), 20 cm line bisection (Rousseaux et al. 2001), the Fluff test (Cocchini et al. 2001), and the OTA test (Ota et al. 2001). The patient was considered as neglect if he/she had at least three positive tests out of the four. The presence or the absence of a homonymous hemianopia was clinically tested with a confrontation visual field test on each quadrant with a ball. Concerning the laterality of patients, this was determined by the hand preference for writing. Patients had to be aged less than 80-year old presenting a weight-bearing asymmetry with less weight on the hemiplegic leg evaluated on the force plate form. Those patients who were symmetrical on their weight bearing were excluded given that the objective was to better understand mechanism of disturbance of postural balance. The exclusion criteria also ruled out patients with ischemic or hemorrhagic brainstem stroke, with an orthopedic and or a rheumatologic history affecting the distribution of weight bearing when standing or a visual history which does not allow the realization of visual assessments as well as those patients with major disorders of understanding. Concurrently, healthy subjects, from the care team at the PMR, those without any history of neurological, orthopedic and vestibular disturbances, which could probably alter the balance and the feasibility tests, were included in the study so as to obtain a normal range of the spatial frame of reference. This study was approved by the local Ethics Committee of Rennes University Hospital number 16.23.

Procedures

The inclusion procedures took place over a period between February 2016 and July 2017 in the Department of the Physical Medicine and Rehabilitation. The patients all went through a doctor–patient medical consultation to validate the inclusion criteria and besides to test out for possible new functional deficits. They then signed up once their approvals were obtained after having explained the protocol. After the evaluation of the severity of stroke, patients followed an assessment in this order: assessment of postural asymmetry, evaluation of space representation (SSA, SVV, LBA), and finally the balance test rating (TUG and BBS).

Assessment of postural asymmetry

Weight-bearing asymmetry (WBA)

Postural assessment of the patient was performed on a double force platform (FP) (PostureWin V143 Techno Concept ©). The patient placed bare feet (without socks or stockings) separately at a distance of 14 cm apart, with the objective being to stand as straight as possible with arms alongside the body, looking straight ahead (position open eyes OE) or wearing a headband (eyes closed position EC). The percentage of the WBA on the hemiparetic lower limb (WBA) was calculated as the mean of the four trials, each of a 30 s duration was chosen—two opened eyes (OP) and two closed eyes (CE) (Pérennou 2005; Pérennou et al. 2005a, b).

Evaluation of the egocentric space representation

Subjective straight ahead (SSA) (Chokron et al. 2004)

The evaluation was carried out on a measuring table on which the patient was required to move his hand in a blindfolded state. The table is graduated and 1° angle corresponds to 1 cm linear. The midsagittal almost coincides with the middle of the table with the head and trunk of the patient being placed in alignment. From a starting position where the hand of the patient was placed by the examiner and with no imposed time limit, the patient was pointing his right arm, for those patients with RBD and the left arm for patients with LBD; with fingers extended sliding on the support table, with the instruction to point "straight ahead" so as to divide the space into two parts. Ten tests were conducted with different starting positions in a randomized sequence (− 10°, 5°, − 15°, 10°, 30°, − 5°, − 20°, 15°, − 30°, 20). The positive sign corresponded to the ipsilesional side, i.e., the scores on the right were positive annotated, whereas the scores on the left were negative for patients with RBD and vice versa for patients with LBD. The value (in degrees up to 0.5°) used was both the mean (M_SSA), the mean absolute value (AbM_SSA), and the standard deviation (SD_SSA) for ten measurements.

The longitudinal body axis (LBA) (Barra et al. 2009)

The evaluation of the LBA was performed using a light strip in front of the patient in supine position, in complete darkness, with the head, the trunk, and the lower limbs aligned and maintained by cushions. The rotation center of the visual line was aligned with the patient's navel and with the plumb line. The light wand was moved around its axis of rotation by the examiner from a starting position inclined at a prescribed angle [ten tests were performed with starting positions in a randomized sequence (− 10°, 5°, − 15°, 10°, 30°, − 5°, − 20°, 15°, − 30°, 20)]. The patient was given the task to indicate when the strip was parallel to the axis of his body. The test took place in the dark with the patient's eyes open throughout the test. No visual reference other than the wand was available, and there was no time limit. The positive sign corresponded to the ipsilesional side, i.e., the scores on the right were positively annotated, whereas the scores on the left were negative for patients with RBD and vice versa for patients with LBD. The value (in degrees up to 0.5°) used was both the mean (M_LBA), the mean absolute value (AbM_LBA) and the standard deviation (SD_LBA) for 10 measurements.

Evaluation of the allocentric reference: subjective visual vertical (SVV) (Bonan et al. 2006a, b)

The evaluation of the SVV was performed in a sitting position with the head fixed, using virtual reality helmet (Oculus®). From an imposed starting position without a time limit, the patient was presented with a blue background with an oblique red line with ten different starting positions in a random sequence (− 10°, 5°, − 15°, 10°, 30°, − 5°, − 20°, 15°, − 30°, 20). The patient was given the task to indicate when the line is aligned to the vertical. The positive sign corresponded to the ipsilesional side, i.e., the scores on the right were positive annotated whereas the scores on the left were negative for patients with RBD and vice versa for patients with LBD. The value (in degrees up to 0.5°) used was both the mean (M_SVV), the mean absolute value (AbM_SVV), and the standard deviation (SD_SVV) for ten measurements.

Balance rating

Other balance tests to assess the functional impact of balance disorders have been carried out: Time Up And Go (TUG) (Podsiadlo and Richardson 1991) evaluating the time during which the patient gets up from a chair, walks 3 m, turns around and comes back to his seat, and Berg Balance Scale (BBS) (Berg et al. 2009) which includes 14 items assessing equilibrium in different positions such as picking up an object off the ground. The maximum score was 56.

Evaluation of the severity of stroke

Clinical tests were conducted as a motricity test (Motricity index which evaluates the hip flexion, the knee extension, and the ankle dorsiflexion with a score of 100 Collin and Wade 1990) and the spasticity test (Ashworth modified MAS) (Bohannon and Smith 1987) which targets the following muscle groups: sural triceps, quadriceps, and adductors, and finally the sensitivity (by a clinical examination of superficial tact on the foot and the lower limb and the arthrokinetic sensitivity of the knee, ankle, and toe).

Statistical analysis

Statistical analysis was performed using SAS 9.3 Software. The clinical data between the patients with RBD and LBD were compared using a Student's test or Mann and Whitney test when the distribution was not normal at a significance level of $p=0.05$. The relations between the spatial reference frame (SSA, LBA, and SVV) and the postural asymmetry (WBA) were first tested on the two groups of patients (RBD and LBD) byway of a multivariate analysis of variance (MANOVA) adjusted by the variable motricity and sensibility when the distribution was normal or by an ANOVA on ranks. After that, second, a partial correlation test with motor function and sensitivity as covariables was performed. The partial correlation was carried out for all the patients (RBD and LBD) and only thereafter taking the RBD group and the LBD into consideration. The space representation (SSA, LBA, and SVV) of patient with RBD and LBD was compared using a Student's test or Mann and Whitney test when the distribution was not normal. The comparison was based on the mean (M), standard deviation (SD), and absolute mean (AbM). The AbM was a unsigned mean not to take into account the plus or minus of the deviation and to better estimate what is moving away from zero for both group of patients. The relation between the assessment of space representation (SSA, LBA, and SVV) was tested by a Pearson correlation (or a Spearman correlation) taking into consideration M, AbM, and SD. The results of the evaluation of the spatial cognition for the healthy group were used so as to obtain a normal range of the spatial cognition.

Results

Population (Table 1)

From the list of stroke patients, 41 patients were contacted based on the inclusion criteria during the set period. With the exception of two patients who refused to participate, and one who died, all patients provided their approval. After having informed the patients and obtained their consent, 38 patients were integrated into the study. Of these, however, five patients with RBD patients and two patients with LBD patient were eventually excluded as they did not show signs of weight-bearing asymmetry on the force platform. Finally, one patient with RBD was also excluded because of neglect. Therefore, in this study, a total of 30 patients, 24 men and 6 women with an average age of 60.3 ± 10 years having had a delay after stroke (4.78 ± 3 years), with 15 patients with RBD and 15 patients with LBD cases were included (Fig. 1). Excepted two patients in each group, all the others were right handed. None of the patients presented a hemianopia. Out of the patients with LBD, two patients were with aphasia, but it did not induce any difficulty when preforming the assessment in understanding the aim of the protocol. When considering the severity of stroke with the Student's test, the two groups, patients with RBD and LBD, were similar in age ($p=0.4$) as, in motricity ($p=0.9$) and with the Mann and Whitney test in delay post-stroke ($p=0.4$) and sensibility ($p=0.2$). The weight-bearing repartition was similar for both groups according to the Student's test and as for the balance rating with the Mann and Whitney test (Table 2). Half of the patients of each group needed a cane while walking. Further, 20 healthy volunteers (7 men and 13 women) with a mean age of 23.9 ± 3.09 years, including 15 right handers and 5 left handers participated in the study.

Spatial frame of reference

The healthy volunteers obtained a mean for LBA [0.24° ± 1.34°], for SVV [−0.97° ± 1.48°], and for SSA [−0.15° ± 2.37°] when the test was performed with the right hand and [−1.50° ± 4.28°] when the test was performed with the left hand. We arbitrarily selected the threshold of normality as—average healthy subjects ± 2 standard deviations, i.e., for the LBA [−2.44°; 2.92°], for the SSA [−4.89°; 4.59°], and for SVV [−3.93°; 1.99°]. Despite the fact that our healthy subjects are not matched in aged with

Table 1 Clinical characteristics of the patients

Participants	Lesion side/delay stoke (year)	Sex/age	Cane	Laterality	Etiology	VSN (/4)	Hemianopia	Motricity (/100)	Sensitivity (/6)	SCP (/6)	WBA (%)	LBA (°)	SD (°)	SSA (°)	SD (°)	SW (°)	SD (°)	BBS (/56)	TUG (s)
P1	RBD/4.2	M/69	0	RH	I	2/4	–	73	6	0	30.6	2.35	3.5	−6.5	2	1.55	1.8	47	19.9
P2	RBD/2.7	M/62	1	RH	H	1/4	–	70	1	0	38.7	−2.3	2.04	4.5	2.3	−2	2.99	47	48.41
P3	RBD/2.1	M/41	0	RH	H	0/4	–	76	3	0	43.15	−1.9	2.4	1.9	4.45	4.7	3.52	47	13.13
P4	RBD/14.4	F/60	0	RH	H	0/4	–	54	6	0	45.225	1.35	1.49	−2.55	2.47	2.7	2.2	48	19.18
P5	RBD/3.1	M/78	1	RH	I	0/4	–	84	5	0	44.9	1.75	2.51	9	1.05	1.1	1.52	52	11.53
P6	RBD/3.6	M/48	0	RH	I	0/4	–	78	6	0	38.175	0.4	1.19	−4.4	2.24	4.6	3.2	51	11.19
P7	RBD/7	F/69	1	RH	H	2/4	–	59	2.5	0.5	25.075	−4.9	3.2	−7.7	3.8	1.5	3.86	26	62.5
P8	RBD/4.5	M/45	1	LH	I	1/4	–	60	2	0	43.2	−2.5	2.6	1.6	2.37	1	3.2	48	20.87
P9	RBD/4.9	M/49	1	RH	I	2/4	–	59	6	1	19	−4	2.7	3.1	3.9	−2.2	2.2	25	50.47
P10	RBD/12.3	M/72	0	RH	H	1/4	–	78	2.5	0	33	−1.9	1.9	−2.2	2.8	−0.38	4	46	20.37
P11	RBD/1	M/75	0	RH	I	0/4	–	92	5.5	0	46.3	0.05	2.51	−4.8	2.14	−1.6	3.9	49	11.32
P12	RBD/1.7	M/58	1	RH	I	2/4	–	45	4	0	32	−1.3	2.16	2.4	2.8	−0.76	3.27	41	26.65
P13	RBD/2.3	M/62	0	RH	H	0/4	–	91	6	0	28.8	0.55	1.09	−0.3	1.88	−0.41	3.1	46	19.91
P14	RBD/6.7	M/71	1	RH	I	0/4	–	91	4.5	0	26.72	−1.4	2.62	−4.45	2.38	−0.21	3.68	49	18.72
P15	RBD/12.4	M/62	0	RH	H	0/4	–	60	5.5	0	34.42	−1.1	3.45	−0.75	3.04	2.01	4.14	45	13.28
P1	LBD/3.1	M/51	1	RH	I	1/4	–	53	6	0	29.5	−0.4	1.07	5.5	1.7	2.1	3.54	40	25.69
P2	LBD/4.1	M/60	0	RH	H	0/4	–	81	4.5	0	41	−0.6	0.9	1.8	2.3	1.66	2.09	48	21.22
P3	LBD/4.9	M/72	1	RH	I	2/4	–	64	5.5	0	37.8	−1.4	2.03	4.8	3.85	−0.02	2.48	25	27.93
P4	LBD/7.2	F/69	0	RH	I	0/4	–	91	6	0	40.6	−0.95	1.58	2.35	2.05	0.62	1.97	52	12.03
P5	LBD/4.7	F/76	1	RH	I	2/4	–	53	6	0.5	31.7	1.15	1.95	7.4	1.89	0.7	2.87	25	60.02
P6	LBD/1.1	F/50	0	RH	I	0/4	–	92	6	0	38	1.15	0.85	2.95	0.76	1.87	1.91	52	9.87
P7	LBD/7.3	M/67	1	RH	I	0/4	–	92	3.5	0	40.77	−0.35	1.74	−0.75	0.75	0.82	1.1	45	18.34
P8	LBD/1.5	F/72	1	RH	I	0/4	–	59	5.5	0	37.1	0.65	2.77	2.6	1.57	−1.63	2.98	45	21.81
P9	LBD/3.1	M/51	0	RH	I	0/4	–	86	6	0	37.77	−0.9	0.93	−3.9	3.2	−1.89	1.93	51	15.12
P10	LBD/2.4	M/44	0	LH	I	0/4	–	86	6	0	43.87	−4.5	2.74	−0.55	1.7	0.93	1.13	54	10.56
P11	LBD/1.1	M/62	0	RH	I	1/4	–	76	6	0	45.02	−0.15	1.59	−0.6	2.5	0.46	1.19	51	13.69
P12	LBD/4.6	M/53	0	RH	H	0/4	–	45	1.5	0	45.5	−3.7	1.08	−2	2.62	0.11	1.81	46	19.75
P13	LBD/12.8	M/65	1	RH	H	1/4	–	76	3.5	0	38	2.25	2.13	−2.25	2.22	3.88	2.24	25	52.19
P14	LBD/1.1	M/51	1	RH	I	2/4	–	45	4.5	0	37.95	1.65	3.45	0.45	2.71	−1.81	1.81	49	14.25
P15	LBD/1.5	M/47	0	RH	I	0/4	–	67	6	0	41.27	0.75	0.79	−3.25	−1.18	−0.49	0.89	54	8.82

BBS Berg Balance Scale, *H* hemorrhagic, *I* ischemia, *LBA* longitudinal body axis, *LH* left handed, *RH* right handed, *SCP* Scale for Contraversive Pushing, *SD* standard deviation, *SSA* subjective straight ahead, *SVV* subjective visual vertical, *TUG* time up and go, *VSN* visuo-spatial neglect, *WBA* weight-bearing asymmetry

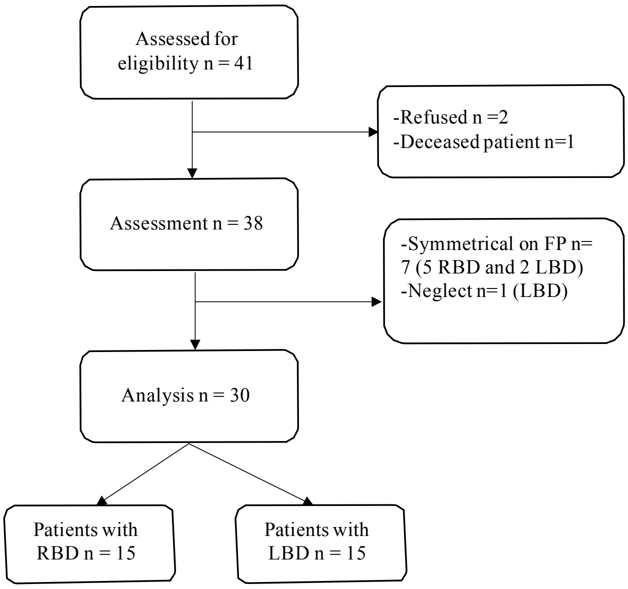

Fig. 1 Flowchart of participants (*RBD* right brain damage, *LBD* left brain damage, *FP* force plateform)

Table 2 Clinical data, patients with right brain damage (RBD) and patients with left brain damage (LBD)

	RBD (15)	LBD (15)	*p*
Characteristics			
Male/female	13/2	11/4	–
Ischemic/hemorrhagic	8/7	12/3	–
Age (year)	61 +/− 11	59 +/− 10	0.45
Delay post-stroke (year)	5.5 +/− 4	4.25 +/− 3.1	0.41
Severity of stroke			
Motricity (/100)	71 +/− 14	71 +/− 17	0.96
Sensivity(/6)	4.3 +/− 1.7	5.1 +/− 1.3	0.2
Visuo-spatial neglect/hemianopia	0/0	0/0	–
Assessment of postural asymmetry			
Weight-bearing asymmetry (%)	35 +/− 8	39 +/− 4	0.13
Assessment spatial cognition			
Longitudinal body axis (°)	−1.3 +/− 1.9	−0.35 +/− 1.8	0.1
Subjective straight ahead (°)	0.7 +/− 4.6	0.9 +/− 3	0.2
Subjective visual vertical (°)	0.8 +/− 2.2	0.4 +/− 1.5	0.6
Balance rating			
Time up and go (s)	24 +/− 16	22 +/− 15	0.71
Berg Balance Scale (/56)	44 +/− 8 0.66	44 +/− 10	

Data are presented with mean (±standard deviation)

our patients, these results are consistent with those of the literature (Barra et al. 2007; Chokron et al. 2004; Pérennou et al. 2008).

Using the Student's test, no difference was found between the patients with RBD and LBD on the evaluations of the space representation when taking the mean (LBA $p=0{,}1$; SSA $p=0.2$; SVV $p=0.6$), the AbM (LBA $p=0.1$; SSA $p=0.2$; SVV $p=0.3$), and the SD (SSA $p=0.07$) excepted for SD (LBA $p=0.02$ and SVV $p=0.0006$). However, when examining the individual results, even though most patients were within the normal range, some patients, and particularly those with RBD showed an abnormal shift (for LBA 3 out of 15 patients with RBD versus 2 out of 15 patients with LBD, and for SVV 3 out of 15 patients with RBD versus 1 out of 15 patients with LBD). Therefore, when individually observing the spatial cognition, 66% of RBD patients deviated on at least one of the tests of spatial cognition compared to 40% of the LBD patients.

No relation was found between either LBA, SSA, or SVV (M_LBA/M_SSA: $r=0{,}23$; $p=0.2$; M_LBA/M_SVV: $r=0.14$; $p=0.4$; M_SSA/M_SVV: $r=-0.09$; $p=0.6$); (AbM_LBA/AbM_SSA: $r=0.07$; $p=0.6$; AbM_LBA/AbM_SVV $r=0.01$ $p=0.9$; AbM_SSA/AbM_SVV $r=0.07$; $p=0.6$); (SD_LBA/SD_SSA $r=0.35$; $p=0.1$ SD_LBA/SD_SVV $r=0.27$; $p=0.1$) expected for SD_ SSA/SD_SVV $r=0.41$; $p=0.02$.

By use of the MANOVA, no relation was found between WBA/SSA ($p=0.58$); and WBA/SVV ($p=0.47$) when considering both patients with RBD and LBD. Weight-bearing asymmetry was found to be related to LBA when considering the whole group of patients ($p=0.03$). However, this relation was dependent on the group of patients ($p=0.0006$). The partial correlation confirmed the strong relation between WBA/LBA in the patients with RBD($r=0.77$; $p=0.02$) (Fig. 2), but not in the LBD($r=-0.46$; $p=0.1$). Moreover, by use of the multivariate analysis of variance (MANOVA) in percentage, when taking the whole group of patients into account, LBA represented 16% of WBA (R^2 = 16.24; p = 0.03) and 58.26% when considering only the patients
with RBD ($R^2=58.26$; $p=0.01$) which was not significant

in the group of patients with LBD ($p=0.12$).

Discussion

The main objective of this study was to determine whether the asymmetric posture of patient with RBD and LBD was related to a poor perception of body representation in space. The assumption was that the disturbance of the body perception in space explains at least in part, the postural asymmetry of brain damage patients and that this relation was more pronounced in the patients with RBD.

In this study, different aspects of the body representation in space were taken into consideration, both those with egocentric and allocentric space representation. Overall, 11 several months or years from stroke, there was still space misperception at the stage of recovery, especially in the RBD group (approximately 2 out of 3 patients) but also

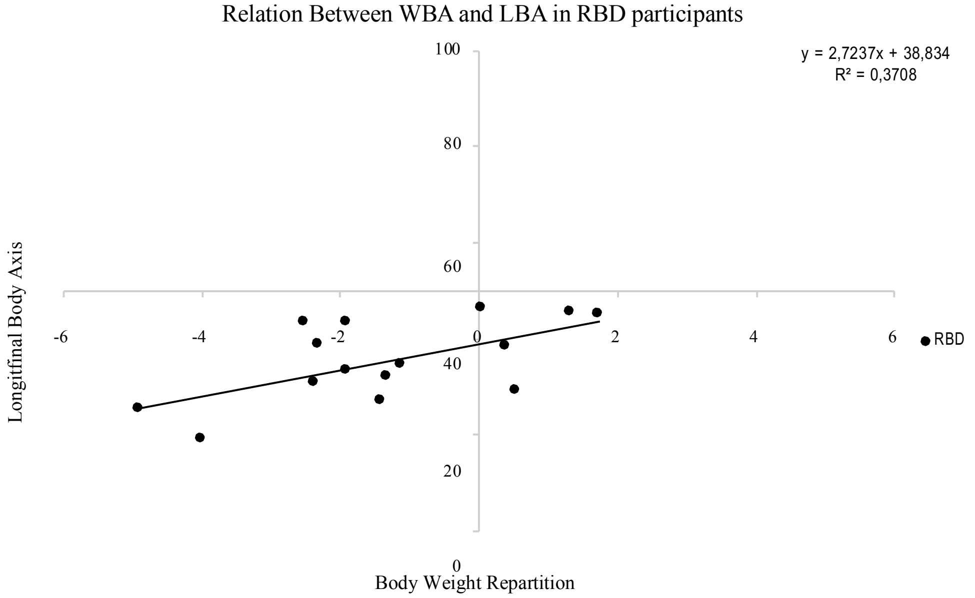

Fig. 2 Relation between weight-bearing asymmetry (WBA) and longitudinal body axis (LBA) in patients with right brain damage (RBD)

for the LBD group (approximately 40% of patients). These results are in line with other studies which assume that the location of the representation of the body in space is in the right cerebral hemisphere (Halligan et al. 2003; Rousseaux et al. 2014; Saj et al. 2014). Regarding the SVV, it is known that this disturbance may last longer in time after a stroke (Bonan et al. 2007). This result is a novelty in the egocentric space representation (LBA and SSA) and which was extensively studied in early stroke (Barra et al. 2009) rather than at a chronic stage (Hugues et al. 2015; Rossit et al. 2017). Patients with RBD had less weight on their paretic limb (35% ± 8) compared to patients with LBD (39% ± 4). However, compared to the literature (Bonan et al. 2007; Pérennou 2005; Rode et al. 1997), this difference was not significant due to a possible insufficient number of patients for statistical power to have a significant effect. Likewise, even if 66% of RBD patients deviated on at least one of the tests of spatial cognition compared to 40% of the LBD patients, no difference was revealed in the statistics concerning the spatial cognition between the two groups.

To meet our main objective related to the relationship between the postural asymmetry and the perception of the space representation in chronic stroke, a relation was found only between WBA and LBA in our group of patients with RBD. Jointly with the results of Barra et al. (2009) who also found the same relation but in early stroke, it seems that the relation between WBA and LBA is persistent whatever the delay after a stroke. This relation is in favor that at least a part of the body weight asymmetry comes from a body misperception in space. Using a multivariate analysis of variance, we did find that LBA represent 16% of WBA. Unlike Barra et al., we analyzed the influence of the side of stroke and found that the relation between postural asymmetry and LBA depended on the side of stroke with a more pronounced relation in the RBD group. Therefore, in patients with RBD, LBA represent 58.26% of WBA. Our result reinforces this hypothesis of spatial body misperception for the reason that the right hemisphere is thought to be the place of spatial elaboration (Barra et al. 2010; Bonan et al. 2013; Halligan et al. 2003; Rousseaux et al. 2014). No relation was found between either WBA or the SSA or the SVV. This quite certainly reinforces the fact that postural asymmetry, could partly be due, more to a disorder of the egocentric personal representation in space (LBA), than to an egocentric extra-personal representation of space (SSA) or to an allocentric representation of space (SVV), at least for chronic patients with a RBD.

Despite the fact that the LBA and the SSA are both two evaluations of the egocentric space representation, to our knowledge, their relationship has not yet been studied. Thus, no relationship was found here between these two evaluations. Our results are not surprising, as one corresponds to the egocentric representation in personal space (LBA), while the other relates to the egocentric representation in extra-personal space (SSA) (Moulinet et al. 2016; Hugues et al. 2015). Moreover, this result is not so original as in lesioned study, dissociated personal and extra-personal neglect were repeatedly found suggesting a different central processing (Committeri et al. 2007; Guariglia and Antonucci 1992). In addition, these two tests are not performed in the same postural position (sitting versus supine). Hence this supports our main result, in that, knowing the relation between WBA and LBA is significant, as they are both in the same personal space. As regards the SVV, no relation was found between the allocentric (SVV) and the egocentric (LBA, SSA) space representation. Some authors (Barra et al. 2009; Rousseaux et al. 2013) did, however, find a relationship and their results are indeed not astonishing as all disturbances of the space representation could coexist without being linked. Because other asymmetrical postural behaviors seem to be related to the verticality misperceptions like body lateropulsion, it would appear that different asymmetric postural behavior exist. Body lateropulsion could be related to the SVV misperception (Pérennou et al. 2008) and asymmetry of body weight repartition would be more linked to the egocentric personal space misrepresentation. Indeed body lateropulsion is tilted toward the hemiparetic side while body weight asymmetry is tilted toward contralateral side.

In our study, we should, however, point out a few limitations, namely, the large range of delay post-stroke, despite the fact that all the patients are chronic. In the same vein, due to the large range and even though the patients were examined by way of a medical consultation to single out the possibility of any new functional deficits, patients could have gone through new cerebrovascular accidents. Therefore, CT-scan or MRI examinations should have been performed at the inclusion to firmly verify that all included patients had a unique and unilateral brain damage. Despite the fact that our results were consistent with those of the literature (Barra et al. 2007; Chokron et al. 2004; Pérennou et al. 2008), another limitation within our study was that our healthy subjects were not matched in aged with our patients. Then, if all our patients were without neglect, confirmed through our battery of visuo-spatial neglect tests (3 positive tests out 4), some of our patients (7 out of 30) had 2 out 4 positives tests. This result reflects an element of doubt and may be questionable, not allowing us to totally consider them absolutely without neglect. For further future studies and to ensure that patients have no neglect, the entire group should not have any positive tests of the four carried out. Finally, the entire assessment was carried out in the same order which could have also been handled in a randomly manner so as to avoid exhaustion in the repetition.

To conclude, disturbances in the perception of the longitudinal body axis and its relationship with the balance disorders have already been pointed out. Our study goes a step further and confirms this relationship also at the chronic stage. We also disclose that the relation is dependent on the location of the stroke. In all our findings are in favor that the weight-bearing asymmetry of patients after a stroke is almost in part due to a disorder of the egocentric spatial representation, whereby the causal relationship still remains to be established. Moreover, our results show the absence of relation found between WBA and SSA and between WBA and SVV and when considering the results of other studies (Pérennou et al. 2008) who established a relation between body lateropulsion and disturbance in verticality perception, it would clearly appear that different mechanisms of asymmetrical postural behavior exist; body lateropulsion and asymmetry of body weight repartition. Further studies are therefore necessary so as to investigate in depth these different asymmetrical postural behaviors and their mechanism.

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Discussion :

L'objectif de ce travail est de répondre à la question des mécanismes d'action impliqués dans le déficit d'asymétrie d'appui en fonction du côté de la lésion cérébrale.

Notre étude montre que même à la phase chronique de l'AVC, certains patients et en particulier des patients AVC droit présentent des perturbations de leur représentation spatiale. En effet, 60% des patients AVC droit sont perturbés sur au moins un des biomarqueurs de la représentation spatiale contre 40% pour le groupe de patients AVC gauche. Ce résultat traduit une persistance des troubles de la représentation spatiale, notamment, chez les patients AVC droit. Il persiste également une asymétrie d'appui (patients AVC droit (35% ± 8) versus patients AVC gauche (39% ± 4)).

Au sujet de la relation, notre étude conforte la relation mise en évidence par Barra *et al.* au stade subaiguë dans une population de patients AVC en phase chronique (Barra et al., 2009). Nous retrouvons, comme ces auteurs, une relation entre l'asymétrie d'appui et le trouble de la représentation spatiale appréhendé par la mesure de l'axe longitudinal du corps (LBA) ($p=0.03$). Nous montrons de plus que cette relation est nettement plus marquée dans le groupe de patients AVC droit ($r=0.77$ $p=0.02$) alors qu'elle est inexistante dans le groupe de patients AVC gauche ($r=-0.46$ $p=0.1$). Ainsi la relation en phase subaiguë est persistante en phase chronique. A ce stade de l'AVC, cette relation est fonction du côté de la lésion cérébrale, elle n'est retrouvée que dans le groupe de patients AVC droit. Ce résultat diffère de celui de (Barra et al., 2009) qui trouve une relation moyenne entre l'asymétrie d'appui et le LBA ($r=-0.52$ $p<0.02$) dans l'ensemble de son groupe de patients comprenant des patients AVC droit et gauche. Son résultat pourrait s'expliquer par le faible nombre de patients AVC gauche inclus dans son étude (9 AVC gauche versus 13 AVC droit). Une autre hypothèse est qu'à un stade initial de l'AVC, la relation entre l'asymétrie d'appui et le LBA est présente dans le groupe de patients AVC droit mais également dans le groupe de patients AVC gauche. En effet, ces derniers pourraient présenter initialement des troubles de la représentation spatiale reliée à une asymétrie d'appui mais qui se corrigeraient plus rapidement que ceux des patients AVC droit.

Chapitre 2 : les vibrations des muscles du cou

Article 3: Effect of neck muscles vibration on postural orientation and spatial perception : a systematic review ; Karim Jamal, Stéphanie Leplaideur, Frédérique Leblanche, Annelise Moulinet-Raillon , Thibaud Honoré, Isabelle Bonan.

Effet des vibrations des muscles du cou sur l'équilibre postural et la représentation spatiale : revue systématique de la littérature

Parmi les différents sites de vibration, ce travail de recherche s'est focalisé sur les vibrations des muscles cervicaux. L'application de stimulations proprioceptives par vibration des muscles du cou a montré des résultats intéressants dans le traitement de l'héminégligence, un trouble de la cognition spatiale qui affecte principalement les cérébrolésés droits (Johannsen et al., 2003; Karnath et al., 1993; Schindler et al., 2002). Il s'agit de muscles très particuliers puisqu'il existe un lien direct entre les récepteurs proprioceptifs contenus dans ces muscles et le système vestibulaire et le système oculomoteur (Biguer et al., 1988). De par leur localisation spécifique entre la tête et le tronc, les muscles du cou sont impliqués dans le contrôle postural (Pettorossi & Schieppati, 2014). Lors de leur stimulation par vibration, (Bottini et al., 2001) a obtenu une activation des aires d'intégration multisensorielle. Les résultats sur la négligence et les activations retrouvées suggèrent que la vibration de ces muscles pourrait avoir un effet sur les troubles de la représentation spatiale via une action centrale.

L'objectif était d'effectuer une revue systématique sur l'effet des vibrations des muscles du cou sur la représentation spatiale et sur l'équilibre postural et d'appréhender les mécanismes d'action de cette stimulation sensorielle, à la fois sur des sujets sains et également sur les patients perturbés dans leur équilibre postural et/ou au niveau de leur représentation spatiale, en particulier chez les patients cérébrolésés et vestibulaires. Notre hypothèse sous tendant cette recherche est que les vibrations des muscles du cou pourraient avoir un effet sur les perturbations posturales secondaires aux troubles de la représentation spatiale. Cet article a fait l'objet d'une publication dans la revue « *Neurophysiologie Clinique, Clinical Neurophysiology*» .

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COMPREHENSIVE REVIEW

The effects of neck muscle vibration on postural orientation and spatial perception: A systematic review

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KEYWORDS
Neck muscle vibration;
Postural orientation;
Review;
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Summary
Background. — Neck muscle vibration (NMV) is increasingly used for its modulation of body orientation and spatial perception, but its mechanisms of action are still not well known.
Objectives. — To describe the effects of NMV on postural orientation and spatial perception, in both healthy people and patients with disturbed balance potentially related to distorted body orientation perception.
Methods. — Following the PRISMA guidelines, a systematic search was performed using the databases MEDLINE, EMBASE, Cochrane library and PEDrO with the key words ((Postural balance) OR (Spatial reference)) AND (Neck muscle vibration) for articles published through to July 2016.
Results. — A total of 67 articles were assessed; these exhibited wide heterogeneity and generally poor quality methodology. In healthy subjects, under bilateral NMV, the body tilts in the anterior direction (Level of Evidence LoE II). Under unilateral NMV, the visual environment moves towards the side opposite the vibration (LoE II) and the subject's experience of ''straight ahead'' is shifted towards the side of the vibration (LoE II). NMV also modulates both spatial and postural bias between stroke and vestibular patients.

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Discussion. — NMV modulates both spatial and postural bias and could thus be proposed as a tool in rehabilitative therapy. However, due to the heterogeneity of published data and the various significant shortfalls highlighted, current research does not allow clear guidelines to be proposed.

Introduction

Postural orientation requires integration of vestibular, visual, and somatosensory information in order to develop perception of the body in space and thus both maintain a position and allow the body to move [3,28]. This postural orientation can be altered by nervous system pathology, especially stroke or vestibular disease. By modulating one or more of the sources of input information, sensorial stimulation is known to manipulate the subject's posture [6].

Focusing on proprioceptive input, muscle vibration has been extensively used in two different approaches. The first is vibration applied to a specific tendon or muscle, termed ''focal vibration'', and the second is global stimulation of the body based on a vibrating platform referred to as ''Whole body vibration'' [84]. This review will focus on the former approach.

Several postural muscles, such as muscles of the trunk and the lower limbs, have been subjected to vibration in order to modulate postural orientation [20,25]. The neck muscles are unique for their localization between the head and the trunk. Their proprioceptive receptors play a crucial role in the detection of the position of the head in relation to the trunk [65]. Together with visual and vestibular inputs [5], the neck muscles are particularly involved in the perception of the body in space [5,40,44,65]. This perception of body in space can be captured by measuring the perception of allocentric space representation such as the vertical misperception (Subjective Visual Vertical) [7,66] and the egocentric space representation such as the body midsagittal misperception (Subjective Straight Ahead) [19]. By vibrating the neck muscles, a shift of the visual environment is observed, expressed clinically as the illusion of movement of a visual target [41]. As a consequence of this anatomical configuration, neck muscle vibrations (NMV) are used not only for their postural effect but also for their action on spatial perception. It is therefore essential to gather in-depth qualitative information on the effects of NMV on the perception of space as well as the effect on posture, in order to understand its action. Our objective was to conduct a systematic review of the characteristics and findings of these studies, and to assess the effects of neck muscle vibration (NMV) on postural orientation and spatial perception in both healthy people and patients with disturbed balance, in order to understand the potentially corrective effect of NMV in the patient population.

Methods

This review followed the PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [55]. Details of the protocol for this systematic review were registered on PROSPERO (CRD42016045392). Studies were only considered eligible if they involved the effect of NMV on either balance or spatial perception, with or without comparators. Studies in which the primary outcome was postural orientation evaluated by posturography in standing or sitting position were included, as were those with assessment of spatial perception (subjective straight ahead (SSA), subjective visual vertical (SSV), subjective haptic vertical (SHV), longitudinal body axis (LBA), pointing task or visual target).

A systematic search was performed using the databases MEDLINE, EMBASE, the Cochrane library and PEDrO. The keywords used in the search were ((postural balance*) OR (Spatial reference*)) AND (Neck muscle vibration). With the exception of reviews and meta-analyses, only studies published in French and in English up to July 2016 were considered. Lastly, a manual search was carried out on Google Scholar, Research Gate and clinical trial.gov for on-going studies. The reference lists of manuscripts and the bibliography of relevant reviews and meta-analyses were also searched.

After having eliminated all duplicates, an eligibility examination for the remaining studies was performed independently by two researchers (KJ and SL) on the basis of titles and abstracts. In the event of divergence between them, this was resolved by a third reviewer (IB). Data extraction was assessed by one reviewer (KJ) and then evaluated by a second (SL) for final validation. Any disagreement between them was resolved by a third reviewer (IB). Valid information was extracted from each eligible study on the basis of the following criteria:

- characteristics of the study — authors, year of publication and the type of design;
- characteristics of the trial participants — age, number of people involved in the analysis and the population analyzed;
- type of intervention — muscle vibrated, the side treated, duration and frequency;
- outcome measure: postural orientation, evaluated by posturography in standing or sitting position, and spatial perception (subjective straight ahead [SSA]), subjective visual vertical [SSV], subjective haptic vertical [SHV], longitudinal body axis [LBA], pointing task and visual target;

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- status of the main results — the effect of the vibration; under vibration, the immediate effect as soon as the vibrator stops and the lasting effect at a distance from the vibration.

The methodological quality of both the randomized control trials (RCTs) and the crossover trials (CO) was assessed using the PEDro scale [21,51]. This scale is based on 11 items scored out of 10: namely, eligibility criteria, randomization, concealed allocation, blinding (subjects, therapists, and assessors), follow-up, intention-to-treat analysis, between-group comparisons, point estimates and variability [57,63]. This scale gives a classification of quality with different cut-off score possibilities whereby 9 to 10 is considered excellent; 6 to 8 good; 4 to 5 fair; and < 4 poor quality [54,57,63]. Other studies were assessed by way of the Quality Assessment Tool for Before—After (Pre-Post) Studies with No Control Group [61] based on 12 items: objective clearly stated, eligibility criteria described, representative patient population, all eligible participants enrolled in the study, adequate sample size, intervention described, outcome measure specified, outcome assessors blinded, loss to follow-up, statistical analysis of outcome measure before and after intervention, interrupted time-series design and individual data used for group effects. According to the guidelines, the rating quality was considered to be good, fair or poor. The efficiency of NMV was scored according to the level of evidence (LoE) following the Sackett et al guidelines [14,70] for each outcome. For LoE I: large RCTs with clear results (only RCTs with a PEDro score of 6/10 or more), for LoE II: small RCTs with unclear results (poorer quality RCTs with a PEDro score under 6/10), for LoE III: cohort and case-control studies, for LoE IV: historical cohorts or case-control studies, for LoE V: case series, studies with no controls [54]. The quality of methodology was assessed independently by two researchers (KJ and SL) and in the event of a disagreement between them, this was resolved by a third reviewer (IB).

Results

In this systematic review, 290 references were identified, to which 15 references were added thereafter by way of a manual search (Fig. 1). Only 92 articles met the eligibility criteria and their full texts were requested. In the end, 67 articles, published between 1979 and May 2016, were included in this review, divided into 41 articles concerning postural orientation, 27 articles on spatial perception, and one article was included in both categories. These 67 articles covered a total of 74 experimental sessions, of which 56 (75%) were related to cross-over designs with median quality on the PEDro scale of 5/10 [min = 3/10; max = 6/10] (Table 1) and 18 (25%) to other study designs (Quality Assessment Tool for Before—After (Pre-Post) Studies with No Control Group), most of these being studies of fair to poor quality (Table 2). A total of 21 out of 75 were of good quality (i.e. above the PEDro cut-off of 6/10), among which 4 experimental sessions were based on spatial perception and the others (17) on postural orientation (Table 1).

A total of 1522 participants [min = 4; max = 104] were included in this systematic review, among whom 958 were healthy subjects, 235 were patients with vestibular lesions and 158 were stroke patients (Table 3). All the characteristics of the interventions are presented in Table 4. The median frequency and amplitude applied by the vibrator was 90 Hz [min = 20; max = 140] and 0.8 mm [min = 0.13; max = 1.4]. The most common muscle sites were the dorsal neck muscles for 23 studies (31%) with the identification of posterior or paravertebral or paraspinal neck muscles. Vibration was performed on one side (either right or left) for 20 studies (27%) and bilaterally for 21 (28%) studies. In most cases, muscle tracking was either not performed (46%) or established by anatomical location (40%) for the studies on postural balance; for spatial perception, however, most authors used the illusion of movement of a visual target to position the vibrator (59%). The median duration of the vibration was 20s [min = 1 s; max = 28min].

Postural orientation

The results for the effect of NMV on postural orientation are presented in Tables 5 and 6. Concerning bilateral NMV in healthy subjects, authors were in agreement, and many good-quality studies reported that the body tilted in the anterior direction (LoE II) [50,56,58,62,75,81]. Further to this, two studies (one of fair quality and the other of poor quality) described body tilt as soon as the vibrator was switched on, within the first milliseconds of onset of the vibration, generating first a backward body tilt and only thereafter a forward tilt at 250 ms [1,80]. One fair-quality study described a vectoral additive effect when vibrating back and oblique neck muscles: the body tilted in both the antero-posterior and the medial-lateral direction and when the vibrators were placed on two antagonist muscles; the effect vanished and no displacement was found [42].

Unilateral NMV applied to healthy subjects tilted the subject either in the anteroposterior plane or in the medial-lateral plane, depending upon which muscle was vibrated or the manner in which the vibrator was placed on the back of the neck (LoE IV). In the medial-lateral plane, bearing in mind that studies were only of fair quality, most of them found that subjects usually tilted in the direction opposite the vibrated side [11,20,42]. Only three studies of poor quality found that subjects could also tilt forward in the anteroposterior plane [46,69] (Table 5).

With regard to the retention effects after the vibrator was switched off, the systematic review highlights some disagreement. Only one study, albeit of good quality, did not observe any retention effect as their test subjects returned to their initial position after a short-duration bilateral NMV (1 s—4 s) [13]. In the case of unilateral NMV, three fair-quality articles found variability from one subject to another after stopping the vibration [16,22,82]. The length of the effect after stopping NMV was dependent on each individual experiment, for example, Wierzbicka et al. [82] described a retention effect between 3 minutes up to 3 h, while this was attained for at least 5 min for Leplaideur et al. [16] and 13 min for Duclos et al. [22]. Besides this, a variability was also observed in the direction of the retention effect as Duclos et al. [22] found a long lasting effect which was a tilt towards the NMV side for half of the healthy subjects while the other half, the tilt was in the opposite direction.

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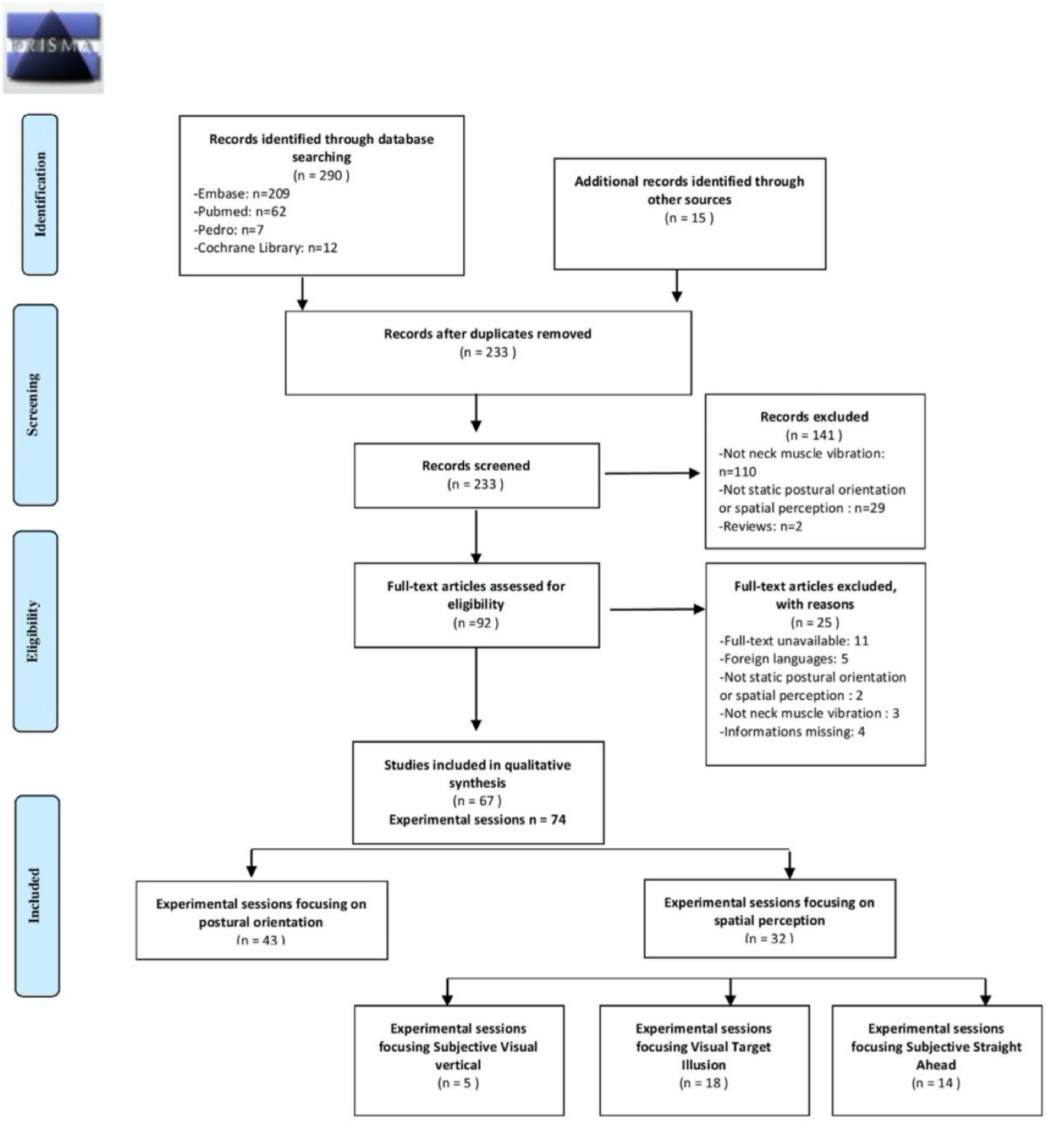

Figure 1 Prisma flow diagram.

This being said, three studies of fair to poor quality observed that when vibrating with different eye, head or trunk orientations, the body tilted towards the orientation of gaze rather than head or trunk orientation [29,33,34]. Five studies of good quality showed that vibrating with the eyes open had little or no effect on postural orientation (LoE II) [26,56,62,64,81] and one study (good quality) showed that the effect of vibration can be reduced or even suppressed by finger contact on a stable surface [10]. One good-quality study described an increase in the effect after successive sessions [13]. Magnusson et al. [50] (good quality) found that the amplitude of the tilt was related to the amplitude of the vibration, with a greater effect when the vibration amplitude was increased.

Results for patients are summarized in Table 6. For patients with vestibular lesions, this systematic review showed some disagreement. Among studies on patients with unilateral vestibular lesions, two studies of fair to very poor quality put forward the idea that unilateral NMV on the contra-lesional side tilted the body forward, whereas unilateral NMV on the ipsi-lesional side tilted the body in the medial plane towards the side of the lesion [45,67]. Controversially, one study of fair quality did not find any effect, and this is possibly due to a longer time-lapse since the lesion, to which they refer in their article [24]. Focusing on bilateral NMV in the case of unilateral vestibular lesions, two studies of fair to poor quality found that the body tilted towards the side of the lesion (LoE V) [79,83]. In the case of bilateral vestibular lesions, only one study of fair quality found no effect [45]. Regarding the retention effect, only one study of fair quality [83] focused on the effect after 15 s of vibration and found that patients moved gradually back to their initial position. Therefore, on the basis of these studies, this systematic review provides a low level of evidence (LoE V)

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Table 1 Quality of methodology of randomized control trials and crossover trials with Pedro scale.

Title	Author	1	2	3	4	5	6	7	8	9	10	11	Total/10
Adaptation of a bimodal integration stage: Visual input needed during neck muscle vibration to elicit a motion aftereffect (experiment 2)	Seizova-Cajic et al.	X	0	0	0	0	0	0	1	1	1	0	3
Eye movements cannot explain vibration-induced visual motion and motion after-effect.	Seizova-Cajic et al.	X	0	0	0	0	0	0	1	1	1	0	3
Time course of gaze influences on postural responses to neck proprioceptive and galvanic vestibular stimulation in humans	Grasso et al.	X	0	0	1	0	0	0	1	1	0	0	3
Effects of neck muscle vibration on subjective visual vertical: Comparative analysis with effects on nystagmus	Kawase et al.	X	0	0	1	0	0	0	1	1	1	0	4
Adaptation of a bimodal integration stage: Visual input needed during neck muscle vibration to elicit a motion after-effect (experiment 1)	Seizova-Cajic et al.	X	0	0	1	0	0	0	1	1	1	0	4
Neck muscle vibration modifies the representation of visual motion and direction in man (Experience 2)	Biguer et al.	X	0	0	1	0	0	0	1	1	1	0	4
Changes in apparent body orientation and sensory localization induced by vibration of postural muscles: vibratory myesthetic illusions (Experience 3)	Lackner et al.	X	0	0	1	0	0	0	1	1	1	0	4
Asymmetric vestibular function in the elderly might be a significant contributor to hip fractures	Kristinsdottir et al.	X	0	0	1	0	0	0	1	1	1	0	4
Vibration-induced postural post-effects	Wierzbicka et al.	X	0	0	1	0	0	0	1	1	1	0	4
The Subjective Visual Vertical and the Subjective Haptic Vertical Access Different Gravity Estimates	Frase et al.	X	0	0	1	0	0	0	1	1	1	1	5
Prism adaptation and neck muscle vibration in healthy individuals: Are two methods better than one?	Guinet et al.	X	0	0	1	0	0	0	1	1	1	1	5
Neck muscle vibration in full cues affects pointing.	McIntyre et al.	X	0	0	1	0	0	0	1	1	1	1	5
Effects of neck muscles vibration on the perception of the head and trunk midline position (experience 1)	Ceyte et al.	X	0	0	1	0	0	0	1	1	1	1	5
Convergent and divergent effects of neck proprioceptive and visual motion stimulation on visual space processing in neglect	Schindler et al.	X	0	0	1	0	0	0	1	1	1	1	5
The perception of body orientation after neck-proprioceptive stimulation: Effects of time and of visual cueing (Experience0)	Karnath et al.	X	0	0	1	0	0	0	1	1	1	1	5
Vibration-induced shift of the subjective visual horizontal: A sign of unilateral vestibular deficit	Karlberg et al.	X	0	0	1	0	0	0	1	1	1	1	5
Neck muscle vibration alters visually-perceived roll after unilateral vestibular loss	Betts et al.	X	0	0	1	0	0	0	1	1	1	1	5
Visual and oculomotor responses induced by neck vibration in normal subjects and labyrinthine-defective patients	Popov et al.	X	0	0	1	0	0	0	1	1	1	1	5
Changes of visual localization induced by eye and neck muscle vibration in normal and strabismic subjects	Han et al.	X	0	0	1	0	0	0	1	1	1	1	5
Ocular exploration of space as a function of neck proprioceptive and vestibular input - Observations in normal subjects and patients with spatial neglect after parietal lesions	Karnath et al.	X	0	0	1	0	0	0	1	1	1	1	5

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Table 1 (*Continued*)

Title	Author	1	2	3	4	5	6	7	8	9	10	11	Total/10
Properties of eye movements induced by activation of neck muscle proprioceptors	Lennerstrand et al.	X	0	0	1	0	0	0	1	1	1	1	5
The interactive contribution of neck muscle proprioception and vestibular stimulation to subjective ''straight ahead'' orientation in man	Karnath et al.	X	0	0	1	0	0	0	1	1	1	1	5
Subjective body orientation in neglect and the interactive contribution of neck muscle proprioception and vestibular stimulation	Karnath et al.	X	0	0	1	0	0	0	1	1	1	1	5
Clinical interest of postural and vestibulo-ocular reflex changes induced by cervical muscles and skull vibration in compensated unilateral vestibular lesion patients	Dumas et al.	X	0	0	1	0	0	0	1	1	1	1	5
Vibration-induced post-effects: A means to improve postural asymmetry in lower leg amputees?	Duclos et al.	X	0	0	1	0	0	0	1	1	1	1	5
Neck proprioception and spatial orientation in cervical dystonia	Bove et al.	X	0	0	1	0	0	0	1	1	1	1	5
Neck vibration causes short latency electromyographic activation of lower leg muscles in postural reactions of the standing human	Andersson et al.	X	1	0	1	0	0	0	1	1	1	0	5
Neck muscle vibration disrupts steering of locomotion	Bove et al.	X	0	0	1	0	0	0	1	1	1	1	5
Methods for evaluation of postural control adaptation	Fransson et al.	X	0	0	1	0	0	0	1	1	1	1	5
Neck muscle vibration makes walking humans accelerate in the direction of gaze	Ivanenko et al.	X	0	0	1	0	0	0	1	1	1	1	5
Influence of vibration to the neck, trunk and lower extremity muscles on equilibrium in normal subjects and patients with unilateral labyrinthine dysfunction.	Yagi et al.	X	0	0	1	0	0	0	1	1	1	1	5
From balance regulation to body orientation: Two goals for muscle proprioceptive information processing?	Kavounoudias et al.	X	0	0	1	0	0	0	1	1	1	1	5
Postural responses to vibration of neck muscles in patients with uni- and bilateral vestibular loss	Lekhe et al.	X	0	0	1	0	0	0	1	1	1	1	5
Analysis of adaptation in anteroposterior dynamics of human postural control	Fransson et al.	X	0	0	1	0	0	0	1	1	1	1	5
Postural responses to vibration of neck muscles in patients with idiopathic torticollis	Lekhe et al.	X	0	0	1	0	0	0	1	1	1	1	5
Effects of neck muscles vibration on the perception of the head and trunk midline position (experience 2)	Ceyte et al.	X	1	0	1	0	0	0	1	1	1	1	6
Neck Muscle Vibration Alters Visually Perceived Roll in Normals	McKenna et al.	X	1	0	1	0	0	0	1	1	1	1	6
Neck muscle vibration induces lasting recovery in spatial neglect	Schindler et al.	X	1	0	1	0	0	0	1	1	1	1	6
The perception of body orientation after neck-proprioceptive stimulation: Effects of time and of visual cueing (Experience1)	Karnath et al.	X	1	0	1	0	0	0	1	1	1	1	6
Differences in the use of vision and proprioception for postural control in autism spectrum disorder	Morris et al.	X	1	0	1	0	0	0	1	1	1	1	6

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Table 1 (*Continued*)

Title	Author	1	2	3	4	5	6	7	8	9	10	11	Total/10
Effect of neck muscles and gluteus medius vibrations on standing balance in healthy subjects	Challois et al.	X	1	0	1	0	0	0	1	1	1	1	6
Neck muscle vibration can improve sensorimotor function in patients with neck pain	Beinert et al.	X	1	0	1	0	0	0	1	1	1	1	6
Role of proprioceptive information to control balance during gait in healthy and hemiparetic individuals	Mullie et al.	X	1	0	1	0	0	0	1	1	1	1	6
Effects of manipulations with visual feedback on postural responses in humans maintaining an upright stance	Smetanin et al.	X	1	0	1	0	0	0	1	1	1	1	6
Local and global effects of neck muscle vibration during stabilization of upright standing	Verrel et al.	X	1	0	1	0	0	0	1	1	1	1	6
Interaction between vision and neck proprioception in the control of stance (Experience 1)	Bove et al.	X	1	0	1	0	0	0	1	1	1	1	6
Interaction between vision and neck proprioception in the control of stance (Experience 2)	Bove et al.	X	1	0	1	0	0	0	1	1	1	1	6
Effects of ageing on adaptation during vibratory stimulation of the calf and neck muscles	Patel et al.	X	1	0	1	0	0	0	1	1	1	1	6
Stance- and locomotion-dependent processing of vibration-induced proprioceptive inflow from multiple muscles in humans	Courtine et al.	X	1	0	1	0	0	0	1	1	1	1	6
The postural disorientation induced by neck muscle vibration subsides on lightly touching a stationary surface or aiming at it (experience 1)	Bove et al.	X	1	0	1	0	0	0	1	1	1	1	6
The postural disorientation induced by neck muscle vibration subsides on lightly touching a stationary surface or aiming at it (experience 2)	Bove et al.	X	1	0	1	0	0	0	1	1	1	1	6
Cervical muscle afferents play a dominant role over vestibular afferents during bilateral vibration of neck muscles	Magnusson et al.	X	1	0	1	0	0	0	1	1	1	1	6
Head stabilization on a continuously oscillating platform: The effect of a proprioceptive disturbance on the balancing strategy	De Nunzio et al.	X	1	0	1	0	0	0	1	1	1	1	6
Effect of gaze on postural responses to neck proprioceptive and vestibular stimulation in humans	Ivanenko et al.	X	1	0	1	0	0	0	1	1	1	1	6
Postural and symptomatic improvement after physiotherapy in patients with dizziness of suspected cervical origin	Karlberg et al.	X	1	0	1	0	0	0	1	1	1	1	6
Effects of vibrations on gait asymmetry: a prospective randomized controlled study in patients with chronic stroke	Leblong et al.	X	1	0	1	0	0	0	1	1	1	1	6

1/the eligibility criteria were specified, 2/subjects were randomly allocated to groups, 3/allocation was concealed, 4/the groups were similar at baseline regarding the most important prognostic indicators, 5/there was blinding of all subjects, 6/there was blinding of all therapists who administered the therapy, 7/there was blinding of all assessors who measured at least one key outcome, 8/measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups, 9/all subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analyzed by ''intention to treat'', 10/the results of between-group statistical comparisons are reported for at least one key outcome, 11/the study provides both point measures and measures of variability for at least one key outcome.

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Table 2 Quality methodology of experimental studies with the Quality Assessment Tool for Before—After (Pre-Post) Studies with No Control Group.

Titles	Authors	1	2	3	4	5	6	7	8	9	10	11	12	Rating quality
Short-term effect of neck muscle vibration on postural disturbances in stroke patients	Leplaideur et al.	Y	Y	Y	Y	NR	Y	Y	N	Y	Y	Y	NA	Fair
Neck muscle vibration and stroke patients	Challois et al.	Y	Y	Y	Y	NR	Y	Y	N	Y	Y	Y	NA	Fair
Short term effects of neck muscle vibration on balance control of stroke patients: A preliminary study	Challois-Leplaideur et al.	Y	Y	Y	Y	NR	Y	Y	N	Y	Y	Y	NA	Fair
Discrepancy between the directions of body sway and gaze during simultaneous optokinetic and posterior neck muscle vibration stimulation	Tsutsumi et al.	Y	N	N	NR	NR	Y	Y	N	Y	Y	N	NA	Fair
Postural responses to continuous unilateral neck muscle vibration in standing patients with cervical dystonia	Bove et al.	Y	N	Y	NR	NR	Y	Y	N	Y	Y	Y	NA	FAIR
Postural reactions to neck vibration in Parkinson's disease	Valkovic et al.	Y	N	Y	NR	NR	Y	Y	N	Y	Y	N	NA	Fair
Role of dorsal neck proprioceptive inputs to vestibular compensation in humans.	Yagi et al.	Y	N	Y	NR	NR	Y	Y	N	Y	Y	N	NA	Fair
Postural responses to vibration of neck muscles in patients with unilateral vestibular lesions	Popov et al.	Y	N	Y	NR	NR	Y	Y	N	Y	Y	N	NA	Fair
Lasting amelioration of spatial neglect by treatment with neck muscle vibration even without concurrent training	Johannsen et al.	Y	Y	Y	NR	NR	Y	Y	N	Y	Y	Y	NA	Fair
The perception of body orientation after neck-proprioceptive stimulation: Effects of time and of visual cueing (Experience2)	Karnath et al.	Y	N	N	NR	NR	Y	Y	N	Y	Y	Y	NA	FAIR
Subjective straight-ahead during neck muscle vibration: Effects of ageing	Strupp et al.	Y	N	N	NR	NR	Y	Y	N	Y	Y	Y	NA	Fair
Perceptual and oculomotor effects of neck muscle vibration in vestibular neuritis. Ipsilateral somatosensory substitution of vestibular function	Strupp et al.	Y	Y	N	NR	NR	Y	Y	N	Y	Y	Y	NA	Fair
Pattern of postural changes after symmetric neck muscle vibration	Valkovic et al.	Y	N	N	NR	NR	Y	Y	N	Y	NR	N	NA	Poor
Is muscle spindle proprioceptive function spared in muscular dystrophies? A muscle tendon vibration study	Ribot-Ciscar et al.	Y	N	Y	NR	NR	Y	Y	N	Y	NR	N	NA	Poor
The influence of head rotation on human upright posture during balanced bilateral vibration	Gurfinkel et al.	Y	N	N	NR	NR	Y	Y	N	Y	N	N	NA	Poor
Decrease of contralateral neglect by neck muscle vibration and spatial orientation of trunk midline	Karnath et al.	Y	N	N	NR	NR	Y	Y	N	Y	Y	N	NA	Poor
Illusions of head and visual target displacement induced by vibration of neck muscles.	Taylor et al.	Y	N	N	NR	NR	Y	Y	N	Y	Y	N	NA	Poor
Neck muscle vibration modifies the representation of visual motion and direction in man (Experience 1)	Biguer et al.	Y	N	N	NR	NR	Y	Y	N	Y	N	N	NA	Poor

1/objective clearly stated, 2/eligibility criteria described, 3/representative patient population, 4/all eligible participants enrolled in the study, 5/sufficient sample size, 6/intervention described, 7/outcome measure specified, 8/outcome assessors blinded, 9/loss to follow-up, 10/statistical analysis of outcome measure before and after intervention, 11/interrupted time-series design, 12/individual data used for group level effects. Yes (Y), No (N), Not Reported (NR), Not Available (NA). Quality Good, Fair, Poor.

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Table 3 Characteristics of the population.

Population charateristics	Numbers	%
Total population	1522	
Healthy subjects	958	62.6
Vestibular lesion	235	15.4
Unilateral lesions	184	
Bilateral lesions	51	
Strokes	154	10.1
RBD	87	
RBD with Neglect	15	
LBD	58	
Unknown	9	
Neck pain	30	1.9
Cervical dystonia	28	1.8
PD	26	1.7
Hip fractures Subjects	19	1.2
Spasmodic torticoli	19	1.2
Strabismic patients	16	1
Lower limb amputation	14	0.9
Autism spectrum disorders	12	0.7
Muscular dystrophia	11	0.7

RBD: right brain damage; LBD: left brain damage, PD: Parkinson Disease

Table 4 Characteristics of the intervention.

Characteristics	Studies	%
Muscles		
Dorsal neck muscles	23	31
Trapezius	9	12.3
Neck muscles	8	10
Splenius	8	10
SCOM	6	8
Splenius and Trapezius	5	6.7
Splenius and Trapezius and SCOM	5	6.7
Splenius and Semispinalis and Trapezius	3	4
Splenius and Semispinalis	2	2.7
Splenius and SCOM	2	2.7
Trapezius and Dorsal neck muscles	1	1.3
Trapezius and Semispinalis and SCOM	1	1.3
Splenius or SCOM or Trapezius	1	1.3
Side vibrated		
Bilateral	21	28
Right and left side	20	27.3
Left side	14	19.1
Contralesionnel side	5	6.7
Right side	3	4
Symmetrical to the supine	3	4
Bilateral and right side and left side	3	4
Bilateral and left side	1	1.3
Bilateral and right side	1	1.3
Painful side	1	1.3

Table 4 (*Continued*)

Characteristics	Studies	%
Amputation side	1	1.3
Not available	1	1.3
Eyes		
Eyes Open (EO)	31	41
Eyes Closed (EC)	22	30.1
EO and EC	20	27.3
Not available	1	1.3
Vibrator		
Duration = mean 20 s (min = 1 s; max = 28 min)	53	70
Amplitude = mean 0.8 mm (min = 0.13 mm; max = 1.4 mm)	50	66
Frequency = mean 90 Hz (min: 20 Hz; max: 140 Hz)	72	96
Postural orientation	43	
Muscle tracking		
Not available	20	46
Anatomical location	17	39.5
Illusion movement visual target	4	9
Illusion of movement of head	3	7
Position		
Standing position	31	75
Sitting position	5	11
Standing with different head position and eyes position	3	7
Standing with hand contact	2	4.6
Standing with different head position	1	2.3
Not available	1	2.3
Spatial perception	32	
Muscle tracking		
Illusion movement visual target	19	59
Anatomical location	7	21
Muscle palpation	3	9
Not available	3	9
Position		
Sitting position	25	78
Sitting position with different head position	2	6
Standing position	2	6
Sitting and supine position	1	3
Standing with body tilt	1	3
Standing and lying side position	1	3
Room light		
Dark	23	25
Dark/Light	8	3
Light	1	

for the efficacy of NMV on unilateral and bilateral vestibular lesions.

For stroke patients, three studies of fair quality observed that unilateral NMV on the contra-lesional side resulted in a medial-lateral tilt towards the contralesional side, i.e. the hemiplegic side, in both right and left brain damaged

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Table 5 Effect of neck muscle vibration (NMV) on postural orientation of healthy subjects.

Author	Design/ score	S1/number/ Age (Years)	S2/number/ Age (Years)	Zone or muscles vibrated	Muscle tracking/ side	Frequency (Hz)/ Amplitude (mm)	Duration (s)/ repetition	Vibration EO/ EC — position	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Comparator/ adjuvant
Morris et al., 2015	CO (6/10)	Healthy 20/ 23.4 ± 5.1		Dorsal neck muscles	Anatomical location/ Bilateral	NA/NA	5	EO/EC — standing	—	—	Pre-test(15 s)/ test under vibration(5 s)	Antero-postero plane = no effect EO. Effect EC with shift forward		
Challois et al., 2015	CO (6/10)	Healthy 13/23		Splenius and semispinalis	VTI/ left	70/NA	300	EC — standing	GMV Right side	—	Pre-test(52 s)/ test under vibration (5 min)/ post-test (5 min)	Medio-lateral plane = effect not significant (EC). Shift toward the left side in 5/13 subjects. Effect maintained in time		Comparator = effect significant with shift toward the left side in 9/13. Effect not maintained in time
Beinert et al., 2015	CO (6/10)	Healthy 10/21.8		Neck muscles	Anatomical location painful side/ right/ left	100/1	30	NA-NA	—	—	Pre-test(60 s)/ vibration (30 s)/ post test (immediate)	No effect		
Mullie et al., 2014	CO (6/10)	Healthy 12		Dorsal neck muscles	NA/ Bilateral	80/0.5	NA	EC — sitting	TSV paretic/non dominant side	—	Pre-test(10 s)/ test under vibration(20 s)	Antero-postero plane = effect (EC) with a shift forward		Comparator = effect (EC) with a shift backward
Dumas et al., 2013	CO (5/10)	Healthy 9/43 ± 15		Trapezius	Anatomical location/ right/ left	85/NA	10	EO/EC — standing	Mastoid vibration. TSV Left/Right	—	Test under vibration (25.6 s)	No effect		Comparator = TSV effect with a shift backward in healthy and medio-lateral in unilateral vestibular lesion
Valkovic et al., 2012	CS (POOR)	Healthy 12/ 20—35		Splenius and trapezius	Anatomical location/ Bilateral	70/ 1.4	2	EC — standing	—	—	Test under vibration	Antero-postero plane = effect (EC) with a shift backward shift (106 ms) then forward (359 ms)		

Table 5 (*Continued*)

Author	Design/ score	S1/number/ Age (Years)	S2/number/ Age (Years)	Zone or muscles vibrated	Muscle tracking/ side	Frequency (Hz)/ Amplitude (mm)	Duration (s)/ repetition	Vibration EO/ EC — position	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Comparator/ adjuvant
Smetanin et al., 2011	CO (6/10)	Healthy 11/ men 46.6 ± 9.6 and women 54.0 ± 6.2		Trapezius	Anatomical location/ Bilateral	70–100/1	4	EO/EC — standing	TAV bilateral	—	Pre-test (9–10 s)/ vibration (4 s)/ post test (5 s)	Antero-postero plane = effect (EC > EO2 = EO3D) with a shift forward		Comparator = NMV greater than TAV
Verrel et al., 2011	CO (6/10)	Healthy 8/ 21.4 ± 2.4		Dorsal neck muscles	NA/ Bilateral	100/0.8	10	EO/EC — standing	—	—	Pre-test(10 s)/ test under vibration(10 s)	Antero-postero plane = effect (EC > EO) with a shift forward		
Bove et al., 2009	CO (6/10)	Healthy 6/ 26.7 ± 2.5		Splenius and semispinalis and trapezius	Anatomical location/ Bilateral	100/0.8	5 × 10	EO/EC — standing	—	—	Pre-test (15 s)/ vibration (5 s)/ post test (15 s)	Antero-postero plane = effect (ECEC > EOEC/ ECEO > EOEO) shift forward during vibration then return to initial. Effect Increasing with successive vibration pulses		
Bove et al., 2009	CO (6/10)	Healthy 6/26.2 ± 2.6		Splenius and semispinalis and trapezius	Anatomical location/ Bilateral	100/ 0.8	5 × 10	EO/EC — standing	—	—	Pre-test(15 s + 3 s/ 6 s/ 9 s)/ vibration (5 s)/ post test (15 s)	Antero-postero plane = increasing duration EO reduce effect/ increasing duration EC increase effect. Effect with shift forward during vibration then return to initial		

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Table 5 (*Continued*)

Author	Design/ score	S1/number/ Age (Years)	S2/number/ Age (Years)	Zone or muscles vibrated	Muscle tracking/ side	Frequency (Hz)/ Amplitude (mm)	Duration (s)/ repetition	Vibration EO/ EC — position	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Comparator/ adjuvant
Patel et al., 2009	CO (6/10)	Healthy (young) 18/29.1 ± 7.8	Healthy (old) 16/71.5 ± 3.9	Dorsal neck muscles	NA/ Bilateral	85/1	50/(PRBS)	EO/EC — standing	TSV bilateral	—	Pre-test(30 s)/ test under vibration(PRBS)	Antero-postero plane and mediolateral = Decrease effect EO/increase effect EC. When repetition = Adaptation on antero-postero plane and lateral	Antero-postero plane and lateral = Decrease effect EO/increase effect EC. When repetition = Adaptation on antero-postero plane not on lateral	Comparator = TSV lager effect on antero-postero plane and lateral
Duclos et al., 2007	CO (5/10)	Healthy 18/37 ± 10		Trapezius	Illusion head movement/ left side/ amputation side	80/0.5–0.8	30	EC-sitting	GMV left side/ amputation	—	Pre-test(2 × 60 s)/ vibration (30 s)/ post test (immediate until 13 min)	Medio-lateral plane = effect with a shift to one side (half subject) and to the opposite side (half of subject). Effect maintained 13 min		Comparator = no difference CP shift amplitude. No difference in CP shift between two groups
Tsutsumi et al., 2007	CS (FAIR)	Healthy 8/21.4 ± 2.4		Dorsal neck muscles	NA/ Bilateral	50/0.2	NA	EO — standing	—	OKS	Pre-test/ test under vibration	No effect		Adjuvant = the direction of CoP translation was related to OKS velocity
Bove et al., 2007	CS (FAIR)	Healthy 12/51 ± 15.5		SCOM	NA/ right/ left	90/NA	NA	EC — standing	—	—	Test under vibration (51.2 s)	Medio-lateral plane = effect with a shift toward the right with left vibration and to the left with right vibration.		

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Table 5 (*Continued*)

Author	Design/ score	S1/number/ Age (Years)	S2/number/ Age (Years)	Zone or muscles vibrated	Muscle tracking/ side	Frequency (Hz)/ Amplitude (mm)	Duration (s)/ repetition	Vibration EO/ EC — position	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Comparator/ adjuvant
Courtine et al., 2007	CO (6/10)	Healthy 8/26—58		Splenius or SCOM or trapezius	Anatomical location/ left	80/0.8	60	EC — standing	TH. LU. AB. GL. RF. BF. TI. TE. TA. SOL. AI. AE vibration	—	Pre-test (60 s)/ test under vibration (60 s)	Antero-postero plane and mediolateral = effect with a shift toward opposite of the vibrated side. Effect in the mediolateral plane = Splenius/ SCOM/ Trapezius and Antero-Post plane = Splenius		Comparator = Effect in the medio-lateral plane = Lu. TI. TE. AI. AE. Sol. Effect in the Antero-posterior plane = Th. Lu. AB. GL. RF.BF. TA. Sol
Bove et al., 2006	CO (6/10)	Healthy 7/ 28.4 ± 6.7		SCOM	NA/ Bilateral/ right/ left	100/NA	60	EC — standing and hand contact	—	—	Pre-test/ test under vibration/ post test	Antero-postero plane and lateral = Light Finger Touch (LFT) during vibration or post-vibration reduce effect. LFT has more effect in plane of the deviation		
Bove et al., 2006	CO (6/10)	Healthy 5/27 ± 6.4		SCOM	NA/ Bilateral/ left	100/NA	5	EC — standing and hand contact	—	—	Pre-test/ test under vibration/ post test (2/5 s)	Antero-postero plane and mediolateral = LFT before vibration suppress effect. intended reduce effect		

Table 5 (*Continued*)

Author	Design/ score	S1/number/ Age (Years)	S2/number/ Age (Years)	Zone or muscles vibrated	Muscle tracking/ side	Frequency (Hz)/ Amplitude (mm)	Duration (s)/ repetition	Vibration EO/ EC — position	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Comparator/ adjuvant
Magnusson et al., 2006	CO (6/10)	Healthy 10/ 16—27		splenius	NA/ Bilateral	55/85/ 0.4/1	1X10	EC — standing	Mastoid vibration	—	Pre-test (30 s)/ test under vibration (110 s)	Antero-postero plane = effect with vibration on = backward then forward and when vibration switched off opposite effect. Effect larger with higher intensity		Comparator = lower and less effect
Valkovic et al., 2006	CS (FAIR)	Healthy 13/63.9 ± 11.3		Splenius and trapezius	Anatomical location/ Bilateral	80/1	3X10	EO/EC	—	—	Test under vibration (60 s)	Antero-postero plane = Effect wit a shift backward (119 ms to 123 ms) than forward (250 ms to 400 ms). Effect EC > EO. With repetitive vibration no effect EO and decrease effect EC		
De Nunzio et al., 2005	CO (6/10)	Healthy 14/33 ± 11.3		Splenius	Anatomical location/ Bilateral	90/0.9	30	EO/EC — standing	QV. TAV. BFV. TSV bilateral	—	Test under vibration (30 s)	Antero-postero plane = Effect with a shift forward. EC > EO		Comparator = Effect forward = Q/TA and backward for TS/BF

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Table 5 (*Continued*)

Author	Design/ score	S1/number/ Age (Years)	S2/number/ Age (Years)	Zone or muscles vibrated	Muscle tracking/ side	Frequency (Hz)/ Amplitude (mm)	Duration (s)/ repetition	Vibration EO/ EC — position	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Comparator/ adjuvant
Bove et al., 2004	CO (5/10)	Healthy 12/51.6 ± 15.5		SCOM	Anatomical location/ right/ left	90/NA	51.2	EC — standing	—	—	Pre-test (51.2 s)/ test under vibration (51.2 s)	Medio-lateral plane = Effect with a shift to the left with right vibration and to the right with left vibration		
Ribot-Ciscar et al., 2004	CS (POOR)	Healthy 10/ 35.1 ± 10.2		Splenius	Anatomical location/ left	80/0.5	2	EC — standing	TAV bilateral/ TSV bilateral	—	Pre-test(0.5 s)/ test under vibration (20 s)/ post test (immediate)	Antero-postero plane = Effect with a shift forward		Comparator = Effect with a shift forward for TAV and backward for TSV
Andersson et al., 2002	CO (5/10)	Healthy 10/37		Splenius	NA/ Bilateral	85/1	0.25	EC — standing	—	—	Test under vibration (1 s/4 s)	Antero-postero plane = Effect with a shift forward (250 ms) then backward (350 ms). Same effect for 1s or 4 s		
Bove et al., 2001	CO (5/10)	Healthy 9/32.5		Neck muscles	Anatomical location/ right	70/NA	NA	EO/EC — standing	—	—	Pre-test (51.2 s)/ test under vibration (51.2 s)/ post test (60 s)	Medio-lateral plane = Effect both during and before vibration. More effect during than before and EC > EO		
Kristinsdottir et al., 2000	CO (4/10)	Healthy 28/72		Dorsal neck muscles	NA/ Bilateral	60/1	PRBS	EO/ EC- standing	TSV bilateral	—	Pre-test(30s)/ test under vibration (PRBS)	No effect		Comparator = TSV EC S1(8/19) S2(1/28)

Table 5 (*Continued*)

Author	Design/ score	S1/number/ Age (Years)	S2/number/ Age (Years)	Zone or muscles vibrated	Muscle tracking/ side	Frequency (Hz)/ Amplitude (mm)	Duration (s)/ repetition	Vibration EO/ EC – position	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Comparator/ adjuvant
Fransson et al., 2000	CO (5/10)	Healthy 10/37.5		Dorsal neck muscles	NA/ Bilateral	60/1	PRBS	EO/EC – standing	TSV bilateral	–	Pre-test (30 s)/ test under vibration (PRBS)	Antero-postero plane = EC > EO		Comparator = more sway
Ivanenko et al., 2000	CO (5/10)	Healthy 7/22–39		Splenius and trapezius	Anatomical location/ Symmetrical to supine	80/0.8	0.75	EO/EC – standing with different head position and eye position	–	–	Pre-test(5 s)/ test under vibration (6/8 s)	Antero-postero plane = effect to the side of head position but more influenced by to eye position. EO effect toward the visual target and EC toward the imaginary target		
Yagi et al., 2000	CO (5/10)	Healthy 59/25.6		Trapezius and dorsal neck muscles	NA/ Bilateral	100/1	20	EC – standing	–	–	Pre-test(20 s)/ test under vibration (20 s)	Antero-postero plane = Effect maximum with the upper dorsal neck with a shift in the sagittal plane		–

Table 5 (*Continued*)

Author	Design/ score	S1/number/ Age (Years)	S2/number/ Age (Years)	Zone or muscles vibrated	Muscle tracking/ side	Frequency (Hz)/ Amplitude (mm)	Duration (s)/ repetition	Vibration EO/ EC — position	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Comparator/ adjuvant
Grasso et al., 1999	CO (3/10)	Healthy 4/33 ± 7		Splenius and trapezius	Anatomical location/ Symmetrical to supine	50/0.8	NA	EO/EC — standing with different head position and eye position	Galvanic vestibular stimulation	—	Pre-test (5 s)/ test under vibration (2 min)	Medio-lateral plane = Effect with a shift toward the eyes position when EO and toward to the imaginary eye position when EC. Effect with latency 2 s and stable at 5 s. When repetitive neck vibration effect with a shift opposite eye deviation		Comparator = same effect
Ivanenko et al., 1999	CO (6/10)	Healthy 13/20 −39		Splenius and trapezius	Anatomical location/ Symmetrical to supine	50/0.8	15	EO/EC — standing with different head position and eye position	Galvanic vestibular stimulation	—	Pre-test (5 s)/ test under vibration (15s)	Antero-postero plane = Effect with a shift toward the eyes position when EO and toward to the imaginary eye position when EC. Effect linked with eyes position > head position = head and trunk position		Comparator = Effect in the medio-lateral plane and biased toward eyes deviation

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Table 5 (*Continued*)

Author	Design/ score	S1/number/ Age (Years)	S2/number/ Age (Years)	Zone or muscles vibrated	Muscle tracking/ side	Frequency (Hz)/ Amplitude (mm)	Duration (s)/ repetition	Vibration EO/ EC — position	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Comparator/ adjuvant
Kavounoudias et al., 1999	CO (5/10)	Healthy 11/22—55		Splenius and trapezius and SCOM	NA/ right/ left	80/0.2—0.4	2	EC — standing	TSV. TAV. PV	TSV. TAV. PV	Pre-test (1 s)/ test under vibration (2/3 s)/ post-test (4 s)	Medio-lateral plane = Effect with a shift contralateral to the muscle vibrated. When vibration of 2 antagonist muscles. No effect. When vibration of an antero-posterior muscle and lateral one. Effect with a shift in the oblique direction. SCOM = effect backward. Splenius = effect forward		Comparator = Effect with a shift ipsilateral to muscle vibrated/ adjuvant = When vibration of 2 antagonist muscles. No effect. When vibration of an antero-posterior muscle and lateral one. Effect with a shift in the oblique direction
Yagi et al., 1998	CS (FAIR)	Healthy 30/29		Dorsal neck muscles	NA/ Bilateral	110/1	30	EC — standing	—	—	Pre-test (15 s)/ test under vibration (30 s)/ post-test (15 s)	Antero-postero plane = Effect with a shift forward		
Lekhe et al., 1998	CO (5/10)	Healthy 19/33.8 ± 10	Unilateral vestibular lesion 13/49 ± 15	Trapezius	NA/ right/ left	90/0.5	35/PRBS	EC — standing	—	—	Pre-test (4/5 s)/ test under vibration (35 s/PRBS)/ post-test (2/40 s)	Antero-postero plane = When vibration on = effect with a shift backward then forward. When the vibration is switched off = shift goes back to initial		

Table 5 (*Continued*)

Author	Design/ score	S1/number/ Age (Years)	S2/number/ Age (Years)	Zone or muscles vibrated	Muscle tracking/ side	Frequency (Hz)/ Amplitude (mm)	Duration (s)/ repetition	Vibration EO/ EC — position	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Comparator/ adjuvant
Wierzbicka et al., 1998	CO (4/10)	Healthy 12/23—59		Splenius and trapezius and SCOM	NA/ Bilateral	80/0.2	30	EC — sitting	TAV bilateral/ TSV bilateral	—	Pre-test (60 s)/ vibration (30 s)/ post-test (19 min)	Antero-postero plane = Effect with a shift backward when vibration of the front NM and forward when vibration of the back of the neck. Post effect varied across subjects (3min-3H)		Comparator = Effect with shift forward for Soleus = forward and backward for TAV. Same effect for post-vibration
Fransson et al., 1998	CO (5/10)	Healthy 12/34.8		Dorsal neck muscles	NA/ Bilateral	60/1	PRBS	EO/EC — standing	TSV bilateral	—	Pre-test(30s)/ test under vibration (PRBS)	Antero-postero plane = Effect with a shift forward. EC > EO		Comparator = Effect with a shift backward

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Table 5 (*Continued*)

Author	Design/ score	S1/number/ Age (Years)	S2/number/ Age (Years)	Zone or muscles vibrated	Muscle tracking/ side	Frequency (Hz)/ Amplitude (mm)	Duration (s)/ repetition	Vibration EO/ EC — position	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Comparator/ adjuvant
Lekhe et al., 1997	CO (5/10)	Healthy 19/33.8 ± 10		Trapezius	NA/ right/ left	90/0.5	35/PRBS	EC — standing with different head position	—	—	Pre-test (4/5 s)/ test under vibration (35 s/PRBS)/ post-test (2/40 s)	Antero-postero plane = Effect with a shift forward		
Karlberg et al., 1996	CO (6/10)	Healthy 17/36 (25—55)		Dorsal neck muscles	Anatomical location/ Bilateral	20/ 40/60/ 80/100 — 0.4	10	EO/EC-standing	—	—	Pre-test (10 s)/ test under vibration (10 s)	Antero-postero plane = Effect with a shift on the antero-postero direction EO/EC and at different frequency		
Popov et al., 1996	CS (FAIR)	Healthy 19		Trapezius	NA/ right/ left	90/0.5	PRBS	EC — standing	—	—	Pre-test (30 s)/ test under vibration (PRBS)	Antero-postero plane = Effect with a shift forward and little right side with left vibration and forward and little left side with right vibration. No difference in amplitude of deviation between right/ left side vibration		
Gurfinkel et al., 1995	CS (POOR)	Healthy 12		Splenius	Illusion head move-ment/ NA	NA/NA	NA	EC — standing	—	—	NA	Medio-lateral plane = effect with a lateral body tilt		

AB: abdominal; AE: ankle external; AI: ankle internal; BF: biceps femoris; CS: case-study; CO: cross-over trail; EO, EC: eye open and closed; GL: gluteus; GMV: gluteus medius vibration; NA: not available; OKS: optokinetic stimulation; PRBS: pseudorandom binary sequence schedule; QV: quadriceps vibration; RF: rectus femoris; S: soleus; S1, S2: Subjects; TE: thigh external; TI: thigh internal; TAV: tibialis anterior vibration; TSV: triceps surae vibration; LU: trunk lumbar; TH: trunk thoracic; VTI: visual target illusion.

Table 6 Effect of neck muscle vibration on postural orientation of patients with disturbed balance.

Author	Design/ score	S1/ number/ Age (Years)	S2/ number/ Age (Years)	Zone or muscles vibrated	Muscle tracking/ side	Frequency (Hz)/ Amplitude (mm)	Duration (s)/ repetition	Vibration EO/EC — position	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Difference between groups	Comparator/ adjuvant
Leplaideur et al., 2016	CS (FAIR)	Stroke (RBD) 15/62.1 ± 8.5	Stroke (LBD) 16/60.9 ± 12	Splenius and semispinalis	VTI/contral-esionnel side	80/NA	600	EC — sitting	—	—	Pre-test (50 s)/ vibration (10 min)/ post test (immediate)	Medio-lateral plane = Significant effect with a shift toward the hemiplegic side	Medio-lateral plane = Significant effect with a shift toward the hemiplegic side	No difference	
Morris et al., 2015	CO (6/10)	Autism spectrum disorders 12/23.6 ± 7.9		Dorsal neck muscles	Anatomical location/ Bilateral	NA/NA	5	EO/EC — standing	—	—	Pre-test (15 s)/ test under vibration(5 s)	Antero-postero plane = Effect both EO/EC with shift forward			
Beinert et al., 2015	CO (6/10)	Neck pain 13/22.4		Neck muscles	Anatomical location painful side/ right/ left	100/1	30	NA-NA	—	—	Pre-test (60 s)/ vibration (30 s)/ post test (immediate)	No effect			
Challois et al., 2014	CS (FAIR)	Stroke (RBD) 14/61.6	Stroke (LBD) 16/61.6	Neck muscles	VTI/ contral-esionnel side	80/NA	600	EC — sitting	—	—	Pre-test (50 s)/ vibration (10 min)/ post-test (immediate)	Medio-lateral plane = Effect (EO/EC) with a shift toward the hemiplegic side	Medio-lateral plane = Effect (EO/EC) with a shift toward the hemiplegic side	No difference	
Mullie et al., 2014	CO (6/10)	Stroke 9/47.8 ± 11.8		Dorsal neck muscles	NA/ Bilateral	80/0.5	NA	EC — sitting	TSV paretic/ non dominant side	—	Pre-test (10 s)/ test under vibration(20 s)	Antero-postero plane = Effect (EC) with a shift forward			Comparator = Effect (EC) with a shift backward

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Table 6 (*Continued*)

Author	Design/ score	S1/ number/ Age (Years)	S2/ number/ Age (Years)	Zone or muscles vibrated	Muscle tracking/ side	Frequency (Hz)/ Amplitude (mm)	Duration (s)/ repetition	Vibration EO/EC — position	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Difference between groups	Comparator/ adjuvant
Dumas et al., 2013	CO (5/10)	Compensate Unilateral vestibular lesions (left) 12/54± 8		Trapezius	Anatomical location/ right/ left	85/NA	10	EO/EC — standing	Mastoid vibration. TSV Left/ Right	—	Test under vibration (25.6 s)	No effect		No difference	Comparator = TSV effect with a shift backward in healthy and mediolateral in unilateral vestibular lesion
Challois-Leplaideur et al., 2012	CS (FAIR)	Stroke (RBD) 7/60.3	Stroke (LBD) 7/60.3	Neck muscles	VTI/ contralesionnel side	80/NA	600	EC — sitting	—	—	Pre-test (50 s)/ vibration (10 min)/ post-test (immediate)	Mediolateral plane = Effect (EC) with a shift toward the hemiplegic side		Effect on RBD only	
Duclos et al., 2007	CO (5/10)	Lower limb amputation 14/43 ± 10		Trapezius	Illusion head movement/ left side/ amputation side	80/0.5-0.8	30	EC — sitting	GMV left side/ amputation	—	Pre-test (2 × 60 s)/ vibration (30 s)/ posttest (immediate until 13 min)	Mediolateral plane = Effect with a shift to one side (half subject) and to the opposite side (half of subject). Effect maintained 13 min		Effect with a shift larger for Amputees	Comparator = No difference CP shift amplitude. No difference in CP shift between two groups

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Table 6 (*Continued*)

Author	Design/ score	S1/ number/ Age (Years)	S2/ number/ Age (Years)	Zone or muscles vibrated	Muscle tracking/ side	Frequency (Hz)/ Amplitude (mm)	Duration (s)/ repetition	Vibration EO/EC — position	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Difference between groups	Comparator/ adjuvant
Bove et al., 2007	CS (FAIR)	Cervical dystonia 16/60.2 ± 14		SCOM	NA/ right/ left	90/NA	NA	EC — standing	—	—	Test under vibration (51.2 s)	Antero-postero plane = No effect or minor shift			
ValkoviÄ et al., 2006	CS (FAIR)	PD (severe) 13/61.8 ± 9.2	PD (moderately affected) 13/ 64.2 ± 8.9	Splenius and trapezius	Anatomical location/ Bilateral	80/1	3X10	EO/EC	—	—	Test under vibration (60 s)	Antero-postero plane = Effect with a shift backward (119 ms to 123 ms) than forward (250 ms to 400 ms). Effect EC > EO. With repetitive vibration no effect (EO/EC)	Antero-postero plane = Effect with a shift backward (119 ms to 123 ms) than forward (250 ms to 400ms). Effect EC > EO. With repetitive vibration no effect EO and decrease effect EC	Larger effect in S1	
Bove et al., 2004	CO (5/10)	Cervical dystonia 12/59.6 ± 15		SCOM	Anatomical location/ right/ left	90/NA	51.2	EC — standing	—	—	Pre-test (51.2 s)/ test under vibration (51.2 s)	No effect		Weaker effect for S1	
Ribot-Ciscar et al., 2004	CS (POOR)	Muscular dystrophia 11/35.4 ± 13		Splenius	Anatomical location/ left	80/0.5	2	EC — standing	TAV bilateral/ TSV bilateral	—	pre-test (0.5 s)/ test under vibration (20 s)/ post-test (immediate)	Antero-postero plane = Effect with a shift forward		Same effect	Comparator = Effect with a shift forward for TAV and backward for TSV

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Table 6 (*Continued*)

Author	Design/score	S1/number/Age (Years)	S2/number/Age (Years)	Zone or muscles vibrated	Muscle tracking/side	Frequency (Hz)/Amplitude (mm)	Duration (s)/repetition	Vibration EO/EC — position	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Difference between groups	Comparator/adjuvant
Kristinsdottir et al., 2000	CO (4/10)	Hip fracture subjects 19/72.5		Dorsal neck muscles	NA/Bilateral	60/1	PRBS	EO/EC — standing	TSV bilateral	—	Pre-test (30 s)/test under vibration (PRBS)	Antero-postero plane = Effect in EC for 2/19			Comparator = TSV EC S1(8/19) S2(1/28)
Yagi et al., 2000	CO (5/10)	unilateral vestibular lesions 12/55.5		Trapezius and dorsal neck muscles	NA/Bilateral	100/1	20	EC — standing	—	—	Pre-test (20 s)/test under vibration (20 s)	Medio-lateral plane = Effect with dorsal neck toward the ipsilesional side. No effect with the trapezius		Less effect for S1 with the upper dorsal neck	
Yagi et al., 1998	CS (FAIR)	Unilateral vestibular lesions (compensated) 37/55.5 ± 11.8	Unilateral vestibular lesions(acute) 37/51.9 ± 12.6	Dorsal neck muscles	NA/Bilateral	110/1	30	EC — standing	—	—	Pre-test (15 s)/test under vibration (30 s)/post-test (15 s)	Antero-postero and medio-lateral plane = Effect with a shift forward and toward the lesion side	Antero-postero and medio-lateral plane = Effect with a shift forward and toward the lesion side	S1/S2 larger shift then S3	

Table 6 (*Continued*)

Author	Design/ score	S1/ number/ Age (Years)	S2/ number/ Age (Years)	Zone or muscles vibrated	Muscle tracking/ side	Frequency (Hz)/ Amplitude (mm)	Duration (s)/ repetition	Vibration EO/EC — position	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Difference between groups	Comparator/ adjuvant
Lekhe et al., 1998	CO (5/10)	Bilateral vestibular lesions 11/52 ± 14	Unilateral vestibular lesion 13/49 ± 15	Trapezius	NA/ right/ left	90/0.5	35/PRBS	EC — standing	—	—	Pre-test (4/5 s)/ test under vibration (35 s/PRBS)/ post-test (2/40 s)	No effect	Antero-postero and medio-lateral plane = Ipsilateral vibration = effect with a shift toward the side of lesion and backward. Contralesional vibration = Effect with a shift forward		
Lekhe et al., 1997	CO (5/10)	Spasmodic torticollis 19/42.4 ± 7	Bilateral vestibular lesions 11/52 ± 13	Trapezius	NA/ right/ left	90/0.5	35/PRBS	EC — standing with different head position	—	—	Pre-test (4/5 s)/ test under vibration (35 s/PRBS)/ post-test (2/40 s)	Antero-postero plane = Little effect with a shift forward or no effect	Antero-postero plane = Little effect with a shift forward or no effect	S1 = S2	

Table 6 (*Continued*)

Author	Design/score	S1/number/Age (Years)	S2/number/Age (Years)	Zone or muscles vibrated	Muscle tracking/side	Frequency (Hz)/Amplitude (mm)	Duration (s)/repetition	Vibration EO/EC — position	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Difference between groups	Comparator/adjuvant
Karlberg et al., 1996	CO (6/10)	Neck pain 17/37 (26-49)		Dorsal neck muscles	Anatomical location/Bilateral	20/40/60/80/100 - 0.4	10	EO/EC — standing	—	—	Pre-test (10 s)/test under vibration (10 s)	Antero-postero plane = Effect with a shift on the antero-postero direction EO/EC and at different frequency		Effect significantly greater in S1	
Popov et al., 1996	CS (FAIR)	Unilateral vestibular lesions 9		Trapezius	NA/right/left	90/0.5	PRBS	EC — standing	—	—	Pre-test (30 s)/test under vibration (PRBS)	Medio-lateral plane = Effect vibration of the contralesional (forward) side higher than ipsilesional side (backward and rotation to the ipsilesional side)		Effect smaller during vibration of the affected side	
Leblong and al. Unpublished	CO (6/10)	Stroke (RBD) 11/63.3 ± 14	Stroke (LBD) 10/58.2 ± 11	Dorsal neck muscles	NA/contralesional side	70/NA	300	EO — standing	Ipsilesional GMV/contralesional Biceps Brachial vibration	—	Pre-test (52 s)/test under vibration (5 min)/post-test (2/10 min)	No effect	No effect	No difference	Comparator = No effect

CS: case study; CO: crossover trail; EO, EC: eye open and closed; GMV: gluteus medius vibration; LBD: left brain damage; NA: not available; PD: Parkinson disease; QV: quadriceps vibration; RBD: right brain damage; S1, S2: subjects; TAV: tibialis anterior vibration; triceps surae vibration (TSV); visual target illusion (VTI).

groups [17,18,48] with a greater body tilt among the stroke patients who experienced the illusion of movement of a visual target under vibration [48]. On the other hand, only one study of good quality showed that bilateral NMV in standing position led to a forward tilt [58]. This systematic review revealed the absence of studies focusing on the retention effect amongst stroke patients.

Spatial perception

Illusion of movement of a visual target (VT)

Sixteen articles focused on VT with a total of 304 subjects, of whom 92 were patients, for the most part stroke patients (n = 72) (Tables 7 and 8). The six articles, of fair quality, without exception all found that during unilateral NMV in healthy subjects, the VT shifted towards the direction opposite to the vibrated side (LoE II) [31,37,41,47,52,68]. This systematic review found two means of assessing the illusion of movement of a VT; the first was to ask the subject to give a self-report on whether there was an illusion of movement of the VT and to define its direction [37] and the second was the administration of a pointing task [52]. One poor quality study found that the illusion of motion was consistent whether the subject was pointing towards it or just viewing it [5]. Two studies of fair to poor quality observed that in a few cases the illusion could also move on the vertical plane [5,41].

Four studies of poor quality highlighted that this illusion was not consistent [5,38,74,77]. Biguer et al. [5] specified that whatever the side of vibration, only 78% of the healthy subjects were found to be susceptible to visual illusions. A greater amplitude of deviation was found when the vibration amplitude was increased [5]. Regarding the effect after the cessation of the vibration, the most relevant studies were found to be of poor quality with authors in disagreement on the topic; some authors stated that the VT could reverse its direction to return to its initial position [5,74], while others claimed that for some subjects [31] the VT continued in the same direction after the vibration was switched off. The same effect was observed in both sitting and supine positions [68] (fair quality).

Concerning stroke patients, apart from the poor quality of most studies, 3 authors reported a frequency of illusion of movement of the VT (LoE IV) identical to the proportion found among healthy subjects [35,37,48] (Table 8). Unilateral spatial neglect did not influence this proportion [37,38]. In the vestibular lesion population, no studies on the effect of NMV on the illusion of VT movement were found.

Mid-sagittal plane perception: Subjective Straight Ahead (SSA)

Eleven articles focused on SSA with a total of 271 trial subjects, of whom 60 were patients, stroke patients for the most part. Two good quality articles and the others of fair to poor quality found that the SSA shifted towards the vibrated side whatever the method used (visual or haptic condition), in both healthy subjects (LoE II) (Table 7) [15,40] and stroke patients, independently from the side of the brain damage [39,48,72,73] (LoE II). Only one study of fair quality focused on patients with vestibular lesions and found a shift towards the side of the vestibular lesion [76] (Table 8). In addition, some studies of fair quality [30,41] found that the healthy subjects who deviated on SSA were those who were susceptible to the illusion of movement of the VT.

Biguer et al. [5] reported that increasing the amplitude of vibration led to a greater amplitude of SSA deviation. Karnath et al. (fair quality) showed that the duration of the vibration resulted in an effect maintained over time [40]. The same effect was found when vibrating in both upright and sitting positions, but when the body was maintained tilted in the roll plane, the SSA deviation was greater (fair quality) [15].

Gravitational perception: Subjective Vertical (SV)

Five articles with a total number of 140 subjects were included in the analysis, 76 of whom were healthy subjects (Table 7) and the rest vestibular patients (Table 8). There was one good quality study [53]. Regarding the healthy subjects, unilateral vibration on either the sternocleidomastoid (SCOM) or other dorsal neck muscles induced a tilt in the roll plane of Subjective Visual Vertical (SVV) towards the vibrated side [53] as compared to the subjective visual horizontal (SVH) where the effect was absent (fair quality) [4,36]. NMV with the head-roll tilt to the opposite side induced a greater tilt of the SVV towards the side of the vibration (the Müller effect) [53]. This result, found in the sitting position, was also found in the standing position [27] (fair quality). This systematic review revealed the absence of studies focusing on the retention effect. Similarly, this systematic review pointed out, that no studies provided evidence on evaluating the effect of NMV on the SV in the stroke population.

Among patients with vestibular lesions, three studies of fair quality showed that, independently from the time-lapse since the lesion, both contralesional and ipsilesional NMV increased the abnormal ipsilesional SV tilt with a greater effect when vibrating the ipsi-lesional side (LoE IV) [4,36,43]. In addition, compared to healthy subjects, this effect was influenced by the head orientation in the roll plane, given that it increased when the head was tilted towards the contra-lesional side, but not towards the ipsi-lesional side (fair quality) [4].

Discussion

To our knowledge, there have been only a limited number of reviews on the subject of neck muscle vibration [59,65]. In the perspective of moving towards better understanding of the mechanism of action of NMV on postural orientation and body perception in space, this review differs from others: first by its systematic methodology, secondly, the fact that it takes both postural orientation and spatial perception into account, and thirdly, the fact that it includes both healthy subjects and patients with a disturbed balance, in order to evaluate the potentially corrective effect of NMV in the patient population.

This review highlights the fact that the effect of NMV has been studied extensively, with literature on this research going as far back as 1979 and continuing to be substantial. It can be noted that the effect of NMV on postural balance has been studied more widely than its effect on spatial perception. It must however be recalled that only 56

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Table 7 Effect of neck muscle vibration (NMV) on spatial perception of healthy subjects.

Author	Design	S1/ number/ Age (Years)	S2/ number/ Age (Years)	Outcome measures	Muscle vibrated	Muscle tracking/ side	Frequency (Hz)/ Amplitude (mm)	Vibration EO/EC — Duration (s)	Vibration position — Room light	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Comparator/ Adjuvant
Frase et al., 2015	CO (5/10)	Healthy 16/21—60		SVV/SHV	Dorsal neck muscles	Anatomical loca-tion/bilateral	30/NA	EO — NA	Standing with body tilt — light	—	—	Test under vibration	Effect with a shift opposite body tilt		
Guinet et al., 2013	CO (5/10)	Healthy/ 54/ 25.11 ± 8.28		SSA. VTI	Splenius	VTI/ right	80/NA	EO — 150	Sitting — dark	Prism	Prism	Pre-test/ vibration/ post-test	SPA = Effect on subjects with illusion of LED in sagittal plane. SVA = No effect		Comparator = Effect/ adjuvant = Effect
McIntyre et al., 2007	CO (5/10)	Healthy/11		VTP	Splenius	Anatomical location/ muscle palpa-tion/ VTI/ right/ left	90/NA	EO — 8	Sitting — dark/ light	—	Prism	Test under vibration	Effect toward the opposite side of stimulus in dark (11/11) and light (3/11) but more pronounced in dark		
Seizova-Cajic et al., 2007	CO (4/10)	Healthy/21		VTP	Splenius and trapezius and SCOM	Anatomical location/ right/ left	140/NA	EO — 15	Sitting — dark/ light	—	—	Test under vibra-tion(15 s)/ post-test (15 s)	Effect with a shift toward opposite side of the vibration. Post-effect in all condition light with less post effect when the VT was not present during the period of vibration		
Seizova-Cajic et al., 2007	CO (3/10)	Healthy/9		VTP	Splenius and trapezius and SCOM	Anatomical location/ right/ left	140/NA	EO — NA	Sitting — dark/ light	—	—	Test under vibration (15 s)/ post-test (15 s)	Post-effect in all condition but smaller when the VT was absent under the period of vibration		

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Table 7 (*Continued*)

Author	Design	S1/ number/ Age (Years)	S2/ number/ Age (Years)	Outcome measures	Muscle vibrated	Muscle tracking/ side	Frequency (Hz)/ Amplitude (mm)	Vibration EO/EC — Duration (s)	Vibration position — Room light	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Comparator/ Adjuvant
Ceyte et al., 2006	CO (5/10)	Healthy/ 13/27		SSA	Trapezius	Muscle palpation/ left	100/0.2	EO — NA	Standing — dark	—	—	Test under vibration	Effect with a shift toward the left side (vibrated side)		
Ceyte et al., 2006	CO (6/10)	Healthy/ 7/30		SSA	Trapezius	Muscle palpation/ left	100/0.2	EO — NA	Standing or lying Right/ left side — dark	—	—	Test under vibration	Effect with a shift toward the left side. Effect larger when lying on the left side than standing. No effect when lying on the right side		
Seizova-Cajic et al., 2006	CO (3/10)	Healthy/12		VTP	Trapezius and semispinalis and SCOM	Anatomical location/ Bilateral/ right	125/NA	EO — 15	Sitting — dark	—	—	Pre-test (60/2 s)/ test under vibration (15 s)/ post-test (15 s)	Effect for SCOM upward during vibration. downward during post-vibration and for splenius = Left and/or upward during vibration and opposite during post-vibration. Effect in 7/10 subjects		
McKenna et al., 2004	CO (6/10)	Healthy/ 26/36		SVV	Dorsal neck muscles	Anatomical location/ right/ left	100/A	EO — NA	Sitting with different head position — dark	Left and right mastoid vibration	—	Pre-test/ test under vibration	Effect with a shift opposite direction head roll-tilt with more effect when vibration on the side of the head opposite to the head tilt		Comparator = Main effect for neck vibration

Table 7 (*Continued*)

Author	Design	S1/number/Age (Years)	S2/number/Age (Years)	Outcome measures	Muscle vibrated	Muscle tracking/side	Frequency (Hz)/Amplitude (mm)	Vibration EO/EC — Duration (s)	Vibration position — Room light	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Comparator/Adjuvant
Karnath et al., 2002	CO (5/10)	Healthy 18/27.3		SSA	Neck muscles	VTI/left	80/0.4	EO — 180	Sitting — dark	Left hand vibration	—	Pre-test/test under vibration (3 min)	Effect with a shift toward the left side (vibrated side)		Comparator = No effect
Karnath et al., 2002	CO (6/10)	Healthy 6/29.5		SSA	Neck muscles	VTI/left	80/0.4	EO — 60/300/900/1800	Sitting — dark	—	—	Pre-test/test under vibration/post-test (3 min)	No difference of the duration on the deviation but on the maintaining of the effect. The more the duration is increased the more the effect is maintained		
Karnath et al., 2002	CS (FAIR)	Healthy 6/27.5	Healthy/6/25	SSA	Neck muscles	VTI/left	80/0.4	EO — 1680	Sitting — dark	—	Visual information	Pre-test/test under vibration/post-test (3 min)	Effect with a shift toward the left side (vibrated side)		Adjuvant = Reduce effect of NMV
Karlberg et al., 2002	CO (5/10)	Healthy 13/32		SVH	SCOM	Palpation muscle/right/left	92/0.6	EO — NA	Sitting — dark	Mastoid bone vibration	—	Pre-test/test under vibration	Effect only in 1/13 subjects		Comparator = Less effect
Betts et al., 2000	CO (5/10)	Healthy 21/40		SVH	SCOM	Palpation muscle/right/left	100/0.4	EO — 100	Sitting with different head position or standing with whole body tilt — dark	—	—	Pre-test (100 s)/test under vibration (100 s)	No effect		
Strupp et al., 1999	CS (FAIR)	Healthy 30/46.1 ± 12.9		SSA	Dorsal neck muscles	NA/right/left	100/1	EO — 20	Sitting — dark	—	—	Pre-test/test under vibration	Effect with a shift toward the side of stimulation, which increases with the age		

Table 7 (*Continued*)

Author	Design	S1/ number/ Age (Years)	S2/ number/ Age (Years)	Outcome measures	Muscle vibrated	Muscle tracking/ side	Frequency (Hz)/ Amplitude (mm)	Vibration EO/EC — Duration (s)	Vibration position — Room light	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Comparator/ Adjuvant
Popov et al., 1999	CO (5/10)	Healthy 5/25—51		VTI	Trapezius	VTI/ right	90/0.5	EO — 10	Sitting and supine position — dark/ light	—	—	Pre-test (5 s)/ test under vibration (10 s)	Effect with a shift toward the left. Same effect in sitting and supine position. In supine position also a shift in the vertical plane (up or down). No effect when light on		
Han et al., 1999	CO (5/10)	Healthy 8/32—49		VTP. VTI	Splenius and SCOM	VTI/ right/ left	70/1	EO — 8/10	Sitting — Dark	—	—	Pre-test (8/10 s)/ test under vibration (8/10 s)	Effect with a shift to the left when vibration of the left SCOM/right splenius and to the right with right SCOM/ left splenius. Vibration off VTI goes back or continue		
Strupp et al., 1998	CS (FAIR)	Healthy 25/49.1 ± 14.2		SSA	Dorsal neck muscles	VTI/ right/ left	100/1	EO/EC — 20	Sitting — dark	—	Prism	Pre-test/ test under vibra- tion/ post-test (1 year)	Effect with a shift toward the side of muscle vibrated. No difference between Right/ Left vibration		Adjuvant = Opposite effect
Karnath et al., 1996	CO (5/10)	Healthy/ 10/50		SSA	Dorsal neck muscles	VTI/ left	100/0.4	EO — NA	Sitting — dark	Vestibular stimula- tion	—	Pre-test/ test under vibration	Effect with a shift toward the left side		Comparator = Same effect

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Table 7 (*Continued*)

Author	Design	S1/number/Age (Years)	S2/number/Age (Years)	Outcome measures	Muscle vibrated	Muscle tracking/side	Frequency (Hz)/Amplitude (mm)	Vibration EO/EC — Duration (s)	Vibration position — Room light	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Comparator/Adjuvant
Lennerstrand et al., 1996	CO (5/10)	Healthy 8/29–36		VTI	Splenius and SCOM	NA/Bilateral/right/Left	70/1	EO — 10	Sitting — dark/light	—	—	Pre-test (10 s)/test vibration (10 s)/post-test (10 s)	Effect with a shift toward the left when vibration of the left SCOM and right splenius. To the right with right SCOM and left splenius. Downward with both splenius. No effect in fully light		
Karnath et al., 1994	CO (5/10)	Healthy 17/31		SSA. VTI	Dorsal neck muscles	VTI/right/left	100/0.4	EO — NA	Sitting — dark	Vestibular stimulation	Vestibular stimulation	Pre-test/test under vibration	Deviation of SSA only for patients with VTI (9/17). VTI = Effect with a shift toward the right with left NMV vis versa (±vertical). SSA = Effect with a shift toward the left with left NMV vice versa		Comparator =Effect with a shift on the right side for 17/17/ Adjuvant = When in the same side = Larger effect than alone. When in opposite side = Neutralize effect
Karnath et al., 1994	CO (5/10)	Healthy/10/50		SSA. VTI	Dorsal neck muscles	VTI/right/left	100/0.4	EO — NA	Sitting — dark/light	Vestibular stimulation	Vestibular stimulation	Pre-test/test under vibration	Effect with a shift toward the left and (±vertical) with left vibration vice versa and Effect on SSA only on patient with VT motion (10/10)		Comparator = Effect in 10/10/ Adjuvant = Same side = Larger effect than alone. Opposite side = Neutralize effect

Table 7 (*Continued*)

Author	Design	S1/number/Age (Years)	S2/number/Age (Years)	Outcome measures	Muscle vibrated	Muscle tracking/side	Frequency (Hz)/Amplitude (mm)	Vibration EO/EC — Duration (s)	Vibration position — Room light	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Comparator/Adjuvant
Karnath et al., 1993	CS (POOR)	Healthy/15/46		VTI	Dorsal neck muscles	VTI/right/left	100/NA	EO — NA	Sitting — dark	Left hand vibration		Pre-test/test under vibration	Effect in 10/15 subjects with a shift to the right with Left NMV and to the left with right NMV		Comparator = No effect
Taylor et al., 1991	CS (POOR)	Healthy 13		VTI	Neck muscles	VTI/left	100/NA	EO — 15	Sitting — dark	—	—	Test under vibration	Effect in 9/13 subjects with a shift toward the left (3) and toward the right (6)		
Biguer et al., 1998	CS (POOR)	Healthy 10/25—55		VTP. VTI	Dorsal neck muscles	VTI/left	100/0.3	EO — NA	Sitting — dark/light	—	—	Pre-test/test under vibration	Effect with a shift to the right side (±vertical). Relation between VTI and VTP. Effect 9/10 subjects in Dark and middle dark and 2/10 when in light. Vibration off VTI goes initial position		
Biguer et al., 1998	CO (4/10)	Healthy 9		SSA. VTP	Dorsal neck muscles	VTI/left	100/0.13/0.29/0.49	EO — NA	Sitting — dark	—	—	Pre-test/test under vibration	When increasing the amplitude of vibration. it increases the amplitude of deviation of VTP		
Lackner et al., 1979	CO (4/10)	Healthy 10/25—55		VTI	Splenius and trapezius and SCOM	NA/Bilateral/right/Left	120/NA	EO — NA	Standing — dark/light	Muscles vibration		Test under vibration	VTI moving according to head change. No effect in fully light		Comparator = Moving according to head or body motion

CS: case study; CO: crossover trail; EO, EC: eye open and closed; NA: not available; SSA: subjective straight ahead; SVH: subjective visual haptic; SVV: subjective visual vertical; S1, S2: VTI: Subjects, visual target illusion; VTP: visual target pointing.

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Table 8 Effect of neck muscle vibration (NMV) on spatial perception of patients with disturbed balance.

Author	Design	S1/ number/ Age (years)	S2/ number/ Age (years)	Outcome measures	Muscle vibrated	Muscle tracking/ side	Frequency (Hz)/ Amplitude (mm)	Vibration EO/EC-Duration (s)	Vibration position-Room light	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Comparator/ Adjuvant
Leplaideur et al., 2016	CS (FAIR)	Stroke (RBD) 15/62.1 ± 8.5	Stroke (LBD/16/ 60.9 ± 12)	VTI	Splenius and semispinalis	VTI/ contralesional side	80/NA	EO-600	Sitting-dark	—	—	Test under vibration	Effect toward the opposite side of the stimulus in 11/15 subjects	Effect toward the opposite side of the stimulus in 9/16 subjects	
Kawase et al., 2011	CO (4/10)	unilateral vestibular lesions/ 14/ 54.2		SVV	Dorsal neck muscles	Anatomical location/ right/ left	110/NA	EO-NA	Sitting-dark	—	—	Test under vibration	Effect with a shift toward the ipsilesional side. Effect larger when vibration in the ipsilesional side		
Schindler et al., 2004	CO (5/10)	Stroke (RBD)/5/ 44–70		SSA	Splenius	VTI/ left	100/NA	EO-NA	Sitting – dark	vibration left dorsal palm and visual motion stimulation (left and right)	—	Pre-test/ test under vibration	Effect with a shift toward the left side (vibrated side)		Comparator = vibration left dorsal palm = no effect. No difference between VMS and NMV
Johannsen et al., 2003	CS (FAIR)	Stroke (RBD with neglect) /6/68 ± 9.5		VTI	Dorsal neck muscles	VTI/ left	80/0.4	EO-120	Sitting – dark	—	—	Test under vibration	Effect of deviation in 3/6 subjects toward the right		
Schindler et al., 2002	CO (6/10)	Stroke (RBD) 20/48.7 ± 14.3		SSA. VTI	Dorsal neck muscles	VTI/ contralesionnel side	80/0.4	EO-NA	Sitting – dark	—	Visual exploration training	Pre-test/ test under vibration/ post-test (2 months)	Effect with a shift toward the left side and stable. VTI in all subjects		Adjuvant = More effect

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Table 8 (*Continued*)

Author	Design	S1/number/Age (years)	S2/number/Age (years)	Outcome measures	Muscle vibrated	Muscle tracking/side	Frequency (Hz)/Amplitude (mm)	Vibration EO/EC-Duration (s)	Vibration position-Room light	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Comparator/Adjuvant
Karlberg et al., 2002	CO (5/10)	Unilateral vestibular lesions 23/53.6		SVH	SCOM	Palpation muscle/right/left	92/0.6	EO-NA	Sitting — dark	mastoid bone vibration	—	Pre-test/test under vibration	Effect with a shift toward the ipsilesional side. Effect larger when vibration in the ipsilesional side. Effect in 21/23 subjects		Comparator = Less effect
Betts et al., 2000	CO (5/10)	Unilateral vestibular lesions 27/32		SVH	SCOM	Palpation muscle/right/left	100/0.4	EO-100	Sitting with different head position or standing with whole body tilt — dark	—	—	Pre-test (100 s)/test under vibration (100 s)	More effect when vibration in the ipsilesional side with the head roll-tilt in the contralesional side		
Popov et al., 1999	CO (5/10)	Bilateral vestibular lesions 4/43—76		VTI	Trapezius	VTI/right	90/0.5	EO-10	Sitting and supine position — dark/light	—	—	Pre-test (5 s)/test under vibration(10 s)	Effect with a shift downward. Same effect in sitting and supine position. In supine position also a shift in the vertical plane (up or down). No effect when light on		

Table 8 (*Continued*)

Author	Design	S1/number/Age (years)	S2/number/Age (years)	Outcome measures	Muscle vibrated	Muscle tracking/side	Frequency (Hz)/Amplitude (mm)	Vibration EO/EC-Duration (s)	Vibration position-Room light	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Comparator/Adjuvant
Han et al., 1999	CO (5/10)	Strabismic patients 16/26—54		VTP. VTI	Splenius and SCOM	VTI/right/left	70/1	EO-8/10	Sitting — dark	—	—	Pre-test (8/10 s)/test under vibration (8/10 s)	Effect for good binocular with a shift to the left when vibration of the left SCOM/right splenius and to the right with right SCOM/left splenius. Effect variable for poor binocular		
Strupp et al., 1998	CS (FAIR)	Unilateral vestibular lesions 25/50.2 ± 12.3		SSA	Dorsal neck muscles	VTI/right/left	100/1	EO/EC-20	Sitting — dark	—	Prism	Pre-test/test under vibration/post-test (1 year)	Effect with a shift toward the side of the stimulus. Effect ipsilesional side > contralesional side. Effect maintained 60/80d then decreases. No effect with SSA finger EC		Adjuvant = Opposite effect
Karnath et al., 1996	CO (5/10)	Stroke (RDB with neglect) 3/61 ± 15		SSA	Dorsal neck muscles	VTI/left	100/0.4	EO-NA	Sitting — dark	Vestibular stimulation	—	Pre-test/test under vibration	Effect with a shift toward the left side		Comparator = Same effect

Table 8 (*Continued*)

Author	Design	S1/ number/ Age (years)	S2/ number/ Age (years)	Outcome measures	Muscle vibrated	Muscle tracking/ side	Frequency (Hz)/ Amplitude (mm)	Vibration EO/EC-Duration (s)	Vibration position-Room light	Comparator	Adjuvant	Protocol	Effect of vibration (S1)	Effect of vibration (S2)	Comparator/ Adjuvant
Karnath et al., 1994	CO (5/10)	Stroke (RDB with neglect) 3/61 ± 15	Stroke (LBD) 4/50.5	SSA. VTI	Dorsal neck muscles	VTI/ right/ left	100/0.4	EO-NA	Sitting — dark/ light	Vestibular stimulation	Vestibular stimulation	Pre-test/test under vibration	Left NMV (contralesional side) = Correction effect. Right NMV (ipsilesional side) = Worsen effect. Effect on SSA only on patient with VT motion (2/3)	Effect with a shift toward the left with left vibration vis versa. Effect on SSA only on patient with VT motion (2/4)	Comparator = Effect in 17/17/ Adjuvant = Same side = Larger effect than alone. Opposite side = Neutralize effect
Karnath et al., 1993	CS (POOR)	Stroke (RDB with neglect) 3/68 ± 15	Stroke (LBD)/5/58	VTI	Dorsal neck muscles	VTI/ right/ left	100/NA	EO-NA	Sitting — dark	Left hand vibration		Pre-test/ test under vibration	Effect in 1/3 subjects with a shift to the right with Left NMV and no effect with right NMV	Effect in 2/5 subjects with a shift to the right with Left NMV and to the left with right NMV	Comparator = No effect

CS: case study; CO: crossover trail; EO, EC: eye open and closed; LBD: left brain damage; NA: not available; PD: Parkinson disease; RBD: right brain damage; SSA: subjective straight ahead; SVH: subjective visual haptic; SVV: subjective visual vertical; S1, S2: Subjects; VTI: visual target illusion; VTP: visual target pointing.

experimental sessions out of 74 were based on cross-over trial designs, while the remaining 25% were experimental designs, translating into poor methodological quality for these studies. The Pedro Scale and the Quality Assessment Tool for Before—After (Pre-Post) Studies with No Control Group also confirmed this conclusion. Consequently, some results should be interpreted with caution. This being said, our findings could help get a better understanding of the mechanism of action of NMV on postural muscles.

This systematic review has outlined some general points for healthy subjects, with a good level of evidence; first under bilateral NMV, the body tilts in the anterior direction, and secondly, under unilateral NMV, the external visual environment (VT) has repeatedly been found to move towards the side opposite the vibrator whereas the subject's experience of straight ahead was found to be shifted towards the vibrated side, so that the environment appears to move relative to the body mid-sagittal plane. Furthermore, albeit to a lesser extent, a body tilt is produced under unilateral NMV, but the direction is not always the same. This can be explained by the very heterogeneous methodologies used for the localization of the vibrated muscle. Moreover, the muscle is not always clearly identified, which could confuse the postural results. Therefore, the method of muscle location should be carefully defined in future studies. Some authors have suggested the use of the illusion of displacement of a visual target [41,48]. This method can be used to identify the muscle that causes the most marked environmental-lateral shift. In addition, the patients who perceived the illusion of the displacement of a visual target responded better on both spatial perception and postural balance, with an adequate level of evidence [30,41,48]. However, this method does have some limitations: firstly, the illusion is inconstant (78% in both healthy subjects and patients) and secondly, the link between a visual illusion and postural effects is still under discussion in the literature [78].

With regards to the effect once the vibration was switched off, no clear consensus was found in the literature. A retention effect had been identified only in healthy subjects for postural orientation. Karnath et al. showed that increasing the duration of the vibration resulted in an effect maintained over time [40]. However, the duration of the effect was subject-dependent and the direction of the effect after end of vibration was variable. The retention effect on the spatial perception seems to stop after its use. Regretfully, due to the limited number of studies which dealt with the topic of the retention effect and in particular, rehabilitation of patients with postural disorders, it is difficult to draw any noteworthy conclusion. A second retention effect was observed after several sessions as a cumulative effect. This retention effect appeared more intensive as the sessions progressed repeated. Indeed, Bove et al. described an increase in the effect after successive sessions [13], which suggests the implication of chronic vibration use in future studies involving patients with postural disorders in rehabilitation. This should however be confirmed by experimental studies.

In order to gain a better understanding of the specificity of neck muscle vibration, we chose to highlight the specificities of neck muscle vibration compared to vibration of other muscles. Interestingly, some points differ. First, the direction of the body tilt under bilateral neck muscle vibration is in the opposite direction to that obtained under back postural lower limb vibration (triceps surae) [82]. Moreover, unlike lower limb vibration in the sitting or the upright position [2], the effect of NMV is constant regardless of the position. Indeed, the reaction to vibration of the triceps surae results in a backward tilt in upright position [23,62] and a forward tilt in sitting position [82] whereas the forward shift is produced regardless of the body position for NMV [62,82]. This is also the case for space perception under NMV; the same effect was repeatedly obtained whatever the position, sitting or standing [68]. This difference between NMV and lower limb muscle vibration supports the notion of a different frame of reference involved in the perception of body in space, i.e. body-referenced for lower limb vibration, and head-referenced for NMV [68]. In our opinion, this is due to the particular configuration of the neck muscles between the head and the trunk and their close relationship with other sensory receptors. In the case of NMV, the forward tilt is the response to the illusion of the body tilting backwards relative to the head, due to the absence of stimulation of the vestibular receptor, since the head is the reference [34,65]. This explanation is further supported by the fact that the effect of NMV was found to be influenced either by the orientation of the head or by the direction of gaze [33] which was found for postural balance [32,33], spatial perception (SSA [15], SVV [27,53] and VT) [68]. An additional point is, as expected, that NMV modulates body orientation and also the perception of space. When compared to other forms of sensorial stimulation such as vestibular or visual stimulations, the modulation of NMV on body mid-sagittal plane perception (SSA) [37,72], on external environment perception (VT) [38] or on gravitational environment perception (SV) [36], was similar. In addition, the effect of NMV can also be altered by external sensorial information [10], which shows with a fair level of evidence that it is more relevant to carry out vibration either with eyes closed or in a dark room [5,12,13,68,80]. In general, this suggests that NMV, like any other stimulation, acts on supramodal cerebral centers, and especially in areas where the representation of the body in space is elaborated [49,60,71]. Indeed, Bottini et al., who studied NMV during position emission tomography scans, confirmed brain activity particularly in the areas of multisensory integration where the egocentric representation of space is involved [9]. Therefore, our hypothesis is that the interconnected information by way of the neck or oculomotor muscle proprioceptive receptors and/or vestibular receptors is probably processed in addition to the proprioception information contributed by NMV.

This modulation of both body orientation and space perception therefore supports the use of this modulation among patients with altered postural and spatial perception. In fact, for stroke patients, both postural orientation and spatial perception shift towards the side opposite the vibrator and more precisely towards the contra-lesional side, with good evidence for SSA. Therefore, the findings of this review are in favor of the application of vibration to the contralesional side of the neck in order to correct the ipsi-lateral bias in both postural and spatial perception. Interesting results were found for the correction of misperceptions of the body in space for subacute patients [37,48], but no articles have confirmed these results relating to either long-term studies or for stroke patients at a chronic stage.

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Similarly, vestibular patients are of particular interest, as their asymmetrical behaviors could be at least partially due to body misorientation in space in acute disorders, as a result of imbalance of left and right vestibular inputs [8]. For unilateral vestibular patients, unilateral NMV induces a body tilt either in the antero-posterior plane or towards the lesional side, translating into the misinterpretation of vestibular information, which is not corrected [45,67]. In the case of bilateral vestibular or compensated vestibular lesion, no effect was found. Regrettably, the small number of studies, often of low quality and with small numbers of patients, does not enable us to firmly conclude to the interest of NMV.

There are several limitations to this review. Although this review yielded interesting results with an adequate level of evidence, some results need to be confirmed with better quality designs and larger population samples. These limitations open a new avenue for further studies, especially since this review has highlighted the small number of studies on the subject in relation to studies entailing comparisons of NMV with other muscles and also the very small number of studies on stroke and vestibular lesions. The findings require confirmation by way of better quality studies. Therefore, the effect of NMV on both postural orientation and spatial perception still remains a subject for research and for future studies.

Conclusion

The strength of this original review is that it highlights the specific characteristics of NMV for modulating both postural orientation and spatial perception in healthy subjects and patients, in that NMV induces body shifts and deviations in spatial perception. This review has provided some interesting results with an adequate level of evidence, but some results need to be confirmed with better-quality designs and larger populations. As a consequence, the effect of NMV on postural orientation and spatial perception remains a subject for further research studies with improved methodological quality.

Disclosure of interest

The authors declare that they have no competing interest.

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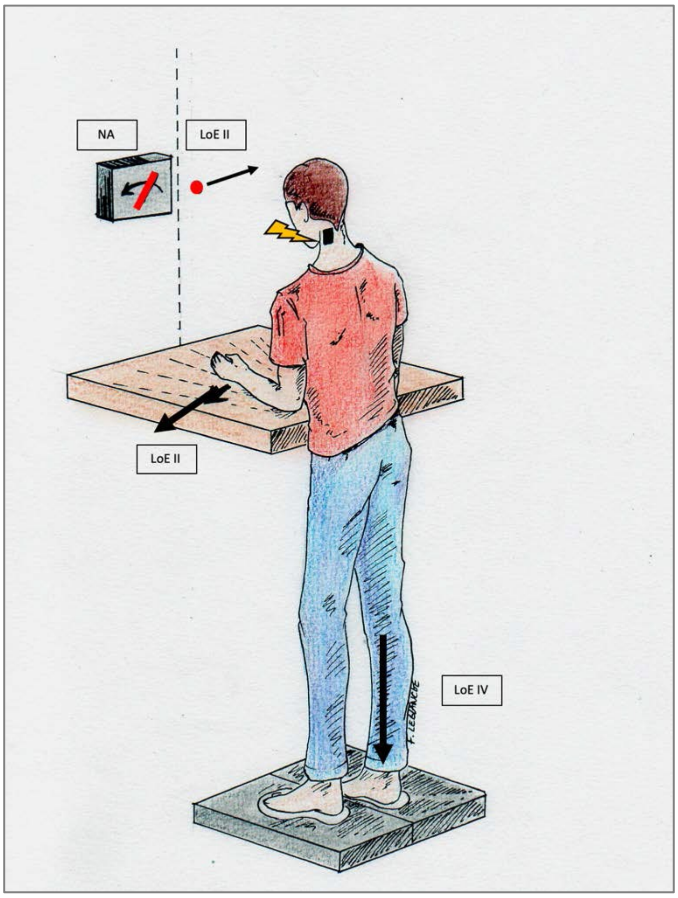
Discussion :

67 articles, dans l'ensemble de qualité méthodologique moyenne, ont été inclus dans cette revue systématique. Les effets se dégageant avec un bon niveau de preuve sont que chez les sujets sains évalués sur plateforme de force et sous vibration bilatérale des muscles du cou, on observe un déplacement du centre de pression (CoP) en avant. La vibration unilatérale des muscles du cou induit un déplacement de l'environnement visuel matérialisé par un point lumineux du côté opposé à la vibration, un déplacement de la perception du droit devant (Subjective Straight Ahead SSA) vers le côté vibré. La vibration unilatérale des muscles du cou induit un déplacement du CoP dans le plan médio-latéral du côté opposé à la vibration chez les sujets sains mais le niveau de preuve de ce dernier effet est faible.



Niveau de preuves (Level of Evidence LoE) (Sackett, 1989)

Niveau (LoE)	Type d'études
1	Essais randomisés contrôlés avec des résultats clairs (score PEDro> 6/10)
2	Essais randomisés contrôlés avec des résultats peu clairs (score PEDro< 6/10)
3	Etudes de cohorte et cas témoins
4	Etudes historiques ou cas témoins
5	Séries de cas

Figure 5 : Effet des vibrations unilatérales des muscles du cou sur le déplacement du centre de pression sur la plateforme de force (Niveau de preuve faible LoE IV), sur le déplacement d'un un point lumineux (niveau de preuve correct LoE II), sur le SSA (niveau de preuve correct LoE II) et SVV (niveau de preuve non évaluable) chez les sujets sains.

Chez les patients ayant subi un AVC ainsi que chez les patients avec des atteintes vestibulaires, cette revue systématique a aussi montré que la vibration des muscles du cou peut moduler à la fois les biais spatiaux et les biais posturaux. Ces résultats nous encouragent à proposer les stimulations sensorielles par vibration des muscles du cou comme outil de correction de l'asymétrie d'appui via une correction de l'orientation du corps dans l'espace.

Article 4: The effects of repetitive neck-muscle vibration on postural disturbances after a chronic stroke ; Karim Jamal, Stéphanie Leplaideur, Chloé Rousseau, Frédérique Leblanche, Annelise Moulinet-Raillon, Simon Butet, Armel Cretual, Isabelle Bonan

Effets d'un programme de vibrations répétées des muscles du cou sur l'asymétrie d'appui de patients AVC droit et gauche en phase chronique.

Les patients peuvent présenter une asymétrie d'appui persistant à distance de l'AVC *(Article 1 et Article 2).* Une étude réalisée par notre équipe (Leplaideur et al., 2016) a montré des résultats encourageants après une séance de vibration des muscles du cou, puisqu'une correction immédiate de l'asymétrie d'appui de patients AVC en phase subaiguë a été obtenue. Les études retrouvées dans la littérature sur la répétition de stimulations vibratoires font état d'un effet cumulatif de sessions de stimulations vibratoires répétées sur un temps court de quelques minutes (Bove et al., 2009). L'application répétée de vibrations des muscles du cou, de 10 répétitions de 5 secondes de vibrations séparées de 15 secondes de repos, produit un effet croissant avec les vibrations successives sur le déplacement du centre de pression (Bove et al., 2009). On ne connaît pas encore l'effet de stimulations répétées dans le temps au cours de séances successives sur plusieurs jours. Notre hypothèse était que l'on pouvait cumuler les effets sur l'asymétrie d'appui de séances de vibration des muscles du cou répétées chez des patients hémiplégiques via un effet sur leur trouble de la représentation spatiale.

L'objectif de cette étude est d'évaluer l'effet d'un programme de vibrations répétées des muscles du cou sur l'asymétrie d'appui et sur les troubles de la représentation spatiale de patients AVC droit et gauche en phase chronique. Cet article a été publié dans la revue «*Neurophysiologie Clinique, Clinical Neurophysiology*» .

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ORIGINAL ARTICLE

The effects of repetitive neck-muscle vibration on postural disturbances after a chronic stroke

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KEYWORDS
Neck muscle vibration;
Postural asymmetry;
Spatial representation;
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Abstract
Objective. — We aimed to test a repeated program of vibration sessions of the neck muscles (rNMV) on postural disturbances and spatial perception in patients with right (RBD) versus left (LBD) vascular brain damage.
Methods. — Thirty-two chronic stroke patients (mean age 60.9 ± 10 yrs and mean time since stroke 4.9 ± 4 yrs), 16 RBD and 16 LBD, underwent a program of 10 sessions of NMV over two weeks. Posturography parameters (weight-bearing asymmetry (WBA), Xm, Ym, and surface), balance rating (Berg Balance Scale (BBS), Timed Up and Go (TUG)), space representation (subjective straight ahead (SSA), longitudinal body axis (LBA), subjective visual vertical (SVV)), and post-stroke deficiencies (motricity index, sensitivity, and spasticity) were tested and the data analyzed by ANOVA or a linear rank-based model, depending on whether the data were normally distributed, with lesion side and time factor (D-15, D0, D15, D21, D45).
Results. — The ANOVA revealed a significant interaction between lesion side and time for WBA ($P < 0.0001$) with a significant shift towards the paretic lower limb in the RBD patients only ($P = 0.0001$), whereas there was no effect in the LBD patients ($P = 0.98$). Neither group showed

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a significant modification of spatial representation. Nonetheless, there was a significant improvement in motricity ($P = 0.02$), TUG ($P = 0.0005$), and BBS ($P < 0.0001$) in both groups at the end of treatment and afterwards.
Conclusions. — rNMV appeared to correct WBA in RBD patients only. This suggests that rNMV could be effective in treating sustainable imbalance due to spatial cognition disorders.

Introduction

One of the causes of disability in patients following a stroke is postural imbalance, characterized by increased postural sway and weight-bearing asymmetry (WBA) as evaluated on a force-platform [1—3]. WBA is recurrent and long-lasting, with a prevalence of 50% in chronic stroke patients [4], even higher in those with right brain damage [3,5]. WBA is often associated with level of independent self-care and length of hospital stay [6]. Thus, there is an interest in correcting WBA.

Apart from sensory and motor deficit [1,6,7], WBA may also be at least partially due to a bias in body orientation in space [8,9]. Spatial bias, such as neglect or biased subjective vertical (SV), subjective straight ahead (SSA) and longitudinal body axis (LBA) parameters, are common after stroke and related to poor balance [7,10—12]. These spatial biases are more frequent and longer lasting in RBD patients, probably because spatial cognition, in particular the central process of the representation of the body in space, is located within the right cerebral hemisphere [9,10,13,14]. This could explain why patients with right brain damage (RBD) have an excessive WBA compared to patients with left brain damage (LBD) and have poorer prognosis in terms of balance [3,5,10].

A previous study conducted by our group showed encouraging results after one session of neck muscle vibration (NMV) in patients with acute stroke [15]. Our hypothesis is that the stimulation of sensory information reduces WBA, probably through reduction of bias in orientation [8]. No study has yet examined a program of repeated vibration sessions on the neck muscles of chronic stroke patients.

The first objective of the study was to compare the effect of a program of repeated vibration sessions on the neck muscles on WBA in patients with RBD versus those with LBD. We hypothesized that repeated sensory stimulation would be effective in the treatment of imbalance due to body orientation bias and consequently lead to a greater reduction of WBA in RBD patients, due to the correction of body orientation disorders, which correspond at least partially to the WBA of these patients. We also studied the effect of the program on other spatial biases of our patients in order to better understand the mechanism of action of such stimulation.

Methods

Patients

Stroke patients were recruited from a list of patients who were treated in the Department of Physical Medicine and Rehabilitation (PMR) at the University Hospital of Rennes. From March 2017 to February 2018, patients who fulfilled the inclusion criteria were contacted by telephone and those who immediately responded were included in the study. All patients received information concerning the protocol and gave their signed consent. The inclusion criteria were as follows: right or left brain supratentorial vascular damage, more than one year since the stroke, and age < 80 years. Chronic patients were considered, as they may show little or no evolution of their balance and may still have a postural imbalance dating from the time of their stroke. As WBA was the principal criteria, selected patients had to be able to maintain an upright position for at least 30 s with their eyes closed for the force-platform test. Previous studies [4] have defined the normal range of weight bearing as between 47 and 53%; patients who were within this range were considered to be symmetrical and were therefore excluded. Patients who had either an ischemic or hemorrhagic brainstem stroke, bilateral hemispheric stroke, an orthopedic and/or rheumatological history affecting the distribution center of pressure when standing, a visual history that did not allow assessment of their vision, and those with major comprehension disorders were also excluded. The sample size calculation was based on a result obtained during a program of repetitive prism adaptation, i.e. the percentage correction of WBA +3.5% (±1) in the chronic RBD group with initial WBA of 30.4% (±10.6) [11]. The goal was to achieve the same benefit. We determined that subgroups of 16 patients would ensure 95% power, with an alpha risk of 5%. This study was approved by the local Ethics Committee of Rennes University Hospital, number 16.23, and registered (Clinicaltrial.gov NCT03112616).

Evaluations

Posturography parameters

Postural assessment of the patient was performed using a double force platform (FP) (PostureWin V143 TechnoConcept©). Patients stood on the platform in their bare feet with their feet 14 cm apart, with the instruction to stand as straight as possible with their arms alongside the body while looking straight ahead. The percentage of the weight on the nonparetic limb (WBA), mean mediolateral (Xm), and anterolateral (Ym) position of the center of pressure (COP) (mm) and surface (mm^2) were calculated as the mean of four trials, each lasting 30 s: two with opened eyes (OP) and two with closed eyes, with the patient wearing a blindfold (CE).

Evaluation of spatial representations

Subjective Straight Ahead (SSA) [16]. Evaluation of the SSA was carried out on a measuring table (Fig. 1). Patients were instructed to point ''straight ahead'', so as to divide the space into two parts, with no imposed time limit in 10 starting positions in a randomized sequence with the right arm for RBD and the left arm for LBD patients. A positive sign corresponded to the ipsilesional side. The value (in degrees up to 0.5°) obtained consisted of the mean (M) and standard deviation of 10 measurements (SD).

Longitudinal Body Axis (LBA) [17]. Evaluation of the LBA was performed using a light strip in front of the patient in a supine position, in complete darkness, with the head, trunk, and lower limbs aligned and maintained by cushions (Fig. 2). The patient was given the task of indicating when the strip was parallel to the axis of his body. No visual reference other than the wand was available and there was no time limit. A positive sign corresponded to the ipsilesional side. The value (in degrees up to 0.5°) obtained consisted of the M and SD of 10 measurements.

Subjective Visual Vertical (SVV). Evaluation of the SVV was performed in a sitting position with the head fixed, using a virtual reality helmet (Oculus®, Virtualis). From an imposed starting position, the patient was presented with a blue background with an oblique red line with 10 different starting positions in a random sequence (−10°/5°/−15°/10°/30°/−5°/−20°/15°/−30°/20°). No visual reference, other than the red line, was available and there was no time limit. The patient was given the task of indicating when the line was aligned with the vertical axis and the position of the head was monitored throughout the exercise task. A positive sign corresponded to the ipsilesional side. The value (in degrees up to 0.5°) consisted of the M and SD of 10 measurements.

Assessment of post-stroke deficiencies

A lower limb motricity test (motricity index) with a score of 100 [18]; a spasticity test (Ashworth modified MAS) [19], which targets the sural triceps, quadriceps, and adductors; and a sensory test, consisting of two clinical examinations and the sum of the obtained results were conducted. The first test consisted of tactile localization on the lower limb and the second, an arthrokinetic sensitivity test on the knee, ankle, and toes. Four tests of visuospatial neglect were also conducted: the bell cancellation test [20], 20-cm line bisection [20], the Fluff test [21], and the OTA test [22]. Visuospatial neglect was considered if the patient had at least three out of four positive tests. Finally, the presence or absence of homonymous hemianopia was clinically tested with a confrontation visual field test on each quadrant with a ball.

Balance Rating

Evaluation of functional impact of balance disorders was carried out using the Timed Up and Go (TUG) [23], and the Berg Balance Scale (BBS) [24].

Protocol

The intervention consisted of NMV in a dark room with one session per day, five days per week, for two weeks. Evaluations were performed two weeks before the intervention (D-15), just before the first intervention (D0), at the end of the intervention (D15), one week later (D21), and one month later (D45) (Fig. 3). Vibration was carried out in a sitting position using a VB 115® vibrator (TechnoConcept, France) at a frequency of 80 Hz and an amplitude of 0.4 mm. The examiner manually positioned the vibrator on the left side of the neck muscle for RBD patients and on the right for patients with LBD. The position of the vibrator was individualized by looking first at the position in which the subject perceived a maximum deviation of a visual target placed in front of them and moving to the opposite side of the vibrated muscle side. If there was no deviation, the vibrator was placed under the occiput. In this position, vibration was applied above the semispinalis and splenius. Then the patient was blindfolded, and the intervention applied for 10 min. In addition to repetitive NMV (rNMV), all patients received their usual rehabilitation treatment.

Statistical analysis

Statistical analysis was performed using SAS 9.3 Software. The clinical data between the patients with RBD and LBD were compared using Student's t-test or the Mann Whitney test (normality of the distribution was assessed using the Kolmogorov—Smirnov test). A comparison of the posturography parameters (WBA, Xm, Ym, Surface) and Balance rating (TUG and BBS) at D-15 and D0 in both groups (RBD and LBD) was performed using a Student's t-test for paired data in order to verify the absence of evolution under their usual rehabilitation. Posturography parameters (WBA, Xm, Ym, and surface), spatial reference data (SSA, LBA, and SVV), and characteristics of hemiplegia (motricity and sensitivity) were separately analyzed using ANOVA for repeated measures (rmANOVA) for normally distributed data and a generalized linear model with the gamma law or ranks for non-normally distributed data, with a between subjects factor, ''lesion side'' (RBD and LBD), and within subject factor, ''time'' (DO, D15, D21, D45). Tukey's *post-hoc* test was performed for all significant results. All tests were conducted at a significance level of $P = 0.05$.

Results

Forty-two patients from the list of chronic stroke patients followed by the physicians of the department were contacted by telephone, based on the inclusion criteria. All patients provided their approval, except two who refused to participate and one who died. After informing the patients and obtaining their consent, 39 were enrolled in the study. Five RBD patients and two LBD patients were excluded at D-15, as they did not show any signs of WBA on the force platform. Thirty-two patients, 26 men and six women, with an average age of 60.9 ± 10 years and an average time since their stroke of 4.9 ± 4 years, divided between two groups of 16 RBD and 16 LBD, were included (Fig. 4). Patients were similar in age ($P = 0.55$), time since stroke ($P = 0.7$), motricity ($P = 0.7$), sensitivity ($P = 0.1$) and balance ratings (BBS $P = 0.79$, TUG $P = 0.78$) (Table 1). WBA was different between the RBD and LBD patients (WBA RBD = 65.95% ± 9.4 versus 60.6% ± 4.5 LBD $P = 0.05$). There was no difference in any of

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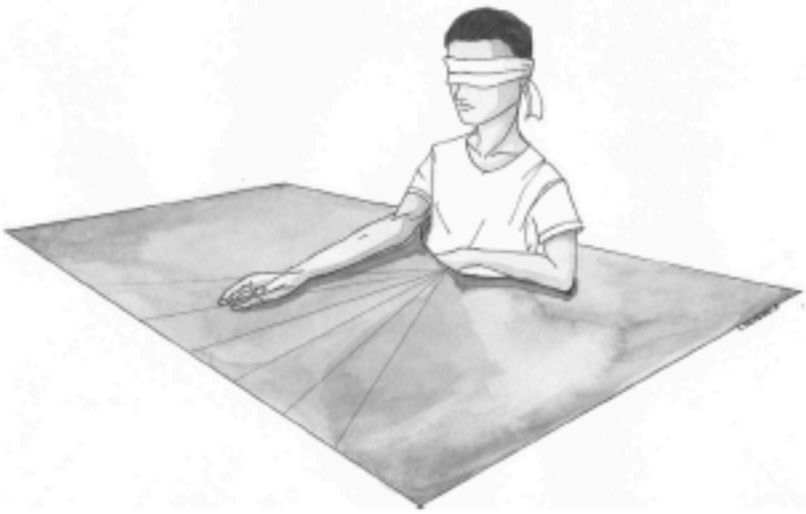

Figure 1 Experimental set-up of the Subjective Straight Ahead (SSA). Evaluation of the SSA was carried out on a measuring table on which the patient was required to move his hand while blindfolded. The table was graduated, and a one-degree angle corresponded to one linear cm. The midsagittal line coincided with the middle of the table with the head and trunk of the patient placed in strict alignment. From a starting position, with 10 starting positions, in a randomized sequence (−10°/5°/−15°/10°/30°/−5°/−20°/15°/−30°/20°) in which the arm of the patient was placed by the examiner, the patients were instructed to point ''straight ahead''.

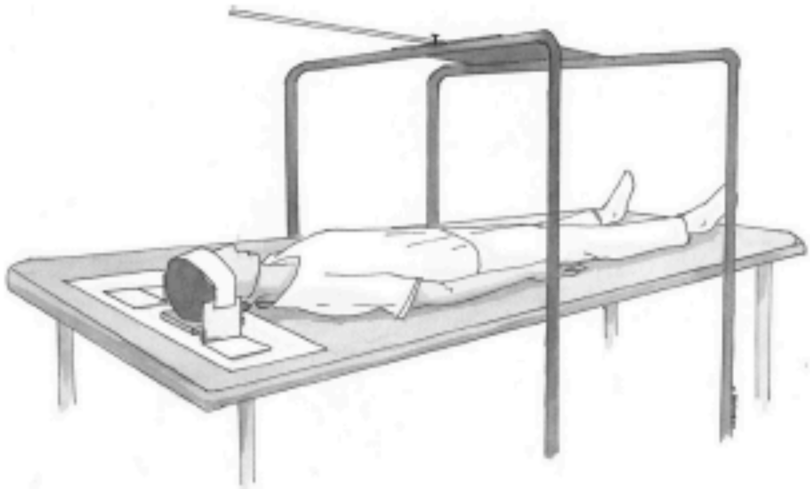

Figure 2 Experimental set-up of the Longitudinal Body Axis (LBA). Evaluation of the LBA was performed using a light strip in front of the patient in a supine position, in complete darkness, with the head, trunk, and lower limbs aligned and maintained by cushions. The rotation center of the light wand was aligned with the patient's navel and the plumb line. The light wand was moved around its axis of rotation by the examiner from a starting position, with 10 starting positions, in a randomized sequence (−10°/5°/−15°/10°/30°/−5°/−20°/15°/-30°/20°). The patient was given the task of indicating when the strip was parallel to the axis of his body.

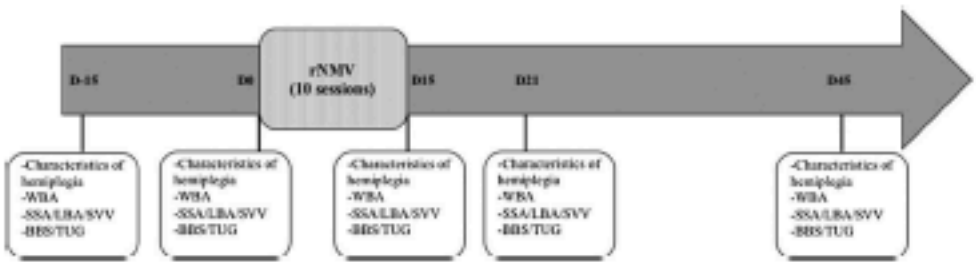

Figure 3 Protocol with evaluation time and neck muscle vibration intervention. (Berg Balance Scale (BBS), Longitudinal Body Axis (LBA), Repetitive Neck Muscle Vibration (rNMV), Subjective Straight Ahead (SSA), Subjective Visual Vertical (SVV), Timed Up and Go (TUG), Weight Bearing Asymmetry (WBA).

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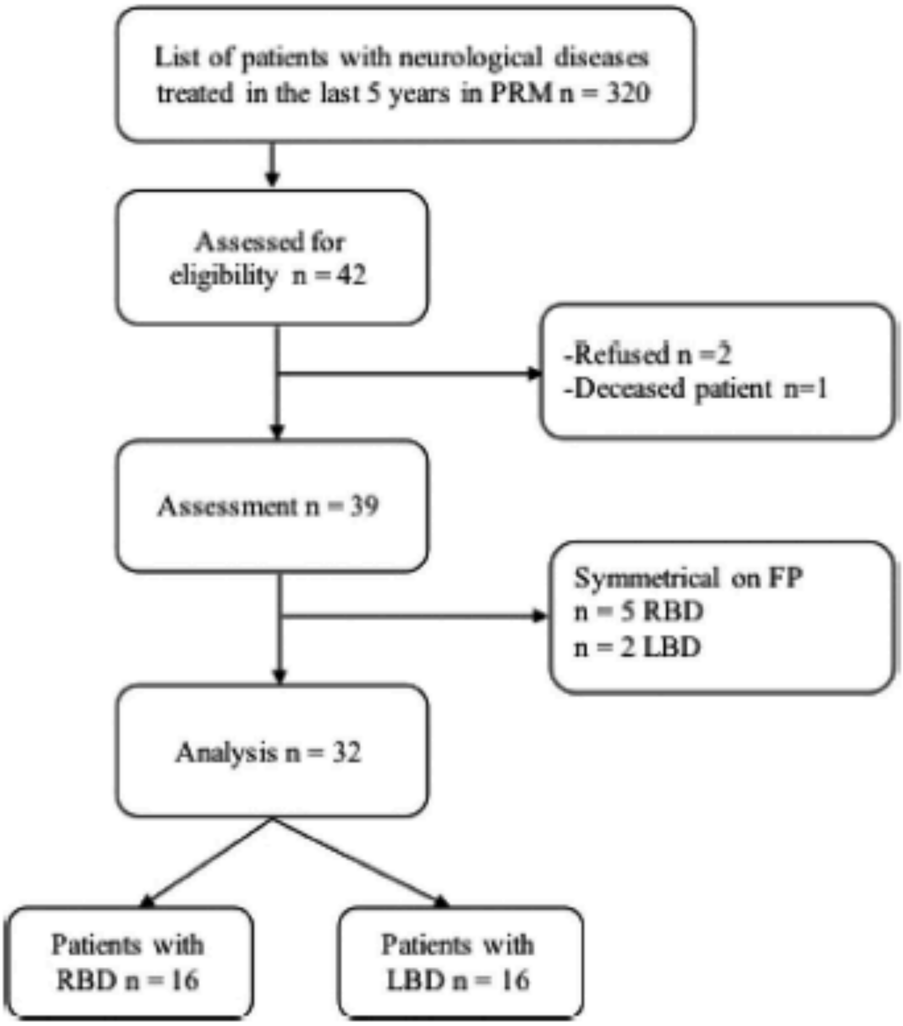

Figure 4 Flowchart of participants (RBD: right brain damage; LBD: left brain damage; FP: Force Plateform).

Table 1 Clinical data, patients with right brain damage (RBD) and patients with left brain damage (LBD).

	RBD (n = 16)	LBD (n = 16)	P
Male/Female	14/2	12/4	–
Ischemic/hemorrhagic	9/7	12/4	–
Age (years)	62.1 (11.3)	59.8 (10.2)	0.55
Delay-post (years)	5.27 (4)	4.71 (4)	0.7
Motricity (/100)	69 (16)	71 (17)	0.77
Sensitivity (/6)	4 (1)	5 (1)	0.15
Visuo-spatial neglect	11/16	0/16	–
Hemianopia	0/16	0/16	–
WBA (%)	65.95 (9.4)	60.6 (4.5)	0.05
LBA_M (°)	−0.81	−0.54	0.1
LBA_SD (°)	2.73	1.76	0.01
SSA_M (°)	−1.1	1.54	0.1
SSA_SD (°)	2.59	3.27	0.1
SVV_M (°)	0.94	0.57	0.5
SVV_SD (°)	3.21	2.26	0.0005
TUG (s)	26 (17)	24 (18)	0.78
BBS (/56)	43 (8)	42 (11)	0.79

BBS: Berg Balance Scale; LBA: Longitudinal Body Axis; SSA: Subjective Straight Ahead; SSV: Subjective Visual Vertical; TUG: Timed Up And Go; WBA: Weight Bearing Asymmetry.

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the posturography parameters (WBA, Xm, Ym, Surface) and Balance rating (TUG and BBS) between D-15 and D0 showing the absence of evolution (WBA RBD $P = 0.38$; LBD $P = 0.09$; Xm RBD $P = 0.6$; LBD $P = 0.4$; Ym RBD $P = 0.6$; LBD $P = 0.9$; surface RBD $P = 0.8$; LBD $P = 0.5$; TUG RBD $P = 0.9$; LBD $P = 0.8$; BBS RBD $P = 1$; LBD $P = 0.1$).

The rmANOVA revealed a significant interaction between lesion side and time for WBA (F[4;120] = 5.25 $P < 0.0001$) with a reduction of WBA only in the RBD patients and only at D15 (4.4% ± 3.5), confirmed by the post-hoc test (D0 vs D15 $P = 0.0001$ and D0 vs D21 $P = 0.43$). The results were similar when accounting for Xm (lesion side × time F[4;120] = 12.45; $P < 0.0001$), with a significant shift in the RBD group (D0 vs D15 $P < 0.0001$). The rmANOVA revealed no effect or interaction between lesion side and time for Ym (F[4;120] = 0.51; $P = 0.72$) and the Surface (F[4;120] = 0.42; $P = 0.79$) (Table 2).

Difference between the mean for RBD and LBD patients were found only between the standard deviation for SVV_SD $P = 0.005$ and LBA_SD $P = 0.01$ (Table 1). The rmANOVA revealed no effect or interaction between lesion side and time (SSA F[4;120] = 1.46; $P = 0.21$; SVV F[4;120] = 1.83; $P = 0.09$; LBA F[4;120] = 0.93; $P = 0.44$) (Table 2).

Vibration did not induce any change in sensitivity test values over time (F[4;120] = 2.25; $P = 0.07$) or by group (F[1;30] = 1.67; $P = 0.2$). Motricity improved for both groups of patients over time (F[4;120] = 3.25; $P = 0.02$), independently of lesion side (F[1;30] = 0.02; $P = 0.89$). The post-hoc test revealed an improvement at D15 ($P = 0.02$) and D21 ($P = 0.02$). The TUG of the patients improved at D21 (F[4;120] = 6.9; $P = 0.0005$) ($P = 0.003$) and D45 ($P = 0.01$), independently of the lesion side (F[1;30] = 0.17; $P = 0.68$). The BBS of the patients also improved over time (F[4;120] = 9.23; $P < 0.0001$), as revealed by the *post-hoc* test at D15 ($P < 0.0001$), D21 ($P < 0.0001$), and D45 ($P < 0.0001$), independently of lesion side (F[1;30] = 0.11; $P = 0.74$) (Table 3).

Discussion

We obtained a reduction in WBA after NMV as expected. This effect was only observed in the group of RBD patients. Surprisingly, balance ratings and motricity improved for patients of both groups (RBD and LBD) after the program, with a long-lasting effect.

WBA was higher in RBD patients before rNMV, even though the same time had elapsed since the stroke for both patients with RBD and LBD [3,5,10]. This disparity, repeatedly found in the literature, has been assumed to be due to body misorientation in space, which occurs mostly in RBD patients [8,9]. Following rNMV, the degree of WBA of RBD patients moved closer to that of the LBD patients before the program (Fig. 5). RBD patients shifted in the medio-lateral plane towards the hemiplegic leg without any change in the antero-posterior plane, whereas there was no significant effect on the posturography parameters for LBD patients. These results strongly suggest that the effect of NMV on RBD patients may be due to correction of the component of the WBA that is due to spatial cognition disorders. Indeed, the right hemisphere is thought to be responsible for spatial cognition [9,14]. Additionally, stimulation of sensory information, i.e. prism adaptation, vestibular caloric stimulation, or galvanic vestibular stimulation, modifies the postural asymmetry of the subject, irrespective of the sensorial modality [11,15,25], with a close relationship between the effects of different sensory modalities [25]. This suggests that sensory stimulation affects supramodal sensorial cerebral structures in the right hemisphere [8], as already shown by Bottini et al. [26]. who studied the effects of proprioceptive sensory stimulation by vibration on regional cerebral blood flow, measured using positron emission tomography.

Neck muscles are directly linked to the vestibular and oculomotor systems and may play a crucial role in egocentric perception of the body in space [27]. The information obtained from proprioceptive receptors of the neck muscles, together with that of the oculomotor muscles and vestibular system, is involved in the location of objects relative to the body. NMV produces a subjective perception of deviations of the axis of the body [28], suggesting that NMV could act on the relative position of the body in space and consequently displace the position of CoP towards the paretic limb. We would thus expect a change in both aspects of egocentric spatial representation, i.e. SSA and LBA. However, our chronic post-stroke patients had normal spatial bias deviation with the exception of a greater uncertainty in the perception of SVV and LBA. We also observed no significant change for either SSA or LBA. A slight change in SSA could be viewed as a mirror image of the change in WBA (Fig. 6). Our results differ from those of two previous studies [11,28]. The first reported an SSA shift towards the vibrated side during NMV [28] and a pilot study established an association between both the shift in SSA and WBA with another form of sensorial stimulation (prism adaptation) [11]. However, our study did not initially focus on SSA and our calculation of the number of patients to be included was based on WBA and not the assessment of spatial representation. Another possible explanation for the absence of the effect of NMV on spatial representation could be related to the cortical dissociation between the different evaluations already mentioned in the literature [14,29,30] and particularly when considering the posture and the modality assessed. Indeed, Pérennou et al. [31], when investigating the perception of verticality by different modality in a group of patients with hemispheric and brain stem stroke, did find a dissociation between postural verticality (PV) and SVV and this was possibly due to different brain regions involved in this spatial process. Therefore, it could be of interest when investigating the perception of verticality to assess the PV in addition to the SVV in further studies.

The reduction of WBA was obtained without decreasing postural stability, as shown by the stability of the surface of the displacement of the CoP, which is a platform parameter that expresses bodily stability. This is an additional argument that suggests that the part of WBA corrected by rNMV is not a compensatory behavior to postural instability, but rather due to a primary disorder, in this case, a spatial cognition disorder. Therefore, WBA can be considered not only as an adaptation to postural disturbance due to motor and sensitivity weakness, but also the reflection of a disturbance in spatial cognition, at least in RBD patients [1,32]. As a result, it may be beneficial to correct at least this aspect of WBA. This result merits exploration of the possibility of obtaining an effect at an early stage after stroke. NMV is

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Table 2 Mean and Standard deviation of posturography parameters and spatial representation after rNMV.

	D0	D15	D21	D45
Posturography parameters				
RBD				
% on none-paretic limb	65.1 (9)	60.7 (9)[a]	63.4 (10)	63 (8)
Xm (mm)	38.6 (23)	26.1 (24)[a]	33.6 (25)	32.9 (22)
Ym (mm)	35.5 (21)	35.5 (18)	35.8 (21)	39.4 (21)
Surface (mm^2)	320 (228)	358 (199)	322 (147)	308 (176)
LDB				
% on none-paretic limb	59.4 (5)	58.9 (5)	57.9 (5)	58 (6)
Xm (mm)	−21 (12)	−20.5 (15)	−19.2 (15)	−18 (18)
Ym (mm)	34.6 (9)	38.4 (9)	36.8 (10)	37.5 (8)
Surface (mm^2)	298 (211)	291 (258)	350 (305)	326 (317)
Spatial representation				
RBD				
LBA (°)	−1 (2)	−1.1 (2.7)	−1.2 (1.3)	−0.5 (2.1)
SSA (°)	0.1 (3.8)	−1.4 (4.4)	−1.4 (3.9)	−0.2 (3.1)
SVV (°)	0.1 (0.7)	−0.5 (3.6)	0.1 (2.1)	−0.4 (2.1)
LDB				
LBA (°)	−0.5 (2.6)	−0.1 (1.9)	−0.1 (2)	−0.7 (1.9)
SSA (°)	0.9 (3.6)	1.3 (3.9)	0.8 (3.4)	0.1 (2.4)
SVV (°)	1 (2.5)	0.5 (2)	0.5 (1.8)	1 (1.8)

LBA: Longitudinal body axis; LBD: Left brain damage; RBD: Right brain damage; SSA: Subjective straight ahead; SVV: Subjective visual vertical.
[a] Significant effect.

Table 3 Mean and Standard deviation of the assessment of post-stroke deficiencies; sensory testing, motricity index, TUG and BBS of patients with left and right brain damage.

	D0	D15	D21	D45
Severity of hemiplegia				
Motricity Index (/100)	70.1 (16)	73 (18)[a]	73.6 (17)[a]	73 (17)
Sensitivity (/6)	4.7 (1)	5 (1.7)	4.9 (1.5)	4.8 (1.6)
Balance rate				
Berg Balance Scale (/56)	43 (10)	44.4 (10)[a]	44.5 (10)[a]	44.6 (10)[a]
Timed up and Go (s)	24.4 (16)	23.3 (16)	23.1 (16)[a]	23.6 (17)[a]

[a] Significant effect.

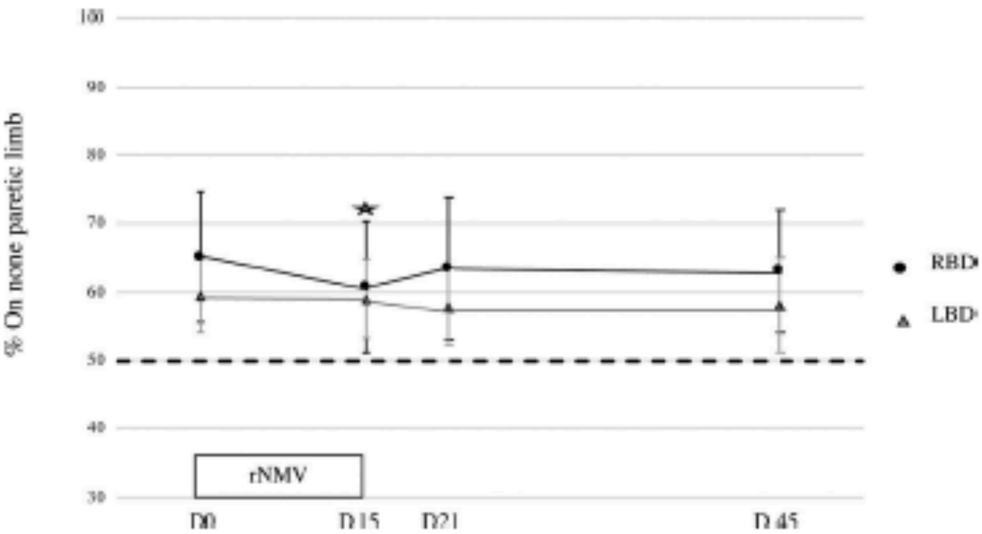

Figure 5 Evolution of Weight Bearing Asymmetry (WBA) of patients with Right brain damage (RBD) and patients with Left brain damage (LBD) Repetitive neck muscle vibration (rNMV). (★) significant effect.

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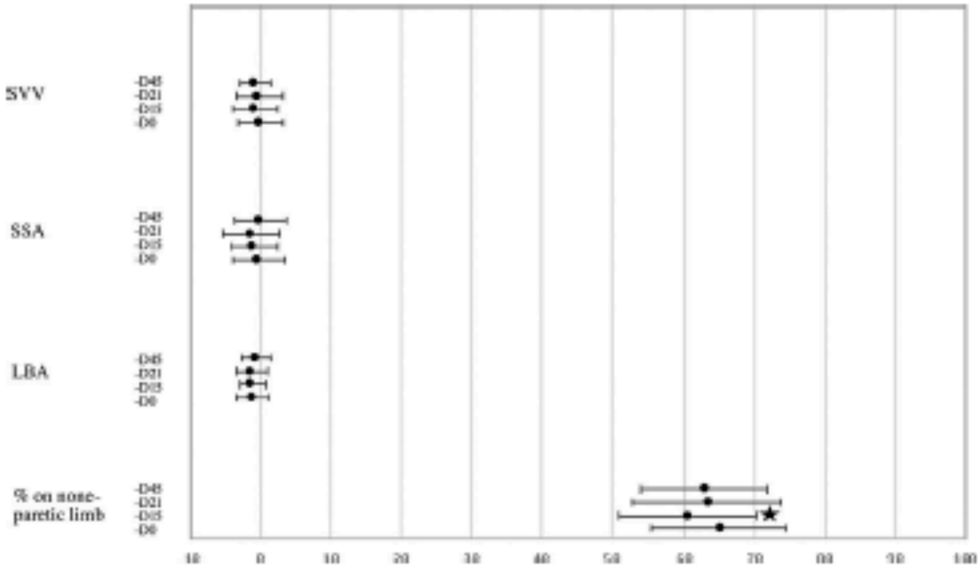

Figure 6 Evolution of both weight-bearing asymmetry (WBA) and spatial representation assessment. Longitudinal body axis (LBA), Subjective straight ahead (SSA), Subjective visual vertical (SVV) in Right brain damage patients. (★) significant effect.

a clinical technique that does not require active participation of the patients, unlike top-down techniques, and is easy to implement and inexpensive. This creates new treatment possibilities early after stroke, when spatial cognition disorders are very troublesome, especially in RBD patients, with the hope to more rapidly improve balance in these patients.

The effect induced by rNMV was evident at the end of the program but was not maintained one week later. In this regard, our program may have been insufficient in terms of intensity, duration or number of sessions. Indeed, Karnath et al. [33] showed that increasing the vibration time resulted in a more stable effect with regards to SSA. It will therefore be necessary in future work to further investigate this sustained effect by increasing the intensity and duration of stimulation. It was also revealed that sensorial stimulation such as neck muscle vibration combined with another stimulation [34] or standard rehabilitation exercises [35] is more effective than a sensorial stimulation on its own and this could possibly be another additional investigation in order to enhance the effect.

Surprisingly, rNMV improved lower-limb strength and dynamic balance (TUG and BBS) in both LBD and RBD patient groups. This unexpected outcome suggests that there may be other mechanisms simultaneously at work aside from the effects on body orientation observed in the RBD patients. However, its direct influence is not evident. It has been hypothesized that that there is a close interconnection between the sensory and motor cortices, initially recognized in animals [36]. Fasold et al. [37], by functional MRI, showed that NMV stimulated cerebral activity in both motor and multisensory integration areas in healthy subjects. It is therefore possible that sensory stimulation by NMV can improve motor recovery. The improved motor control in both RBD and LBD patients following rNMV may involve central activation of the motor areas. However, the observed improvement favors the hypothesis of an effect remote from the stimulation site. It is therefore important to determine the mechanism of NMV and compare it to another type of sensory stimulation, such as transcutaneous electrical stimulation (TNS), to gain a better understanding of its effects. Similar to NMV, TNS equally improves both lower-limb strength and postural balance [38]. Moreover, TNS may modulate the sensory-motor cortex, which is stimulated [39]. In addition, Pérennou et al. [40] reported an improvement in postural balance in stroke patients with neglect when TNS was applied to the neck muscles. Nonetheless, no study has been carried out to assess lower limb strength after TNS of neck muscles. The results of these authors [40] are in accordance with ours and support the interest of stimulating the neck muscles. Neck muscles have a specific role in postural control through their direct link with the vestibular system and could also act on tonus regulation of lower limbs.

Our study had several methodological limitations. Our primary choice was to exclusively include chronic patients. Caution was taken to ensure that there was no modification of WBA or spatial representation during a period of 15 days before the intervention to avoid a confounding bias. In this study, the effect of neck muscle vibration was compared in patients with RBD versus those with LBD without any sham group. Therefore, this design does not allow us to be certain of the real effect of NMV and should as a consequence be repeated with a sham control group in order to confirm our result. Concerning our selection criteria, patients were recruited based on their ability to maintain an upright position for at least 30 seconds with their eyes closed, to allow performance of the force-platform test. As a consequence, the generalizability of our results is limited to patients who are not severely disabled and further studies need to be undertaken with more patients who are at an acute stage and with more marked spatial cognition disorders.

Conclusion

In conclusion, repeated NMV may be effective in treating postural disorders caused by spatial cognition disorders.

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There was a non-significant trend towards maintaining the positive effect longer term. A possible reason for lack of significant long-term effect in our study is that the stimulation may have been insufficient, either in its intensity or duration. This also raises the issue of whether such stimulation should be started at an early stage of stroke. Further studies are necessary to investigate other NMV protocols and the effect of duration. Our second result was an improvement in lower limb strength, as well as the dynamic balance (TUG and BBS) in both LBD and RBD patient groups. This result suggests an effect remote from the stimulation site, highlighting the relevance of vibrating the neck muscles in the course of stroke rehabilitation.

Disclosure of interest

The authors declare that they have no competing interest.

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Discussion :

L'objectif de cet article est d'évaluer l'effet d'un programme de vibrations répétées des muscles du cou sur l'asymétrie d'appui ainsi que sur les troubles de la représentation spatiale d'un groupe de patients AVC droit et gauche en phase chronique.

Dans la lignée des travaux précédents, cette étude montre à la fois la présence d'asymétrie d'appui en phase chronique et que celle-ci est plus marquée chez les patients AVC droit et ce de façon significative. Après dix séances de vibrations consécutives des muscles du cou, les résultats montrent dans le groupe de patient AVC droit un déplacement significatif du centre de pression, évalué sur plateforme de force, vers le membre inférieur hémiplégique ($p=0.0001$). Cette réduction de l'asymétrie d'appui dans le groupe de patients AVC droit a pour effet de rapprocher leur degré d'asymétrie d'appui de celui des patients AVC gauche (Figure 6)

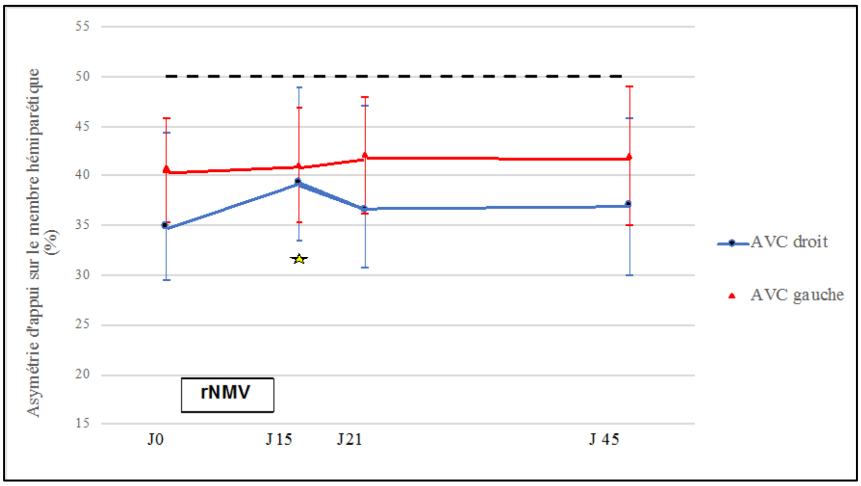

Figure 6 : Effet du programme de vibrations des muscles du cou sur l'asymétrie d'appui des patients AVC droit et gauche.

Cette réduction de l'asymétrie d'appui chute rapidement en une semaine mais se maintient légèrement plus haut qu'initialement, de manière non significative à distance de la stimulation. En revanche aucun effet n'a été retrouvé dans le groupe de patients AVC gauche. Pour étayer notre hypothèse que les vibrations des muscles du cou amélioreraient l'asymétrie d'appui via l'amélioration des troubles de la représentation spatiale, nous avons mesuré les variations de la perception du droit devant (Subjective Straight Ahead SSA), de la verticale (Subjective Visual Vertical SVV) et de l'axe longitudinal (Longitudinal Body Axis LBA). Aucun lien avec l'effet obtenu sur l'asymétrie d'appui chez les patients AVC droit, n'a malheureusement été retrouvé. Ce résultat négatif pourrait s'expliquer par l'absence de fortes perturbations de la perception du SSA, LBA et VVS de nos patients à distance de l'AVC, à l'exception d'une plus grande incertitude pour les LBA et SVV qui n'ont pas évolué avec le traitement. Toutefois, nous avons noté un léger changement pour le SSA, en miroir au changement de l'asymétrie d'appui, mais non significatif (Figure 7).

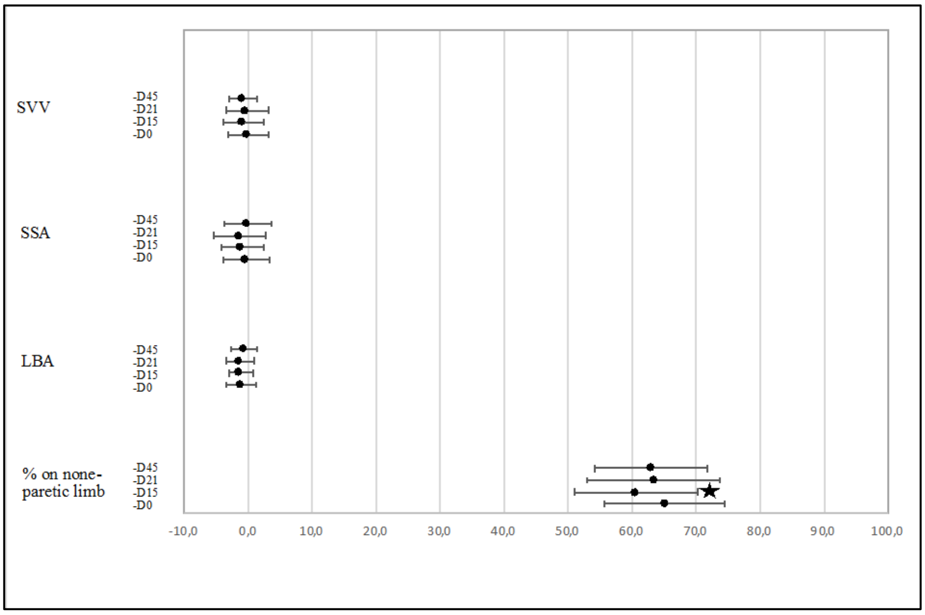

Figure 7 : Évolution de l'asymétrie d'appui et des biomarqueurs de la représentation spatiale (longitudinal body axis (LBA), subjective straight ahead (SSA), subjective visual vertical (SVV) après un programme de 10 séances de vibrations des muscles du cou

Le faible nombre de patients ayant été inclus en raison du choix du critère principal de cette étude basée sur le degré d'asymétrie d'appui et non sur les troubles de la représentation spatiale pourrait expliquer ces résultats par un manque de puissance. Ces résultats nécessitent d'être confirmés par des études à plus grande échelle incluant également un groupe contrôle.

Partie 3 : Discussion générale

Ce travail de thèse répond à deux objectifs : le premier est d'apporter une meilleure compréhension des perturbations posturales suite à un AVC, en particulier de l'un des comportements posturaux qu'est l'asymétrie d'appui et de déterminer l'implication des troubles de la représentation spatiale dans ce comportement postural. Le second objectif est d'évaluer l'effet de stimulations proprioceptives par vibration des muscles du cou à la fois sur l'asymétrie d'appui et sur les troubles de la représentation spatiale afin de mieux appréhender les mécanismes d'action de cette stimulation sensorielle.

1. Les troubles de la représentation spatiale secondaires à une lésion cérébrale

Après un AVC, plusieurs marqueurs de la cognition spatiale sont perturbés, à savoir la perception de la verticale (Verticale Visuelle (VH), Verticale Haptique (VH), Verticale Posturale), l'axe longitudinal (Longitudinal Body Axis (LBA)) et le droit devant (Subjective Straight Ahead (SSA)).

Concernant la perception de la verticale, entre 40% et 60% des patients AVC (Bonan et al., 2010, 2006b; Pérennou et al., 2008; Piscicelli & Pérennou, 2016) présentent des perturbations de leur représentation de la verticale visuelle (VV); déviée le plus fréquemment dans le sens contralésionnel (Bonan et al., 2010, 2006b; Pérennou et al., 2008; Piscicelli &Pérennou, 2016). Toutefois, la déviation dans le sens ipsilésionnel a également été observée pour un faible nombre de patients (10%) sans explication à ce jour (Pérennou et al., 2014, 2008; Piscicelli & Pérennou, 2016). Dans les suites de l'AVC, cette perturbation est identique en cas de lésion cérébrale droite et gauche, puis elle persiste à distance surtout chez les patients AVC droit. Les auteurs Bonan *et al.* dans un suivi de cohorte de 30 patients AVC évalués à 3 mois puis à 6 mois, ont trouvé la même proportion de patients AVC droit et gauche perturbés pour leur VV lors de l'évaluation à 3 mois alors que lors de la seconde évaluation (6 mois), ces auteurs ont noté une nette amélioration mais au profit du groupe de patients AVC gauche suggérant une récupération lésion cérébrale dépendante (Bonan et al., 2007). Nos résultats (*Article 2 et Article 4)* vont dans ce sens d'une amélioration de la VV à la phase chronique mais des perturbations persistantes sont encore retrouvées dans le groupe de patients AVC droit (3 patients AVC droit versus 1 patient AVC gauche sur l'ensemble de la cohorte). Au contraire, l'incertitude définie comme étant la variabilité des ajustements de la VV (Bonan et al., 2007), est moins marquée, lors de la phase subaiguë de l'AVC mais est prédominante chez les patients AVC droits (71% patients AVC droits *versus* 14% patients AVC gauche (Bonan et al., 2007). Cette perturbation reste persistante à distance de l'AVC (Bonan et al., 2007). C'est ce qui a été montré dans nos *Articles 2 et 4*. En effet, nos patients AVC droit présentaient une incertitude significativement plus marquée que le groupe de patients AVC gauche, à ce stade chronique de l'AVC. Cette perturbation de la VV, et plus spécifiquement l'incertitude, est plus fréquemment associée à la négligence spatiale mais avec de possibles dissociations entre ces deux troubles visuo-spatiaux suggérant une proximité d'intégration cérébrale et/ou des mécanismes similaires (Bonan et al., 2006b; Saj et al., 2005; Yelnik et al., 2010). La verticale posturale (VP) est également perturbée au moins dans la période subaiguë de l'AVC. En effet, dans un groupe de patients étudiés à 3 mois, les auteurs (Pérennou et al., 2008) observent une perturbation de la verticale posturale (VP) chez 42% des 80 patients, toujours dans le sens contralésionnel. Ils soulignent un biais de la VP plus important chez les patients AVC droit et plus prononcé chez les patients pushers (Pérennou et al., 2008, 2014). Ce résultat est confirmé à distance sur une population AVC en phase chronique avec une persistance d'un biais de la VP en particulier dans le groupe de patients pushers (Mansfield et al., 2015).

Après la survenue d'un AVC, il peut aussi exister des perturbations de la perception de l'axe longitudinal ou Longitudinal Body Axis (LBA) (Barra et al., 2007). Les auteurs Barra *et al.* constatent un biais contra lésionnel dans leur groupe de patients AVC de moins de 3 mois (Barra et al., 2007). Cette déviation est plus marquée chez les patients ayant une lésion au niveau de l'hémisphère droit (Barra et al., 2007). En effet, parmi leurs 18 patients inclus, 8 patients présentaient une perturbation du LBA (moy.= -5.2°(min=-3° ; max=-9.5°)) dont 6 patients AVC qui présentaient une lésion de l'hémisphère droit et 2 avec une lésion à gauche. Nos travaux sur des patients AVC en phase chronique *(Articles 2 et 4)* montrent, à distance de l'AVC, une perturbation moindre de la perception de l'axe longitudinal (m=-1.3°(min=-4 .9° ;max=2.3°)) mais une persistance de ce biais avec une intensité de la déviation plus importante pour le groupe de patients AVC droit (patients AVC droit (min=- 4 .9° ;max=6.5°) et patients AVC gauche (min=-4.5° ; max=2.25°) (*Article 4*). De plus, nos travaux montrent une incertitude significativement plus marquée pour nos patients AVC droit comparés au groupe de patients AVC gauche à ce stade chronique de l'AVC (patients AVC droit moy.=2.25°, patients AVC gauche moy.=1.76 ; p=0.01). Ces résultats avec la persistance de troubles plus importants en cas de lesion droite suggèrent l'implication de l'hémisphère droit dans les mécanismes de la perception du LBA.

Concernant la perception du droit devant ou Subjective Straight Ahead (SSA), les résultats des premières études ont montré une déviation moyenne du SSA vers le côté ipsilésionnel chez les patients AVC droit négligents (Ferber & Karnath, 1999; Heilman et al., 1983; Richard et al., 2004; Rousseaux et al., 2014). A un stade précoce de l'AVC, les auteurs Heilman *et al.* rapportent une perturbation plus importante dans le groupe de patient AVC droit avec notamment, une déviation plus marquée vers la droite pour ce groupe comparativement au groupe de patients AVC gauche (Heilman et al., 1983). Mais cette déviation ipsilesionnelle systématique n'a pas été confirmée par les auteurs suivants (Chokron, 2003). En effet, les auteurs Chokron *et al.* constatent une inconstance du sens de la déviation à la fois dans le groupe de patients AVC droit héminégligents et non héminégligents et ont montré une double dissociation entre la perturbation du SSA et la négligence (Chokron, 2003). Les résultats de notre étude *(Article 2)* dans le groupe de patients ayant une lésion au niveau de l'hémisphère droit non héminégligents rejoignent les données de ces auteurs avec une variation dans le sens de la déviation. D'autres auteurs ont montré des perturbations du SSA dans le sens contra lesionnel chez des sujets ayant une hémianopsie (Ferber & Karnath, 1999; Saj et al., 2010) ou bien en cas d'AVC droit avec un pushing syndrome (Honoré et al., 2009) or il s'agit de signes cliniques que certains de nos patients présentaient. Ces signes cliniques associés pourraient expliquer la variation du sens de la déviation du SSA chez nos patients. A un stade chronique, quelques-uns de nos patients AVC droit et gauche ont encore une perturbation de leur SSA mais avec une incertitude de la déviation plus importante de façon non significative pour le groupe de patients AVC droit (AVC droit [min = -4.5° ;max = 9°] et AVC gauche [min =-3.9° ; max = 7.4°]).

2. L'implication des troubles de la représentation spatiale dans l'asymétrie d'appui

Dans les suites de l'AVC, les patients peuvent présenter une asymétrie d'appui qui peut être présente à tous les stades de l'AVC (*Article 1*). Notre méta-analyse suggère une différence d'asymétrie d'appui entre les patients AVC droit et gauche.

Une des possibles explications de cette différence d'asymétrie entre patient AVC droit et gauche est l'implication des troubles de la représentation spatiale dans les mécanismes de ce comportement postural. Dans une cohorte de 22 patients victimes d'un AVC en phase subaiguë, les auteurs Barra *et al.* mettent en évidence une relation entre l'asymétrie d'appui et un trouble de la perception de l'axe longitudinal (Barra et al., 2009). Ce résultat est présenté par la méta-analyse (*Article 1).* Nos travaux dans un groupe de patients en phase chronique (*Article 2*) retrouvent ce résultat à distance de l'AVC. Nous montrons en plus que cette relation est dépendante du côté de la lésion. En effet la relation est plus forte dans le groupe de patients AVC droit *(Article 2).* La cohorte des auteurs Barra *et al.,* constituée de patients AVC droit et gauche, comporte un ratio bien plus important de patients avec une lésion à droite (13 patients AVC droit contre 9 patients AVC gauche) et trouve globalement une relation moyenne de r=-0.52 ; p=0.02 (Barra et al., 2009). Nos résultats mettent en avant que cette relation est côté dépendante (*Article 2*). En effet, une forte relation est observée pour le groupe de patients AVC droit (r=0.7 ; p=0.02) et absente lorsque seul le groupe de patients AVC gauche est pris en compte (r=-0.46 p=0.1). A ce délai d'AVC, les troubles de la perception de l'axe longitudinal évalués par le LBA expliqueraient 58% de l'asymétrie d'appui dans le groupe de patients AVC droit contre seulement 16% chez les patients AVC gauche (*Article 2).* A la différence des patients AVC droit, l'asymétrie d'appui des patients AVC gauche ne serait pas liée à un trouble de la représentation spatiale. L'asymétrie d'appui des patients AVC gauche pourrait être la conséquence biomécanique d'une motricité ou d'une somesthésie altérée, ou de processus compensatoires mis en place pour remédier au déséquilibre (Genthon et al., 2008).

Nos travaux ne montrent pas de relation entre asymétrie d'appui et perturbation de la verticale ni entre asymétrie d'appui et perturbation du droit devant. Les perturbations de la verticale pourraient être liées à un autre comportement postural qui est la latéropulsion, qui se caractérise par une chute du côté hémiplégique (Karnath, 2007; Pérennou et al., 2008) pouvant aller jusqu'à une résistance à la correction de cette posture (Karnath et al., 2000). Ce comportement postural comme l'asymétrie d'appui touche plus les patients avec une lésion au niveau de l'hémisphère cérébral droit (Abe et al., 2012; Baier et al., 2012; Karnath, 2007; Karnath et al., 2000; Lafosse et al., 2005). Si certains auteurs rapportent une relation entre ce comportement postural et les troubles de la perception de la verticale évalués en modalité visuelle (VV)(Mansfield et al., 2015; Pérennou et al., 2008; Saj et al., 2005b), d'autres démontrent un lien plus fort avec la modalité posturale (VP) voire haptique (VH) (Karnath et al., 2000; Pérennou et al., 2008). Mais à ce jour, les caractéristiques associées à ce comportement postural ne sont pas encore très claires. Concernant, les troubles de la perception du droit devant (SSA), ceux-ci semblent également être impliqués dans ce comportement postural (Honoré et al., 2009). En effet, les auteurs Honoré *et al.* observent une déviation contralesionelle du SSA de façon significative seulement dans le groupe de patients AVC droit pushers et négligents. Ces auteurs ne retrouvent pas de déviation du SSA ni dans le groupe de patients AVC droit négligents non pushers ni dans le groupe de patients AVC droit non pushers non négligents (Honoré et al., 2009) suggérant une possible relation entre ce comportement postural et les troubles de la perception du droit devant. Du fait du faible effectif de cette unique étude sur la relation entre l'asymétrie d'appui et la perturbation du droit devant, d'autres études sont nécessaires pour confirmer ces hypothèses.

Ainsi les troubles de la perception de l'axe longitudinal seraient impliqués dans les mécanismes de l'asymétrie d'appui en phase subaiguë (Barra et al., 2009) et en phase chronique (*Article 2)* et en particulier dans le groupe de patients AVC droit. Cette hypothèse pourrait expliquer, pour le groupe de patients AVC droit, des déviations plus importantes et persistantes dans le temps (Bonan et al., 2006, *Article 2*), ainsi que le délai d'acquisition d'une position debout de qualité retardé. Ces résultats renforcent l'hypothèse du rôle prédominant de l'hémisphère cérébral droit, et plus probablement, spécifiquement du cortex pariétal impliqué dans l'intégration des informations sensori-motrices (Jeannerod & Biguer, 1989; Lopez et al., 2005; Pérennou et al., 2014; Rousseaux et al., 2014) pour le maintien postural. Toutefois, à ce jour bien que nos résultats s'accordent avec ceux de la littérature concernant la relation entre asymétrie d'appui et LBA, la question de la relation de cause à effet reste encore à démontrer ; l'asymétrie d'appui pourrait, en particulier, être secondaire à un trouble de la perception de l'axe longitudinal ou bien ces deux troubles pourraient coexister par un mécanisme les sous tendant dû à une proximité des lésions responsables.

3. Les stimulations sensorielles par stimulation vibratoire ont-elles leur place en rééducation?

La deuxième partie de ce travail s'est focalisée sur l'utilisation de stimulations sensorielles en rééducation et plus spécifiquement sur la stimulation de l'entrée proprioceptive par l'application de vibrations. Cette partie cherche à établir les mécanismes d'action des vibrations des muscles du cou sur l'asymétrie d'appui et sur les troubles de la représentation spatiale et étudier leur efficacité dans le champ de la rééducation.

Les stimulations sensorielles sont décrites comme étant des approches dites « bottom-up » qui s'opposent à celles dites « top-down » se basant sur un effort volontaire du patient (Azouvi et al., 2017; Bonan et al., 2015; Varalta et al., 2019). Les approches de stimulations sensorielles de type « bottom-up » ont été utilisées initialement pour améliorer les troubles de négligence visuospatiale ; autre trouble de la cognition spatiale qui se manifeste par une difficulté à prendre en compte et à agir dans l'hémi-espace controlatéral à la lésion cérébrale (Frassinetti et al., 2002; Johannsen et al., 2003; Kerkhoff & Schenk, 2012; Schindler et al., 2002). Les troubles de la représentation spatiale et de la négligence visuospatiale constituent différents troubles de la cognition spatiale qui sont très souvent associés partagent en partie une physiopathologie commune et étant la conséquence de l'atteinte de zones cérébrales très voisines. Elles affectent principalement les patients avec une lésion au niveau de l'hémisphère droit (Bonan et al., 2015; Kerkhoff, 1999). A la différence des approches « top-down » qui présentent la limite d'être difficilement applicables pour des patients présentant des troubles attentionnels (Azouvi et al., 2017), les approches « bottom-up » présentent l'avantage de ne pas nécessiter la prise de conscience par le patient de son trouble ni de sa participation active (Azouvi et al., 2017; Bonan et al., 2015; Varalta et al., 2019).

Les mécanismes d'action de ces approches résulteraient de l'activation de structures cérébrales impliquées dans la représentation du corps dans l'espace (Bonan et al., 2015). En effet, des résultats de plusieurs études d'imagerie fonctionnelle chez des patients victimes d'AVC vont dans ce sens. Ainsi, la stimulation optocinétique, qui vise à stimuler l'entrée visuo-vestibulaire, active la partie postérieure du cortex pariétal (Boileau et al., 2002; Bonan et al., 2015; Thimm et al., 2009). Plusieurs auteurs montrent des résultats similaires lors de l'adaptation visuomotrice à l'aide de lunettes prismatiques (Saj et al., 2013; Taniguchi et al., 2012). Concernant l'entrée proprioceptive, les auteurs Bottini *et al.* qui ont étudié en particulier l'effet cérébral des stimulations des muscles du cou par vibration sous tomographie par émission de positons dans une population de sujets sains, confirment l'activité cérébrale dans les zones de l'intégration multisensorielle dans lesquelles la représentation de l'espace égocentrique est impliquée telle que l'insula, l'operculum pariétal ainsi que le gyrus temporal supérieur (Bottini et al., 2001).

Ces différentes stimulations sensorielles, de par leur mécanisme d'action au niveau cérébral, activeraient la composante cognitive des perturbations posturales. Dans une étude sur 35 patients victimes d'un AVC comprenant 18 patients avec une lésion au niveau de l'hémisphère gauche et 17 à droite, les auteurs Bonan *et al.* ont étudié le déplacement du centre de pression sur une plateforme de force lors de stimulations optocinétiques et galvaniques, mettant en avant une réduction de l'asymétrie d'appui dans les deux groupes mais de façon plus importante dans le groupe de patients AVC droit. L'effet proportionnel de la stimulation optocinétique avec celle galvanique suggère une action supra-modale dans les zones d'intégration multisensorielle (Bonan et al., 2015). Concernant l'entrée visuomotrice, une étude préliminaire de (Hugues et al., 2015) a montré, après des séances répétées d'adaptation prismatique, une réduction persistante de l'asymétrie d'appui chez 6 patients atteints de lésions cérébrales droites sans négligence avec une réduction parallèle du biais de la perception du droit devant (SSA).

Les vibrations des muscles du cou, ont une action à la fois sur la représentation spatiale, en particulier égocentrique avec un bon niveau de preuve sur la perception du droit devant (ou subjective straight ahead), et sur le contrôle postural (*Article 3*), probablement grâce aux interconnexions entre les récepteurs proprioceptifs des muscles du cou et le système oculomoteur et vestibulaire via les noyaux vestibulaires (Biguer et al., 1988). Les informations sur les mouvements de la tête (venant des récepteurs proprioceptifs des muscles du cou et des vestibules) couplées à celle de la direction du regard sont fondamentales pour la localisation égocentrique des objets (McIntyre & Seizova-Cajic, 2007). De plus, de par leur localisation spécifique entre la tête et le tronc, les muscles du cou sont également impliqués dans le contrôle postural (Pettorossi & Schieppati, 2014). Une réponse motrice très rapide au niveau des membres inférieurs peut être obtenue (Magnusson et al., 2006). En pratique, la vibration induit un déplacement de l'environnement visuel matérialisé par un point lumineux du côté opposé à la vibration à la fois chez les sujets sains comme chez les sujets hémiplégiques (*Article 3*). Cette illusion de déplacement de l'environnement visuel pourrait être obtenue grâce à la simulation d'un étirement des muscles du cou qui donnerait l'illusion d'un mouvement de la tête sur le tronc par une boucle courte. Il est observé simultanément à l'illusion du déplacement de l'environnement visuel, une déviation de la perception du droit devant du côté de la vibration (Karnath et al., 1994, 2002). Cette action sur la perception du droit devant suggère que le mécanisme d'action n'est pas simplement bas situé avec obtention d'une illusion visuelle mais également haut situé avec une action centrale sur le processus de codage des informations sensorielles en provenance des organes sensoriels périphériques en un système de coordonnées égocentrique de l'espace (Karnath et al., 1994). Cette hypothèse est renforcée par les travaux de (Bottini et al., 2001) en PET scan qui mettent en évidence une activité centrale lors des vibrations des muscles du cou dans les zones d'intégration égocentrique (Galati et al., 2000). De plus, plusieurs études montrent que les vibrations des muscles du cou améliorent l'exploration tactile aussi bien que visuelle des patients négligents vers la gauche (Johannsen et al., 2003). Les auteurs Schindler *et al.* montrent par ailleurs qu'à la différence de la stimulation optocinétique, la vibration des muscles du cou ne semble pas efficace sur les jugements de taille d'objets, ce qui suggère que cette manipulation pourrait ne pas être efficace sur les jugements faisant appel aux références allocentriques (Schindler et al., 2002). Ce résultat est en accord avec les données que nous avons trouvées (*Article 3*), à savoir que la vibration des muscles du cou permet d'obtenir une correction de la représentation spatiale avec un bon niveau de preuves essentiellement pour de la perception du droit devant (SSA). Nous avons donc fait l'hypothèse que les vibrations des muscles du cou provoqueraient une déviation de l'ensemble du corps du côté de la vibration en réponse à la perception égocentrée du déplacement de l'axe du corps vers le côté vibré (Karnath et al., 1994).

Concernant l'application des vibrations des muscles du cou en session unique, des résultats encourageants ont été observés. Après une session de 10 minutes de vibrations des muscles du cou à un stade aigue de la lésion, on obtient une réduction de l'asymétrie d'appui à la fois dans le groupe de patients AVC droit et gauche (Leplaideur et al., 2016). L'absence de différence entre ces deux groupes n'est pas si surprenante. En effet, d'autres stimulations sensorielles telles que la stimulation optocinétique ont montré également des résultats chez les patients avec une lésion au niveau de l'hémisphère gauche (Bonan et al., 2015). Bien qu'aucune évaluation de la représentation spatiale n'ait été faite par ces auteurs, une possible hypothèse, à ce stade de l'AVC (moins de 3 mois), est la présence de troubles de la cognition spatiale, y compris dans le groupe de patients ayant une lésion au niveau de l'hémisphère gauche mais moindre que dans le groupe de patients cérébrolésés droits (Bonan et al., 2015; Genthon et al., 2008; Leplaideur et al., 2016, *Article 2*). De plus, la majeure partie des stimulations sensorielles a un effet également chez des sujets sains sans atteintes neurologiques (Kavounoudias et al., 1999; Michel et al., 2003), avec toutefois un effet moins marqué que chez les cérébrolésés droits (Bonan et al., 2015). Ainsi à un stade précoce de l'AVC (moins de 3 mois), ces stimulations par vibrations des muscles du cou agiraient sur l'asymétrie d'appui à la fois des patients AVC droit et gauche mais de façon moindre pour le groupe de patients AVC gauche (Leplaideur et al., 2016). A un stade plus avancé (6 mois) de l'AVC, du fait d'une persistance des perturbations de la représentation spatiale majoritairement dans le groupe de patient AVC droit, ces stimulations agiraient seulement pour ce groupe (Bonan et al., 2007; Bonan et al., 2015)(*Article 4*).

Plusieurs auteurs ont proposé l'application de stimulations sensorielles de façon répétée avec des résultats intéressants, en particulier dans la prise en charge de la négligence spatiale (Kerkhoff et al., 2006; Thimm et al., 2009). En effet, les auteurs Kerkhoff *et al.* qui ont appliqué 5 sessions de stimulations optocinétiques à des patients négligents gauche à plus de 2 mois de leur AVC (Kerkhoff et al., 2006) ont noté une amélioration significative sur les différents tests que sont le test des cloches, de la bissection et le test de lecture avec un maintien à 2 semaines. De même (Thimm et al., 2009) après un programme de 14 sessions d'optocinétiques confirment ces résultats avec un maintien à 4 semaines. Suite à ces résultats encourageant, on pourrait espérer obtenir un effet similaire sur les perturbations posturales secondaires aux troubles de la cognition spatiale. Concernant l'asymétrie d'appui, l'application d'un programme de 10 séances d'adaptation prismatique a montré des résultats significatifs de correction de l'asymétrie d'appui à une semaine dans une population de patients cérébrolésés droits (Hugues et al., 2015). Nos résultats montrent une correction significative de l'asymétrie d'appui dans le groupe de patients AVC droit chroniques à la fin du programme de 10 sessions de 10 minutes (*Article 4).* Cette réduction de l'asymétrie d'appui dans le groupe de patients AVC droit a pour effet de rapprocher leur degré d'asymétrie d'appui de celui des patients AVC gauche. Concernant la représentation spatiale, en s'appuyant sur les *Articles 1* et *2*, une modification des biomarqueurs SSA, LBA était attendue. Seul un léger changement pour le SSA, en miroir au changement de l'asymétrie d'appui, a été observé mais non significatif. Ce résultat décevant est possiblement, dû au fait que le calcul du nombre de patient a été fait sur le critère principal d'asymétrie d'appui. Un nombre de patients plus important auraient pu permettre de visualiser un changement du SSA qui est très variable. Il faut souligner également que les patients avaient peu de perturbation du SSA, LBA à ce stade, ce qui n'exclut cependant pas que nos patients aient gardé des troubles de la représentation spatiale. On ne peut pas conclure à ce stade que la correction de l'asymétrie d'appui obtenue immédiatement à la fin du programme de vibrations est due à la correction de la partie d'asymétrie d'appui due au troubles de la représentation spatiale, même si cette correction est obtenue uniquement dans le groupe des AVC droits. En effet cette nette différence de comportement en réponse aux vibrations est un argument indirect qui étaye notre hypothèse. L'application d'un programme de 10 séances d'adaptation prismatique a montré des résultats significatifs de correction de l'asymétrie d'appui qui se maintenaient à une semaine dans une population de patients cérébrolésés droits (Hugues et al., 2015). Par ailleurs, un effet cumulatif lors de sessions de stimulations sensorielles par vibration successives a été montré chez des sujets sains (Bove et al., 2009). Considérant ces résultats, notre hypothèse était un maintien de la correction par stimulations de vibrations répétées. La correction de l'asymétrie d'appui n'est plus significative à une semaine (*Article 4).* Nos travaux ne montrent pas de maintien à distance de cette correction chez ce groupe de patients à un stade chronique de leur AVC. Cette absence de maintien pourrait s'expliquer, soit par l'absence de correction durable de la partie de la représentation spatiale de l'équilibre, soit par le fait qu'à ce stade de l'AVC le patient pourrait s'opposer à la correction de son asymétrie d'appui qui pourrait être devenu un schéma complètement intégré. Ces hypothèses restent à étudier notamment en les comparant à des résultats obtenus à un stade aigu de l'AVC. Enfin, ce programme pourrait avoir été insuffisant en intensité, en durée ou en nombre de séances (Biguer et al., 1988; Karnath et al., 2002). Bien que ces résultats restent encourageants, d'autres études sont nécessaires.

4. Perspectives

4.1 Les vibrations des muscles du cou associées à l'adaptation prismatique

Ce travail de thèse s'est focalisé sur la stimulation de l'entrée proprioceptive par vibration des muscles du cou. L'adaptation prismatique afin de stimuler l'entrée visuo-motrice est une approche également facile à mettre en place et peu couteuse, qui a montré des résultats bénéfiques. En effet, l'adaptation prismatique a fait ses preuves dans le traitement de l'héminégligence, autre trouble de la représentation spatiale (Anelli & Frassinetti, 2019; Frassinetti et al., 2002; Rode et al., 2017, 2001). Concernant les troubles posturaux, les auteurs Tilikete *et al.* ont montré que l'adaptation prismatique améliore les perturbations posturales en position debout des patients AVC droit (Tilikete et al., 2001). Ces auteurs utilisaient une déviation prismatique droite, gauche ou neutre dans trois groupes de 5 patients AVC droit et observaient une amélioration de l'équilibre évalué en position debout sur plateforme de force seulement lorsque la déviation prismatique était réalisée à droite. Plus récemment les auteurs Hugues *et al.* ont montré, après des séances répétées d'adaptation prismatique, une réduction persistante de l'asymétrie d'appui chez 6 patients atteints de lésions cérébrales droites sans négligence avec une réduction parallèle du biais de la perception du droit devant appréhendé par le SSA (Hugues et al., 2015). Cette approche pourrait corriger les troubles posturaux secondaires aux troubles de la représentation spatiale. En effet, les auteurs Luauté *et al.* qui ont étudié l'activation cérébrale de sujets sains en IRM fonctionnel rapportent une activation progressive du cervelet lors de l'adaptation prismatique qui pourrait agir sur la représentation spatiale via l'activation du cortex temporal supérieur (Luaute et al., 2009).

Les mécanismes d'action des vibrations des muscles du cou et l'adaptation prismatique, que ce soit dans le traitement de la négligence ou l'amélioration de l'équilibre ne sont donc pas univoques. En effet, les modes d'action de chacune d'entre elles et les structures cérébrales mises en jeu sont différents. Les auteurs Karnath *et al.* ont montré qu'il existait un effet additif lorsque l'on utilisait deux manipulations sensorielles différentes, notamment dans la correction de la perception du droit devant (SSA) (Karnath et al., 1994). C'est pourquoi il serait intéressant de coupler ces deux manipulations que sont la vibration des muscles du cou avec l'adaptation prismatique pour obtenir un effet plus important et durable. Cette idée d'associer plusieurs traitements différents est déjà répandue dans la littérature pour le traitement de la négligence, plusieurs études récentes montrent en effet l'intérêt d'associer différents traitements (Polanowska et al., 2009; Schindler & Kerkhoff, 2004; Wiart et al., 1997) et montrent des résultats intéressants qui pourraient être appliqués dans l'amélioration des perturbations posturales secondaires aux troubles de la représentation spatiale.

4.2 Caractérisation et compréhension des mécanismes de perturbations posturales en position assise suite à un accident vasculaire cérébral

Ce travail de thèse s'est intéressé essentiellement aux perturbations en position debout. Toutefois, à la phase précoce de l'AVC, les patients sont plus susceptibles de présenter des troubles posturaux en position assise qui sont de mauvais pronostic pour l'acquisition des transferts, de la position debout et de la marche (Amusat, 2009; Bohannon et al., 1986; Genthon et al., 2007). Une meilleure compréhension et une prise en charge précoce de ces troubles posturaux en position assise permettrait d'améliorer le pronostic fonctionnel du patient post-AVC.

A ce jour, les mécanismes de ces perturbations posturales en position assise chez le patient AVC ne sont pas parfaitement décrits. En effet, de nombreuses divergences sont retrouvées dans la littérature. Même s'il semble que pour une majeure partie des auteurs (Au-Yeung, 2003; Genthon et al., 2007; Mudie et al., 2002), les patients victimes d'un AVC présentent une plus grande asymétrie en position assise que les sujets sains, tous ne sont pas unanimes (Tessem et al., 2007). De plus, parmi ces auteurs mettant en avant cette asymétrie en position assise, certains notent un déficit plus prononcé sur le plan latéral (Van Nes et al., 2008) alors que d'autres retrouvent un déséquilibre plus marqué sur le plan antéro-postérieur (Genthon et al., 2007). En dehors du déficit moteur et sensitif, l'asymétrie d'appui retrouvée en position assise pourrait également être due à un trouble de la représentation spatiale. (Au-Yeung, 2003) montrant une déviation de la posture assise plus prononcée chez les patients victimes d'un AVC localisé au niveau de l'hémisphère droit. De plus, (Bonan et al., 2006a) soulignent une relation entre les données de posturographie de la position assise et le référentiel allocentrique évalué par la SVV, suggérant ainsi l'implication de la cognition spatiale dans les perturbations posturales en position assise. Toutefois, (Van Nes et al., 2008) n'ayant pas retrouvé ce résultat dans leur étude, cette hypothèse reste à confirmer.

A la différence des troubles de la posture en position debout qui sont couramment évalués sur plateforme de force, les troubles de la posture en position assise bénéficient de peu d'outils de mesure instrumentale en dehors d'échelles de mesure clinique (Tyson & Connell, 2009). De plus, dans la littérature, une très grande variété de méthodes d'évaluation par mesures instrumentales est proposée et aucune n'est validée (Au-Yeung, 2003; Genthon et al., 2007; Mudie et al., 2002; Van Nes et al., 2008; Sackley et al., 2005; Tessem et al., 2007). Dans certains cas, le patient a été placé directement assis sur la plateforme de force (Genthon et al., 2007; Mudie et al., 2002; Sackley et al., 2005; Tessem et al., 2007), d'autres ont fait le choix d'asseoir le patient sur une chaise positionnée sur la plateforme (Van Nes et al., 2008). Les nappes de pression qui sont habituellement utilisées pour adapter les assises des patients porteurs d'escarres pourraient présenter un intérêt pour quantifier l'assise posturale (Maurer & Sprigle, 2004). Mais l'implication de la tête et du tronc dans la posture assise est bien démontrée dans la littérature (Au-Yeung, 2003) et l'ajout d'une évaluation des déplacements du tronc et de la tête semble en conséquence indispensable. A notre connaissance, peu d'auteurs (Pérennou et al., 2002) ont étudié les perturbations posturales assis à l'aide de données quantifiées en tenant compte à la fois de la posture du tronc et de la tête et d'une mesure de l'asymétrie d'appui, ce qui pourrait être le sujet de futures études (Annexe 1). Cette caractérisation des troubles de l'équilibre permettrait une meilleure compréhension des mécanismes des troubles de la posture en position assise et permettrait ainsi de proposer un programme de rééducation adapté en fonction du mécanisme du trouble de l'équilibre.

Conclusion

A ce jour l'asymétrie d'appui, un des comportements posturaux secondaires à l'AVC, reste sujet à discussion. En effet, son évolution dans les suites de l'AVC, ses relations avec les différentes caractéristiques de l'hémiplégie ainsi que ses mécanismes d'action sont régulièrement traités dans la littérature.

Ce travail de thèse confirme la présence d'asymétrie d'appui en phase aiguë mais également persistante en phase chronique. Notre méta-analyse ne montre qu'une légère différence entre les patients AVC droit et gauche avec un déficit plus marqué au dépend du premier groupe. Cette différence entre ces deux populations est un sujet pourtant régulièrement mis en avant dans la littérature. Ainsi ce travail d'analyse conforte ce résultat sans pour autant le confirmer avec un niveau de preuve au vu de nos données suggérant la poursuite des études (*Article 1*).

Ce travail de thèse suggère l'intérêt de l'évaluation des biomarqueurs de la représentation spatiale en systématique afin d'analyser les troubles de la cognition spatiale et de pouvoir proposer un programme de rééducation adapté. En effet, nos travaux montrent une implication plus forte des troubles de la représentation spatiale dans les mécanismes d'action de ce comportement postural d'asymétrie d'appui que du déficit moteur et/ou sensitif, et ce en particulier pour le groupe de patients AVC droit. En effet, ces résultats déjà décrits chez des patients victimes d'un AVC en phase subaigüe, sont retrouvés à distance en phase chronique (*Article 2*). Nos travaux vont dans le sens du rôle de l'hémisphère droit dans la représentation spatiale, ces résultats pourraient expliquer l'asymétrie d'appui plus marquée dans le groupe de patients avec une lésion au niveau de l'hémisphère droit dû à un trouble de la représentation spatiale et de ce fait une difficulté plus importante à acquérir la station debout stable pour les patients avec une lésion à droite.

A ce jour, si les mécanismes des perturbations posturales en position debout sont mieux compris, leur implication dans la posture assise reste à définir. La disparité sur les méthodes d'évaluation de la posture assise observées dans la littérature et le faible nombre d'études sur les mécanismes impliqués (*Article 1*), suggère de poursuivre ces travaux.

La relation retrouvée entre l'asymétrie d'appui et les échelles cliniques d'équilibre soulignent l'intérêt de prendre en compte ce comportement postural lors de la prise en charge de ces patients indépendamment du stade de la pathologie (*Article 1 et 2*). Les stimulations sensorielles par vibration musculaire semblent être un outil intéressant de par leur action sur le contrôle postural et la représentation spatiale (*Article 3*). Bien que les mécanismes d'action de cette stimulation restent complexe, des résultats encourageants chez des patients en phase chronique (*Article 4*) montrent un déplacement significatif du centre de pression évalué sur plateforme de force vers le membre inférieur hémiplégique, réduisant l'asymétrie d'appui dans le groupe de patients AVC droit, se rapprochant du degré d'asymétrie d'appui des patients AVC gauche. Ce gain, légèrement maintenu à une semaine, mais non significatif, s'estompe à distance de la stimulation. Ces résultats ouvrent des perspectives notamment pour proposer ces vibrations en phase précoce de l'AVC.

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Annexes :

Annexe I : Appendix A, B et C de l'article 1 Postural asymmetry and hemiplegia post-stroke: a systematic review and meta-analysis

Appendix A = extraction of the articles included in the review Postural asymmetry and hemiplegia post-stroke: a systematic review and meta-analysis. (Antero-posterior (AP), Berg Balance Scale (BBS), Case-Study (CS), Center of Pressure (CoP), Clinical Outcome Variables Scale (COVS), Clinical Test for Sensory Interaction on Balance (CTSIB) Cross-Over trial (CO), Double Limb Support (DLS), Emory Functional Ambulation Profile (E-FAP), Eyes Opened (EO), Eyes Closed (EC), Female (F), Functional Standing Balance (FSB), Functional Independence Measure (FIM), Functional Reach Test (FRT), Left (L), Left Brain Damage (LBD), Longitudinal Body Axis (LBA), Limit od stability (LOS), Male (M), Medio-Lateral (ML), Not Applicable (NA), Open Eyes (OP), Postural Assessment Scale for Stroke (PASS), Randomized Controlled Trial (RCT), Right (R), Right Brain damage (RBD), Scale for Contraversive Pushing (SCP), Single Limb Support Period, (SLS) Subjective Straight Ahead (SSA), Subjective Visual Vertical (SVV), Surface (Surf), Time Up and Go (TUG), Velocity (Vel), Weight bearing asymmetry (WBA))

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)			
Patterson et al. 2017	Retrospective Study (8/10)	75/70.2 (10.5)	44/31	45 R/30L (4)							NA	Heels 17 cm apart. 14° between the long axes of the feet.	standing-30-EO	47.9 (9.3)	4.1 (2.4)																			
Gray et al. 2016	CS (4/10)	11/71.4 (6.9)	9/2	7R/4L (24.8 (15.2))							AMTI OR6-6-1000 force platforms(Advanced Mechanical Technology. Watertown. MA)	Comfortable position	standing-NA-NA				41																CoP Velocity = arm acceleration (r=0.48 p=0.2)	

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Yin et al. 2016	RCT (3/10)	6/54 (9.14)	1/5	2R/ 4L (60 (42.4))	3/61.3 (6.3)	1/2	3R (53.2 (16.64))				zebris force measure platform. zebris Medical GmbH. Germany)	NA	standing- 40- EO/EC						40.75 (10.51)									43.2 (1.3)						
Wen et al. 2014	CS (8/10)	10/55 (12.8)	8/2	NA (10.8 (6.8))							Good Balance system; Metitur. Jyväskylä. Finland).	Normal (EOEC)/feet together (EO)/ semitandem(EO)	standing- 30- EO/EC				Normal = 5.89 (2.84); Feet together = 13.33 (4.03); semitandem =15.93 (3.15)					normal = 6.74 (2.80)												

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)			
Liu et al. 2009	RCT (7/10)	15/69 (65-72)	9/6	9R/6L (7.7 (3.5-46.2))	15/67 (63-75)	6/9	6R/9L (12.2 (8-51))				Infotronic computer posturography.Netherland)	NA	standing-20-EO/EC (2)			86.7 (57.3)					78.6 (64.9)				62.8 (32.6)					74.1 (40.4)				
Jorgensen et al. 2000	Prospective study (8/10)	40/75 (9)	21/19	19R/21L (NA)							BPM. SMS Healthcare. Elizabeth House. Harlow. UK).	Feet were parallel and kept a uniform distance apart (7 cm) with shoes	standing-30-EO	baseline (n=12)= 51 (6); 2 months (n=15)= 48 (11); 7 months (n=5)=43 (10); immobyle 7months (n=5)= 35 (10)																				
Rizzi et al. 1996	CS (3/10)	10/53 (5)	3/7	5/5 (26)							Electronic baropodometer	NA	standing-15-NA						RBD=41.5/LBD 44.3															
Simons et al. 2009	CS (8/10)	20/57.2	14/6	10R/10L (170.8)							Caren. MOTEK. Amsterdam. The Netherlands).	Both feet slightly apart. distance 20 cm. without AFO	standing-90-EO	40 (11)																				

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Chen et al. 1999	CS (4/10)	24/58.9 (9.5)	17/7	15 R/9 L (56.3)							the Computer Posturo Graphy	NA	standing-30-NA	41.72 (10.4)																				
Vignon et al. 2015	RCT (6/10)	9/55.89 (17)	4/5	3R/6L (153.12 (145))							NA	NA	standing-NA-EO/EC		28.81 (30.8)					26.05 (27.74)														

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Barra et al. 2009	CS (7/10)	22/57.1 (14)	16/6	13 R/9 L (13 (7.5))							PF02. Equi. France	Heels separated by 9 cm. toe out at 30° without orthesis/barefoot	standing-32-EO (4)	37 (10)																			WBA OE = neglect (r =0.53; p =0.01)/hypoesthesia (r=0.54; p=0.01)/ motor weakness (r=0.47; p=0.03)/ Bell test (r=0.31; p=0.15)/ line bisection (r=0.21; p=0.35) / PASS (r=0.51; p=0.035) / gait independence (r=0.70; p=0.001)/ SCP (r=0.36; p=0.01) /LBA (r=0.52; p=0.02) / SVV (r =0.41; p =0.074)	

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)			
Dickstein et al. 1994	CS (5/10)	13/70.2 (7.5)	3/10	NA (26.07 (10.8))							Chattecx corporation. Chattanooga. TN. USA).	Barefoot separate 12 cm	standing-50-EO		19.31 (17.74)																			
Bredikhina et al. 2015	RCT (4/10)	25/NA	NA	NA (NA)	25						Stabilan-01-2" (produced in Russia by ZAO OKB RITM)	NA	NA-EO/EC		6.97 (0.6)		15.3			6.37 (0.6)		16.9 (1.1)		7.01 (0.8)		15.7 (0.9)			6.5 (0.6)		17.1 (1.4)			
Schinkel-Ivy et al. 2017	CS (7/10)	66/64.7 (12.3)	41/25	35/31 (35.63 (4.7))							two adjacent force plates (Advanced Mechanical Technology.Inc.. Watertown. MA).	NA	standing-30-EO/EC		3.3 (2.3)					3.89 (1.29)														

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)			
Samaniego et al. 2015	CS (7/10)	18/57	8/10	8R/10L (NA)							Satel ®.	Separation 4cm rotation 30°.	standing-51.2-EO/EC		RBD=-2.95 / LBD=-6.36	688.71				RBD= -7.82 / LBD=-2.95	RBD/LBD 1904.82													
Tung et al. 2010	RCT (8/10)	16/52.7 (14.1)	11/5	11/5 (51.2 (49.2))	16/51 (12.1)	9/7	11/5 (107.6 (64))				Balance Master System	NA	NA-NA	44.8 (9.7)									47.5 (8.8)											
Matjačić et al. 2003	CS (4/10)	janv-40	0/1	1/0 (78.21)							Ultraflex CDG. Infotronic	NA	standing-NA-EO	35																				
Gasq et al. 2014	CS (10/10)	20/49.7 (15)	14/6	09/11 (44.7)							Win-Posturo. Medicapteurs. Toulouse. France;	Heels 3 cm apart and toes pointed out at an angle of 30°.	standing-51.2-EO/EC (3)		10.7 (9.9)	438.3 (229)	7.6 (3.1)			14.1 (11.6)	558.6 (3.24)	10.7 (5.8)												

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Mansfield et al. 2011	CS (9/10)	33/61 (14)	23/10	17/16 (19 (27.7))							NA	Feet oriented at 14° with 0.17 m between the heels	standing-30-NA	42.9 (12)	2.8 (2.6)																		CoP ML = AP°(r=-0.43.p=0.01) /ML°(r=0.32.p=0.07) - WBA = AP°(r=0.32.p=0.06)/ ML (r=-0.29.p=0.09)	
Jasińska et al. 2014	CS (6/10)	30/66 (10.28)	17/13	12/18 (30.27 (34))							R50300 Cosmogamma balance platform.	feet (without shoes) were arranged according to the guidelines on the platform	standing-60-EO/EC		RBD =13.5 (21.31) / LBD = -9.4 (21.42)					RBD =12.25 (23.51) / LBD =-10.01 (21.86)														

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)			
Cho et al. 2014	CO (5/10)	32/63.5 (4.7)	16/16	19/13 (42.8 (10.9))							Good Balance force platform system (Good Balance system. Metitur Ltd.. Jyvaskyla. Finland).	Barefoot	standing-30-EO/EC (3)			8.82 (2.8)					13.90 (4.92)													
Yu et al. 2012	CS (8/10)	28/63.9 (6.8)	15/13	7/21 (76 (13.47))							Good Balance force platform (Metitur Ltd.. Finland)	Feet 20 cm apart and feet together	standing-30-EO (3)		516.7 (177.6)	78.4 (39.5)	16.8 (6.1)																	
Paillex et al. 2005	CS (8/10)	8/53.5 (27-79)	5/3	3/5 (217 (28-18))							Winposture 2000. version 2.24a	Barefoot with angle of 30° and the heels were separated by 8 cm	standing-51.2-EO (5)		24.3	483.8																		

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Mansfield et al. 2012	CS (9/10)	100/66.9 (14.9)	61/39	26/49/13/0 (3.27 (3.3))							(Advanced Mechanical Technology. Inc.Watertown. Massachusetts)	Feet oriented at 14° with 17 cm between the heels	standing-30-EO	43.5 (5.8)	4.6 (3.5)																			
Bower et al. 2014	RCT (7/10)	17/61.9 (13.6)	8/9	10/7 (3.6 (2.3))	13/65.9 (16.2)	9/4	6/7 (3.45 (2.97))				Wii Balance Board - derived	NA	NA-NA				9.4 (4.5)					13.8 (9.9)				6 (1.3)					8.9 (3.4)			
Jiejiao et al. 2012	RCT (8/10)	45/69.11 (5)	24/21	20/25 (143.8 (24.8))	47/68.61 (4.62)	23/24	27/20 (132.18 (32.32))				Biodex Balance System; New York. USA)	Barefoot heels together with feet forming an angle of 20°	standing-60-EO/EC		138.78 (12.44)	192.41 (17.13)				151.02 (12.71)	244.62 (39.57)			141.14 (11.21)	196.7 (13.03)				149.44 (14.41)	257.68 (27.97)				
Tung et al. 2015	CS (5/10)	1 1/50	1/0	0/1 (57)	1 1/63	1/0	0/1 (41)				Accusway AMTI inc.Watertown. MA	With Shoes	standing-60-EO				9																	
Fishman et al. 1997	CS (5/10)	20/57.9 (13.6)	12/8	12/8 (8.8 (6.8))							Balance SystemTM T.	Parallel stance position	standing-NA-EO	42.7 (11.3)																			WBA OE = Functional Reach test (r=0.66, $p<0.001$)	

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Aruin et al. 2012	RCT (5/10)	9/57.7 (11.9)		5/4 (349.35 (203))	9/57.7 (11.9)		4/5 (349.35 (203))				(Balance Master®. NeuroCom International. Clackamas. OR).	NA	standing-NA-EO	35.7 (2.3)									33.4 (2.8)											
Mohapatra et al. 2012	RCT (6/10)	5/43.8 (4.7)	3/2	3/2 (1.57 (0.12))	6/53.7 (5.1)	4/2	3/3 (2.57 (0.85))				Scale-Tronix. 5005 Stand-On Scale)	NA	standing-NA-EO (2)	32.4 (0.06)									30.2 (0.04)											
Aruin et al. 2000	CO (5/10)	8/59.1 (6.1)	6/2	4/4 (76.1 (36.5))							Balance Master. NeuroCom International. Clackamas. OR).	N=5 with rigid polypropylene ankle-foot orthosis	standing-NA-EO(2)	38.8 (1.8)																				

Genthon et al. 2008	CS (5/10)	41/58.8 (13.5)	30/11	25/16 (13.28 (6.6))							(PF02. Equi. France)	Barefoot. Heels separated by 9 cm. toe out at 30°	standing-30-EO(4)	38 (12)	0.51 (0.32)																		WBA OE = Age (r=0.14 NS), delay PS(r=-0.37; p=0.05), lesion size (r=-0.3 NS), motor weakness (r=-0.33. p=0.05), spasticity (r=-0.4.p=0.01). hypoesthesia (r=-0.4.p=0.01), behavioural neglect (r=-0.41.p=0.01)-CoP ML OE = Age (r=0.09 NS). delay PS(r=11. NS). lesion size (r=-0.32 NS). motor weakness (r=-0.39. p=0.01). spasticity (r=-0.4.p=0.01). hypoesthesia (r=0.35. p=0.05). behavioural neglect	

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
																																	(r=0.45. p=0.01)	
Frykberg et al. 2007	CS (7/10)	20/50.1 (9.8)	12/8	09/11 (199.9 (11-573))							(Kistler type 9284. Kistler Instrumente AG. Winterthur. Switzerland)	Shoes and with their feet in a self-chosen position.	standing-30-EO		3.4 (1)		12.4 (6.2)																CoP ML OE =BBS (r=-0.43, NS)- CoP Velocity OE = BBS (NS r=-0.51)	

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Karlsson et al. 2000	CS (7/10)	20/50 (21-65)	12/8	8/12 (125.14)							(Kistler type 9284. Kistler Instrumente AG. Winterthur. Switzerland)	Wore their own comfortable shoes and stood with self-chosen feet positioning	standing-30-EO(3)		3.5 (1.1)		13 (6.1)																CoP ML OE= CoP AP OE (r=0.71 p<0.01), CoP velocity OE (r=0.62, p<0.01), CoP velocity OE AP (r=0.71 p<0.01), BBS (r=-0.12 NS)- CoP velocity OE ML = CoP velocity OE AP (r=0.§ p<0.01), BBS (r=-0.36)	
Galea et al. 2017	RCT (8/10)	5/72 (5)	NA	NA (NA)	5/74 (6)						NA	NA	standing-NA-EO/EC		8.9	130	149			8.3	130	153		5.9	111	86			9.4	165	123			
Godi et al. 2011	CS (8/10)	20/62.8 (11.3)	12/8	8/12 (417.14 (328))							Medicapteurs. Balma. France	Barefoot, angle 30° and distance 2–3 cm.	standing-51.2-EO/EC (2)		17.3 (14.3)	153.7 (98.1)				18.7 (15.3)	375.9 (375.8)													

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)			
Johannsen et al. 2014	CS (4/10)	11/64 (15.9)	5/6	4/7 (114.7 (99))							(Wii-Fit balance board ; Nintendo. Redmond. WA)	NA	standing-20-EO(2)				18.4																	
Mansfield et al. 2013	CS (9/10)	147/67.4 (12.6)	87/60	74/73 (56.05 (67.78))							NA	Feet oriented at 14° with 0.17 m between the heels	standing-30-EO/EC																					

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Suzuki et al. 1999	CS (4/10)	34/54.2 (12.3)		15/19 (8.6 (3))							NA	10 cm apart.	standing-10-EO				346 (139)																CoP velocity OE = maximum walking speed (r=-0.5. p=0.01), LOS right/left (r=-0.63. p<0.01). LOS AP (r=-0.32 NS), strengh knee extension paretic (r=-0.51.p<0.01). strenght knee extension non paretic (r=-0.37.p<0.03)	

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Bonan et al. 2017	CS (8/10)	19/55.8 (9.9)		19/0 (9.55 (6.5))	21/53.6 (11.3)		0/21 (7.8 (4.7))				FeeTestof TechnoConcept®. France	12 cm apart	standing-NA-EO	34.1 (15.5)									40.2 (10.1)										WBA OE =Delay stroke (r=0.3;p=0.05); motricity (r=0.5; p=0.01). sensibility (r=0.4;p=0.05); BBS (r=0; p=0.01); TUG (r=0.6; p=0.0001); T10m (r=0.6; p=0.0001). Age (r=0.06 NS). Barthel (r=0.23 NS)	
Ten Brink et al. 2017	CS (7/10)	251/61 (16)	158/93	NA (3.28(2.1))	53/62 (16)	32/21	NA (4 (3.14))	31/57 (18)	19/12	NA ((4.71 (4))	Wii balance board	The patient sat with their hands in their lap.	sitting-NA-EO/EC		0.1 (3.8)					-0.03 (3.9)				0.64 (3.55)					0.49 (3.44)			WBA OE =-2.62(6.6) / CoP ML EC =-2.75 (6.69)		

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Jeon et al. 2013	CS (4/10)	22/52.3 (2.1)	12/10	11/11 (110.36 (9.9))							Messen TairuierenDokumentieren (MTD) system (MTD Co.. Germany)	NA	standing-20-EO	45.1 (1.1)																				
Martins et al. 2011	CS (5/10)	20/59.4 (3)	12/8	NA (180.11 (54))							(Plenna)	Barefoot. with their feet free and aligned on the scales with each foot about 20 cm away from the other.	standing-NA-EO (3)	47.9 (7.1)																				

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Jamal et al. in press	CS	15/61 (11)	13/2	15/0 (286 (208))	15/59 (10)	11/4	0/15 (221.6 (161.6))				PostureWin V143 Techno Concept	Barefoot separate of 14 cm	standing-30-EO/EC (4)	34. 1(9)				33.9 (9)	34 (9)				40.1 (4)				38.5 (5)	39 (4)					WBA = LBA (r=0.34; p= NS), SSA (r=0.11; p=NS), SVV (r=0.18; p=NS); WBA = LBA (r=0.77; p= 0.02), SSA (r=0.25; p=NS), SVV (r=0.40; p=NS); WBA = LBA (r=-0.46; p= NS), SSA (r=-0.52; p=NS), SVV (r=-0.41; p=NS);	
Mansfield et al. 2015	CS (8/10)	60/62.9 (14.2)	40/20	21/32/7 (6.44 (3.5))	21/61.8 (10.5)	13/8	9/8/3/1 (7.44 (2.32))	14/62.7 (14.6)	7/7	6/5 (8.04 (2.9))	NA	NA	standing-30-EO		3.9 (2.8)									4.8 (3.2)								CoP ML OE =3.8 (2.5)		
Bae et al. 2017	RCT (6/10)	9/49.6 (8.7)	4/5	NA (62.26 (25.2))	9/49.5 (10.6)	5/4	NA (57.22 (22.5))				Bioresuce system	Angle 30°	standing-60-EO			62.57 (7.93)									61.43 (7.11)									

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)			
Lee et al. 2013	RCT (7/10)	16/53.31 (8.3)	13/3	8/8 (247.25 (111.8))	15/55.73 (8.27)	9/6	7/8 (216.8 (129.9))				Point Distribution Model Multifunction Force Measuring Plate; Zebris. Germany. 2004	NA	standing-30-EO/EC (3)				23.6 (11.4)					30.7 (14.6)				22.4 (6.2)					26.9 (7)			
Mojica et al. 1988	CS (3/10)	8/46-66	5/3	NA (20.7)							(Kistler 9807 Y9 system. Kistler. Zurich. Switzerland)	Barefoot	standing-10-EO		24.2 (13.7)		373.9 (144.8)																	
Kang et al. 2015	CO (6/10)	12/62.07 (10.57)	7/5	5/7 (35.6 (14.7))							Good Balance System (Metitur Ltd.. Jyväskylä. Finland)	NA	standing-NA-NA				7.51 (2)																	

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Song et al. 2015	RCT (6/10)	20/55.37 (20.6)	9/11	9/11 (64.09 (26.33))	20/57.1 (7.8)	12/8	12/8 (62.13 (14.77))				(AP1153 BioRescue. RM Ingenierie. Rodez. France)	NA	standing-NA	43.6 (3.8)									43 (6)											
Park et al. 2016	RCT (4/10)	10/60.2 (7.8)	4/6	10/0 (96.46 (44.3))	10/61.1 (8.1)	5/5	10/0 (101.24 (35.5))				BioRescue apparatus (SyCOMORe. France)	Feet angle 30°	standing-60-EO/EC			450.7 (21.7)					545.8 (49.9)				440.9 (24.5)					545.2 (82.8)				
Kim et al. 2014	CS (6/10)	20/63.9 (8.3)	NA	NA (102.54 (12.16))							Bio-Rescue. RM ingenierie. France	The subjects stood with their feet set apart at 30°	standing-30-EO/EC (3)			129.16 (8.50)	17.7 (5.8)				214.05 (5.83)	28.4 (2.7)												
Choi et al. 2015	RCT (8/10)	19/49.11 (11.9)	17/2	12/7 (78.9 (29.5))	18/49.3 (8.2)	14/4	6/12 (79.43 (20.42))				(Good Balance System. Metitur Ltd. Finland)	NA	standing-30-EO/EC (3)				6.79 (3.52)					9.13 (3.66)				7.50 (2.15)					10.42 (5.75)			
Nakamura et al. 1990	CS (4/10)	7/23-74	NA	NA (20)							NA	NA	standing-10							268 (139)														

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Choi et al. 2014	RCT (5/10)	15/62.8 (9)	9/6	9/6 (52 (21.6))	15/61.5 (15.7)	7/8	10/5 (50.4 (22.8))				Wii Balance Board (Nintendo. Kyoto. Japan)	NA	sitting-30-EO				30 (2)														30 (3)			

Cho et al. 2014	RCT (7/10)	15/65.86 (5.7)	7/8	7/8 (59.14 (21.42))	15/63.53 (5.5)	8/7	4/11 (65.71 (26.57))				(Good Balance systemTM. Metitur Ltd. Jyvaskyla. Finland)	NA	standing-30-EO (3)			20.29 (11.00)	8.52 (3.28)								20.82 (10.50)	9.38 (4.91)							CoP VL = BBS (r=-0.01;p=0.9)/TUG (r=0.04; p=0.8)/ gait speed (r=-0.1; p=0.5)/ cadence (r=-0.1; p=0.3); SLS (r=-0.05; p=0.7); DLS (r=0.03; p=0.8); step lenght (r=0.2; p=0.2); stride lenght (r=-0.02; p=0.6)- CoP Surf = BBS (r=-0.2;p=0.2)/TUG (r=0.1;p=0.5)/ gait speed (r=-0.08; p=0.6)/ cadence (r=-0.1; p=0.5); SLS (r=-0.1; p=0.5); DLS (r=0.08; p=0.6); step lenght (r=-0.08; p=0.6); stride lenght (r=-	

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
																																	0.04; p=0.8)	
Song et al. 2015	RCT (5/10)	20/51.37 (4.6)	10/10	9/11 (64.09 (26.3))	20/50.1 (7.8)	12/8	12/8 (62.13 (14.77))				AP1153 Biorescue RM ingénierie Rodez France	NA	NA-NA						42.8 (6.1)									42.1/4.3						
Wu et al. 1996	CO (5/10)	3/59.3 (8.3)	2/1	2/1 (4.3 (2.3))							The Balance Master System (version 2.20)	NA	standing-20-EO (3)	44.5 (10.15)																				
Dumont et al. 2015	CS (4/10)	1 1/66	1/0	NA (208)							Kistler model 9286 BA	NA	standing-45-EO/EC (3)		19.43 (1.9)	1015.6 (206)	8.98 (0.70)			17.41 (5.73)	1080.4 (264.4)	8.89 (0.56)												
Her et al. 2011	RCT (6/10)	12/64.8 (5.2)	7/5	6/6 (>52.14)	13/64.5 (4.8)	5/8	6/7 (>52.14)	13/63.5 (6.4)	8/5	7/6 (>52.14)	Gaitview (AFA-50. alFOOTs. Corp.	NA	standing-NA-EO(3)			33.4 (10.5)									32.8 (11.9)							CoP Surf OE = 31.6 (13)	CoP Surf OE = BBS-K(r=-0.9.p=0.05); FIM (r=-0.8; p=0.05)	

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)			
Shin et al. 2011	RCT (6/10)	11/58.1 (4.6)	5/6	3/8 (>26.07)	10/57.3 (4.4)	3/7	5/5 (>26.07)				PDM mutlifunction Force Measuring plate Zebris Gemany 2004	NA	standing-NA-EO/EC (3)		302 (110)					456 (259)				306 (115)					508 (273)					
Shim et al. 2012	CS (7/10)	26/64.3 (6.4)	18/8	6/20 (68.65 (7.8))	30/65 (6)	19/11	9/21 (70.8 (13.03))				Good Balance Board (Metitur Ltd. Finland)	20cm appart	standing-30-EO				6.5 (2)									8 (2.2)								
Park et al. 2016	CS (5/10)	15/56.7 (7.7)	7/8	15/0 (124.27 (52.57))							BioRescue (SyCoMO Re. France)	Feet spread at a 30° angle.	standing-60-EO/EC			458.1 (28.7)					547.7 (59.7)													

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Choi et al. 2017	RCT (6/10)	12/61.25 (5.5)	7/5	5/7 (59.7 (16.7))	12/62.58 (5.5)	6/6	9/3 (59 (23.8))	12/61.9 (6.08)	8/4	8/4 (61.9 (20.9))	Wii Balance Board	NA	standing-30-EO		16.4 (5.9)	4.9 (2.5)	25.6 (4.2)							17 (2.9)	4.4 (2)	26.5 (4.4)						CoP ML OE =14.8 (2.8) / CoP surf OE = 3.2 (3.2) / CoP Vel OE = 24.9 (4.1)		
Ko et al. 2011	RCT (6/10)	4/59.25 (6)	2/2	4/0 (325.89 (156.4))	8/61.5 (11.4)	5/3	0/8 (247.6 (179.89))				Advanced Mechanical Technology Inc. Watertown. Massachusetts	With shoes	standing-NA-EO	43.32 (5.1)																				
Bae et al. 2015	RCT (6/10)	15/65.08 (9.3)	NA	NA (>13.03)	15/63.5 (5.9)	NA	NA (>13.03)				Gaitview system. AFA-50 (Alfoots Co.. Korea).	Barefoot	standing-30-NA (2)			45.8 (24.4)									52.4 (26.7)									

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Kim et al. 2015	CS (4/10)	1 1/64	0/1	0/1 (82.55)							A BioRescue (AP 1153. France)	NA	standing-NA			47.9 (1.1)																		
Saito et al. 2013	RCT (6/10)	6/68.7 (9.1)	3/3	4/2 (167.29 (216.39))	10/73.2 (8.5)	6/4	7/3 (275.9 (286.35))				Force Sensitive Application version 4.0 (FSA 4.0) (Takano Inc.. Nagano).	To sit on a stool without a back support. The height of the stool was adjusted so that their knee angle was 90° and their feet were flat on the floor during sitting.	sitting-NA-EO	43 (7) : RBD (41(7)); LBD (47(6))									44 (9) / RBD =42 (10) / LBD = 48 (2)											

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Laufer et al. 2002	CO (6/10)	30/71.2 (7)	18/12	12/18 (11.1 (8.8))							Tetrax Ltd. Ramat Gan. Israel	Barefooted at a 30° angle from each other with the heel end of the plates separated by 3 cm.	standing-30-EO	37.5 (8.8)																				
Morioka et al. 2003	RCT (6/10)	14/61.3 (11)	8/6	5/9 (8.7 (2.9))	12/62.6 (13.3)	9/3	6/6 (9.34 (2.65))				stabilometer (GS2000; Anima Co.. Ltd. Tokyo. Japan)	12 cm apart	standing-0.05EO/EC (3)		98 (47)					145 (57)				122 (49)					151 (84)					
Yang et al. 2016	RCT (5/10)	11/51.9 (13)	9/2	4/7 (48.5 (15.6))	11/55.8 (13)	9/2	5/6 (51.7 (15.2))				Wii Balance	Barefoot	standing-NA-EO/EC				25.5 (5.1)					32.02 (8.3)				27.4 (7.2)					31.4 (6.1)			

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Goliwas et al. 2015	RCT (7/10)	8/62.3 (9.4)	5/3	6/3 (229.42 (161.16))	12/67.7 (9.2)	4/8	7/5 (213.8 (146))				Zebris FDM-TDL treadmill with Win FDM-T	Barefoot. with their feet rotated outwards (at a 14°) and by their the heels 4 cm apart and aligned.	standing-30-EO/EC (5)	34.7 (6.7)				36.6 (8.5)					39.9 (9.9)				40.5 (10.5)							
Lee et al. 2017	RCT (6/10)	10/56.4 (9.6)	9/1	6/4 (42.41 (20.65))	8/53.9 (12.7)	4/4	2/6 (32.44 (12.64))				Good Balance System (MetiturLtd. Jyväskylä. Finland;	NA	standing-NA-EO		244.7 (126.4)		8.3 (4.1)							241.7 (153.2)		8 (3.6)								
Bae et al. 2013	CO (5/10)	8/53.4 (5)	5/3	4/4 (537 (129))	8/52.4 (7.6)	4/4	3/5 (543 (126))				BioRescue (RM ingenerie Co. France)	NA	standing-60-EO			241.10 (64.41)									252.70 (49.89)									

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Leblong-Lecharpentier et al. 2015	CO (6/10)	21/60 (13)	16/5	11/10 (204.22 (195.53))							platform Satel® (Satel. Blagnac. France)	NA	standing-52-EO	44 (10)																				
Lee et al. 2015	RCT (6/10)	12/45.9 (12.2)	8/4	NA (>26.07)	12/49.16 (12.8)	8/4	NA (>26.07)				Wiifit balance board	NA	standing-30-EO/EC				21.2 (11.1)					25.2 (12.5)				20.2 (10)					21.9 (11.6)			
Ghomashchi et al. 2014	RCT (6/10)	16/64.7 (7.4)	NA	NA (16.9 (14.2))	15/55.7 (13.9)	NA	NA (34.7 (14.7))				dual force platform (SOT #1. Equi-Test testing system. NeuroCom International Inc.. Clackamas. OR).	A standardized foot placement	standing-30-EO(3)		19.2 (8.4)	110 (50.9)								11.2 (4.5)	135.6 (73.3)	12.4 (6.6)								
In et al. 2016	RCT (5/10)	15/54.9 (10.9)	9/6	07/08 (56.05 (20.42))							NA	Barefoot and with their heels separated by a distance of 8.4 cm	standing-30-EO/EC (3)		362 (89)		18 (5)			436 (128)		22 (6)												

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Tsaklis et al. 2012	CS (7/10)	9/66 (5.4)	9/0	5/4 (344.14 (213.78))							EPS; Foot Checker 3.2; Comex S.A. / LorAn Engineering Srl. Castel Maggiore. Bologna. Italy)	With their socks and were instructed to stand with their feet in a comfortable position.	standing-15-EO	44.3		106	3.5																	
Dickstein et al. 1989	CS (4/10)	10/61 (12)	5/5	3/7 (13 (3.4))							digital bathroom scales.	NA	standing-20	32 (14)																				

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Corriveau et al. 2004	CS (8/10)	15/71.8 (6.9)	6/9	8/7 (70.26 (64.3))							2 adjacent force platforms	Own shoes	standing-120-EO/EC (4)		1.2 (0.6)					1.4 (0.6)													CoP ML OE= BBS(r=-0.53.p=0.002). Tinetti (r=-0.57.p=0.001). CTSIB (r=0.41. p=0.01). TUG (r=0.69. p=0.0001). REACT II (r=0.44. p=0.01). Fugl-Meyer (r=-0;51.p=0.05). vibration (NS). filament (NS). strenght :abductor (r=0.04). hip flexor (r=0.03). knee extensor (r=-0.1) plantar flexor (r=-0.1) dorsi flexor (r=-0.6) (NS)	

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Carette et al. 2003	CS (5/10)	18/64 (25)	15/3	NA (<13.03)							stabilographic force-plate Dune	Barefoot	standing-51.2-EO/EC		4.36 (9.3)	230.84 (164.87)	11.24 (5.09)			6.59 (10.8)	561.63 (581)	19.22 (10.49)												
Park et al. 2017	CS (7/10)	18/54.3 (8.5)	14/4	10/8 (64.7 (41.2))							Good Balance System Ver. 3.06 (Metitur Oy. Jyvaskyla. Finland).	20cm appart	standing-30-EO				102.3 (34.1)																	
Hung et al. 2016	RCT (5/10)	12/52.75 (46.7-62.9)	8/4	4/8 (76.04 (46.36-95.29))	11/55.2 (43.5-65.5)	8/3	7/4 (80.8 (45.49-141.35))				The Tetrax posturography system	NA	standing-30-EO/EC	46.17 (36.6-49.6)									46.15 (40.9-50.7)											
Chang et al. 2014	CS (6/10)	22/64.7 (10.1)	16/6	NA (11.29 (9.5))							weight scales. one under each leg	NA	inclined plane 80° - 60	43.8 (15.8)																				

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)			
Mansfield et al. 2015	CS (9/10)	359/67.6 (66.1-69)	209/150	123/182/51/3 (2.87 (2.5-3.22))							OR6-7-2000. Advanced Medical Technology. Inc.	Usual footwear (flat-heeled closed-toe shoes) and stand with one foot on each force plate in a standard position: feet oriented at 14° with heel centers 17 cm apart. 12	standing-20/30-EO/EC	46.2 (45-47.5)	4.9 (4.5-5.3)			46.4 (45.2-47.6)		6.3 (5.6-6.9)														
Kunkel et al. 2013	RCT (5/10)	7/64 (15.5)	4/3	2/5 (acute)	7/71.1 (18.8)	4/3	2; 2; 2 (acute)	7/70 (10.6)	4/3	2; 4; 1 (acute)	Balance Performance Monitor (BPM Data Print software. Version 5.3)	NA	standing-5	43.3 (11.1)									46.2 (21.3)									WBA OE =49.2 (8.7)		

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Wei et al. 2017	CS (7/10)	112/69.6 (10.3)	60/52	55/57 (4.34)							Stabilo-platform (Ultralfex. Infotronic. the Netherlands)	Without footwear or ankle foot orthoses.	standing-20-EO(3)		3.43 (1.62)	37.62 (32.51)																	CoP ML OE = cadence (r=-0.34.p<0.01). gait velocity r=-0.02 (NS). CoP AP OE (r=0.34. p<0.01). CoP surf OE (r=0.82. p<0.01). FIM (r=-0.33; p<0.01). MAS (r=0.26. p<0.01)- CoP surf OE = cadence (r=-0.32.p<0.01). gait velocity r=-0.08 (NS). CoP AP OE (r=0.8.p<0.01).	

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Chen et al. 2010	CO (6/10)	10/57.5 (3.3)	10/0	4/6 (9.4 (0.48))							NA	The foot spacing matching their shoulder width.	standing-10-EO	37.9 (1.4)																				
Shin et al. 2017	CO (7/10)	9/64.7 (8.1)	43 19 5	NA (385.8 (93.8))							BIORescue (RM Ingenierie. Rodes. France).	NA	standing-NA-NA				6 (2)																	

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Mückel et al. 2014	RCT (7/10)	10/71.6(9)	6/4	5/5 (8(1))	10/72.7(4)	5/5	5/5 (7(2))				Sensor mat	back unsupported and hands in lap, hip and knee joints flexed 90 degrees and feet placed on the ground; fossa of knees was set on the edge of the bench.	sitting -EO																					
Rahimzadeh Khiabani et al. 2017	CS (7/10)	12/74.3 (3.4)	8/4	7/5 (229 (161))	15/61.8 (3)	11/4	8/7 (500.571 (109.5))				AMTI force plate	NA	standing-60-EO/EC (2)		3.1 (0.3)		9.1 (1.6)			3.4 (0.4)		13.7 (1.6)		3.1 (0.4)		6.1 (2)			3.5 (0.4)		7.7 (2)			

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)			
Ishii et al. 2010	CS (6/10)	22/69.1 (11.3)	14/8	22/0 (2.3 (1.08))	27/68.9 (8.8)	17/10	0/27 (2.25 (1.01))				Tekscan Inc.. Boston. MA. United States	NA	standing-10/30/60-EO	10s =51.2 (5.4); 30s= 50.4 (3.1); 60s=51.6 (5)									10s=46.3 (3.5) / 30s=47.2 (4.5) / 60s=46.9 (4.9)										WBA OE = unilateral spatial neglect (line bisection and line crossing.)(r=0.27; p=0.4) and anosognosia (r=-0.15; p=0.63)	
Lee et al. 2015	CS (5/10)	21/72.2 (7.8)	11/10	11/10 (476.67 (256.8))							Good Balance. Metitur Ltd. Finland	NA	standing-30-EO/EC (3)				8.9 (3.5)					13.8 (5.4)												
Trappier et al. 2006	CS (10/10)	8/49.8 (17.8)	4/4	2/6 (>365)							AMTI	Barefoot	standing-30-EO/EC	47.6		13 (5.9)					38 (24)													

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Bower et al. 2014	CS (7/10)	30/68.3 (15.1)	21/9	19/11 (58.6)							Wii Balance Board	NA	standing-30-EO/EC	46.3 (8.5)			5 (1.9)					7.4 (4.4)											WBA OE = 10m (r=0.1 NS). TUG (r=-0.13 NS); Step test (r=0.14 NS); functional reach (r=-0.13 NS)- CoP Velocity OE = 10m (r=-0.4 p<0.05). TUG (r=0.4 p<0.05); Step test (r=-0.41 p<0.01); functional reach (r=-0.61 p<0.05)	
Clark et al. 2015	CS (8/10)	30/68 (15)	21/9	19/11 (91.25 (82.55)							Nintendo Wii Balance Boards	17 cm between heels and toe-out angle of 14°	standing-30-EO	46.3 (8.5)								20.6 (10.5)												
Furnari et al. 2014	RCT (6/10)	20/68 (3)	10/10	NA (NA)							NA	NA	NA-NA																					

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Martins et al. 2011	CS (5/10)	20/54.2 (3.28)	13/7	9/11 12 4.07 (52.4)							(Plenna®)	barefoot. with their feet free and aligned on the scales with each foot about 20 cm	standing-NA-EO	32.6 (13.4)																				

Peters et al. 2014	CS (10/10)	10/58.1 (15.1)	5/5	6/4 (3.7 (1.6))							2 adjacent AccuGait force platforms (AMTI. Watertown. MA)	18 cm apart	standing-5-EO (10)	32.2 (12.1)																			WBA OE = BBS(r=0.63.p<0.05). Chedoke McMaster Stroke Assessment (r=0.85 p<0.05). Clinical Outcome Variables Scale (r=0.92. p<0.05). FIM (r=0.33 NS). CoP VeL r=−0.72; p < 0.05).- CoP velocity OE = BBS(r=-0.29 NS). Chedoke McMaster Stroke Assessment (r=0.63 NS) Clinical Outcome Variables Scale (r=-0.65 NS). FIM (r=-0.33 NS)	
Hugues et al. 2015	CS (8/10)	6/55.6 (15.7)	6/0	6/0 (194.6 (141.6))							(Techno concept)	NA	standing-30-EO/EC (2)	30.36 (10.7)	52.94 (30.9)	764.91 (696.76)		30.94 (10.21)		51.10 (29.30)														

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)			
Bohannon et al. 1985	CS (4/10)	25/55 (14-87)		12/13 (37 (1-417))							Norelco® digitalbathroom scales (model HS-10)	NA	standing-30-EO	26.9 (40.7)																				
Liuzzo et al. 2017	CS (6/10)	41/67 (13)	28/13	15/26 (273.75 (230.98))							Nintendo Wii Fit balance board	NA	standing-NA-EO (2)	47.7 (7.6)																				
Birnbaum et al. 2015	CS (7/10)	10/66.5 (59-75)	4/6	07/03 (with lateropulsion) (168 (140-210))							Nintendo Wii Balance Board	NA	sitting/standing-NA-EO/EC (2)		sitting (n=9)=7.5 / standing (n=6)=40					sitting (n=7):7.2 / standing (n=3) : 31.6														
Yoshida et al. 1983	CS (3/10)	10/60.7 (40-75)	8/2	8/2 (NA)							Kyowa Dengyo'sfroce plate.	NA	standing-30-EO		32.8 (19.5)	967	1000																	

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)			
Patterson et al. 2013	CS (8/10)	75/70.2 (10.5)	44/31	30/45 (140.1 (130.9))							(heels 17 cm apart. 14 between the long axes of the feet)	NA	standing-30-EO	47.9 (9.3)																				
Roerdink et al. 2009	CS (8/10)	33/61.2 (13)	NA	23/10 (9.8 (5.2))							dual force platform	Barefoot foot separate 8.4cm. 9° angle	standing-30-EO/EC (2)		17.1	591				19	1024													
Goldie et al. 1996	CS (7/10)	20/50.7 (18.5)	14/6	9/11 (10 (6-15))							Kistler force platform system	flat-heeled lace-up or sturdy shoes	standing-5-EO	42.2 (10.2)	80																			
Hoang et al. 2012	CS (7/10)	32/64.6 (11.2)	21/11	NA (10 (6-15))							SATEL. Blagnac. France	Barefoot and with shoes	standing-5-EO/EC			Barefoot =481.7 (324.9) / Shoes =386 (279.2)					Barefoot =1.314 (1.161) / Shoes = 994.1 (801.8)													

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Singer et al. 2015	Retrospective Study (10/10)	29/59.8 (13)	20/9	16/13 (177)	56/66.2 (13.1)	29/27	29/27 (178.5)				Berthec Corp Colombus. OH . USA	17 cm between / 14 degrees from median plane	standing-30-EO																					
Park et al. 2011	RCT (5/10)	23/56.6 (3.9)	13/10	13/10/ (>26)	23/54.56 (8.2)	12/11	12/11 (>26)				Good Balance system	NA	standing-30-EO/EC (3)				14.3 (3.7)					12.5 (5.3)				13.8 (5.5)					12.5 (5.5)			
Alfieri et al. 2016	CS (8/10)	18/68.2 (6.3)	12/6	8/10 (147.3 (107.3))							(AMTI Inc. Watertown. MA)	Bipedal position	standing-60-EO/EC (3)		RBD =26.2 (16.3) / LBD=23.5 (12.6)					RBD =25.3 (14.6) / LBD =27.8 (12.9)														
Portnoy et al. 2017	CS (7/10)	21/61.4 (10.1)	13/8	12/9 (73.8 (44.3))							M-FLEX. Vista Medical Europe B.V.. Maasbree. The Netherlands)	NA	standing-10-EO/EC		10 (19)		43 (58)			12 (20)		10 (11)												

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)			
Garland et al. 1997	CO (6/10)	12/62.75 (20.1)	9/3	7/5 (464 (250.2)							(OR&5-l)	NA	standing-20-EO (5)				6.3 (1.4)																	
Manor et al. 2009	CS (6/10)	15/69 (4)	10/5	NA (375.4 (52.14))							(Kistler Instrument Corp.. Amherst. NY)	15 cm apart.	standing-180-EO/EC		29.2 (12.7)		12.1 (3.8)			42.9 (19.9)		37.3 (9.9)												
Van Nes et al. 2008	CS (8/10)	16/62.7 (7.6)	9/7	8/8 (5.6 (1.7))							AMTI force platform (Model: OR6-7MA-1000)	Barefoot and the hips and knees were in 90° flexion and the ankle joints in a neutral position	sitting-30-EO/EC (2)		0.27 (0.06)	1.71 (0.57)				0.3 (0.07)		1.73 (0.57)											CoP ML OE =BBS (r=-0.66; p<0.01) no correlation age. hemineglect. motricity (data not available)	
Genthon et al. 2008	CS (5/10)	45/59 (13.7)	12/33	19/26 (147.1))							PF02. Equi+	Barefoot; heels 9 cm apart. toe out at 30°	standing-32-EO (4)	37 (11)	25.6 (22)																		WBA OE = CoP ML (r=0.97. p<0.001)	
Elleuch et al. 2016	RCT (7/10)	5/59.4 (13.5)	3/2	3/2 (<26.07)	4/61.5 (11.6)	2/2	0/4 (<26.07)				Satel France	NA	standing-51.2-EO/EC (2)			458.88 (324.98)					792.06 (139.38)				482.83 (237.37)					513.84 (151.2)				

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Dickstein et al. 1993	CS (4/10)	27/72.95 (4)		9/18 (2-56)							Chattecx balance system	NA	standing-10-EO/EC (2)		19.64 (15.4)					18.58	16.14													
Hung et al. 2014	RCT (7/10)	13/55.38 (9.9)	8/5	11/2 (91.25)	15/53.4 (10.03)	10/5	8/7 (69.2 (34.76))				Tetrax Balance System.	NA	standing-32-EO/EC	42.31 (7.9)				43.58 (10.48)					40.81 (10.12)				41.1 (9.8)							
Sheikh et al. 2016	RCT (8/10)	14/56.85 (12.2)	9/5	6/8 (154.86 (65.1))	14/53.42 (12.06)	10/4	7/7 (169.46 (90.2))				two rectangular force platforms (Bertec-MBM 4060)	Feet oriented at 14 degrees with 0.17 m between the heels	standing-20-EO(3)	34.57 (4.2)									36.07 (3.3)											
Kusoffsky et al. 2011	CS (8/10)	8/59 (48-67)		4/4 (78 (78))							2 AMTI force plates a	40 mm apart	standing-5-EO (2)	43.9 (7.6)																				

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Garland et al. 2003	CS (10/10)	27/64.2 (13.7)	17/10	14/13 (5.31 (2.6))							force platform (OR6-5-1a)	18 cm apart	standing-20-EO (5)				8.4 (2.4)																COP velocity with Chedoke-McMaster Stroke Assessment Impairment Inventory. =>leg recovery (r=-0.4) et postural recovery (r=-0.41)	
De Haart et al. 2004	CS (10/10)	37/61.6 (12.9)	20/17	24/13 (10 (5.4))							force platformconsisting of 2 separate aluminum plates.	Barefoot with heels 8.4cm apart and each foot placed with toes outward at a 9º angle from the sagittal midline.	standing-30-EO/EC (4)				18.3					25.4												

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Hyndman et al. 2009	CO (5/10)	76/67.11 (11.3)	56/20	39/36/1 (36.3 (6.4))							Kistler force plate (model 9281; Kistler. Basel)	Preferred stance (PS) or feet together (FT)	standing-15-EO/EC (3)	Not fallers = PS OE 13.8(22.2), FT OE 53.5(61.2), EC 8.3(14.6); Fallers = PS OE 20.8(32.5), FT OE 78.6(106), EC 12.7																				
Hendrickson et al. 2014	CS (10/10)	94/66 (14)	53/41	59/35 (7.7)							(Advanced Medical Technology Inc.. Watertown. MA. USA)	feet oriented at 14° from the sagittal plane with 0.17 m of separation between the heels	standing-30-EO	47.3 (8)																				
Sawacha et al. 2013	CS (6/10)	10/61.6 (8.5)	NA	NA (391.07 (464.07))							1 Bertec force plate (FP4060-10)	30 degrees angle between the right and left toes	standing - 60-EO/EC		186.4 (43.4)	312.26 (168.5)	4.7 (1.1)			215.8 (76.4)	309.3 (169.2)	5.4 (1.9)												

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Cho et al. 2014	CS (7/10)	31/64.25	20/11	6/25 (54.31 (10.8))							(Good Balance system. Metitur. Oy. Jyvaskyla. Finland)	NA	standing-30-EO/EC (3)			33 (24)	10.8 (3.4)				58.6 (64.1)	17 (8.6)											CoP surf OE = TUG (r=-0.21 NS) and BBS (r=0.2 NS) CoP surf EC = TUG (r=-0.24 NS) and BBS (r=0.07 NS).CoP velocity OE = TUG (r=-0.01 NS) and BBS (r=-0.1 NS) CoP velocity EC = TUG (r=-0.07 NS) and BBS (r=-0.11 NS)	

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Dettmann et al. 1987	CS (4/10)	15/64 (46-87)	15/0	7/8 (104.8 - 573.5)							NA	NA	standing-30-EO(2)	36.1 (14.6)																			WBA OE =Barthel score (r=0.6 p=0.05) / Fugel Meyer (r=0.62 p=0.05) / stride lengh (r=0.56 p=0.05) / paretic side step length (r = 0.56. p=0.05) and swing ratio (r =0.67. (p < 0.05).	
Schinkel-Ivy et al. 2016	CS (9/10)	84/68.6 (11.6)	32/52	34/42/8 (2.64 (2.8))	124/65.3 (13.6)	81/43	49/66/6/3 (2.4 (2.27))				two force plates	Standardized position	standing-30-EO/EC		5.1 (4.2-6)					7.54				4.4					5.41					

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Pyöriä et al. 2004	CS (8/10)	26/65 (10)	19/7	19/7 (1-3)	28/60 (8)	17/11	9/17 (NA (26-677.8))				Good Balance force platform	20cm appart	standing-30-EO/EC				6.8 (4.1)					9.5 (6.4)				5.8 (4)					8.6 (6.2)		CoP Velocity G1 / FSB without mouvement (OE r =-0.63; CE r=-0.53); FSB with mouvement (OE r=-0.7; CE r=-0.68).CoP Velocity G2 / FSB without mouvement (OE r =-0.52; CE r=-0.54); FSB with mouvement (OE r=-0.66; CE r=-0.76)	

Lopes et al. 2015	CS (8/10)	21/55.3 (5.9)	15/6	12/9 (141.65 (76.9))							AMTI OR6-7 version 2.0/2004. installed at the Motion Analysis Laboratory).	Preferred stance position	standing-50-EO		RBD =-15 (5) / LBD= -17 (12)		RBD= -16 (8) / LBD= -19 (11)																CoP velocity OE RBD= Step length (r=-0.6 p<0.05) Stride length (r=-0.72 p<0.05). Gait velocity (r=-0.7 p<0.05). Stance phase (r=0.27 NS) . Swing phase (r=-0.27 NS). Double stance onset (r=0.53 NS). Single stance (r=-0.76 p<0.05). Cadence (r=-0.45 NS) . CoP velocity OE LBD= Step length (r=0.35 NS) Stride length (r=0.41 NS). Gait velocity (NS). Stance phase (r=-0.19 NS) . Swing phase (r=-0.01 NS). Double stance	CoP surf OE RBD = Step length (r=-0.55 NS) Stride length (r=-0.79 p<0.05). Gait velocity (r=-0.72 p<0.05). Stance phase (r=0.27 NS) . Swing phase (r=-0.27 NS). Double stance onset (r=0.67). Single stance (r=-0.74)<0.05). Cadence (r=0.38 NS) . CoP surf OE LBD = Step length (r=0.49 NS)

																																	onset (r=0.61 NS). Single stance (r=-0.47 NS). Cadence (r=-0.62 NS)	Stride length (r=0.71 p<0.05). Gait velocity (r=0.18 NS). Stance phase (r= 0.28 NS) . Swing phase (r=-0.29 NS). Double stance onset (r=0.59 NS). Single stance (r=-0.41 NS). Cadence (r=0.49 NS) . CoP velocity OE RBD = FIM (r= -0.19 NS). motor FIM (r=-0.28 NS) CoP surf OE RBD = FIM

		Population 1			**Population 2**			**Population 3**			**Characteristics**			**Population 1**									**Population 2**									**Population 3**	**Correlation**	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
																																		(r=-0.5 NS). motor FIM (r =-0.59 p<0.05); CoP velocity OE LBD = FIM (r=-0.04 NS). motor FIM (r=0.12 NS) CoP surf OE LBD = FIM (r=0.52 NS). motor FIM (r=0.62 NS);
Gray et al. 2014	CS (5/10)	20/60.4 (13.4)	13/7	NA (10.6 (3.5))							two adjacent AMTI OR6-6-1000 force platforms	Barefoot	standing-10-NA (5)		1 (0)	3 (4)	62 (26)																	

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)			
Ha et al. 2014	CS (6/10)	60/63.1 (6.3)	40/20	16/44 (71.26 (12.16))							(Good Balance system. Metitur Oy. Jyvaskyla. Finland)	Their legs spread at shoulder width	standing-30-EO(3)				13.1 (4.5)																	
de Araujo-Barbosa et al. 2015	CS (5/10)	20/59.4 (3)	12/8	NA (180.11 (54.09))							two parallel calibrated scales with a digital display (Plenna)	Barefoot. with their feet free and aligned on the scales with each foot about 20 cm away from the other.	standing-NA-EO	47.9 (7.1)																				
Malezic et al. 1994	CS (3/10)	11/39-64	8/3	6/5 (12 (18.1))							two force plate	feet 30° and appart 30 cm	standing-NA-EO (2)	35.1 (8.7)																				
Leplaideur et al. 2016	CS (10/10)	15/62.1 (8.5)	11/4	15/0 (11.29 (6.9))	16/60.9 (12)	14/2	0/16 (15.64 (6.9))				SATEL®. France	NA	standing-25-EO/EC (2)		21.9 (13)	642 (475)				21.6 (14)	1244 (956)			-21.1 (10)	901 (832)				-18.5(6)	1393 (1169)				

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Gray et al. 2014	CO (6/10)	13/66.7 (11.8)	10/3	4/9 (143.6 (140.7))							AMTI (AMTI. Newton. and MA)	One force platform (FP) was placed under the chair and one FP was placed under each foot. wearing a pair of comfortable shoes.	sitting -30- EO	45.8 (5)	74 (39)																			

Lei et al. 2005	CS (8/10)	19/40 (7)	14/5	14/5 (9.1 (3.9))							G-5500 Japan Anima Company	feet closed shoes removed	standing-60-EO/EC		3.2 (16)	49.8 (25.5)	21 (7.4)			2.1 (19.7)	125.2 (187.5)	36.4 (16.9)											CoP ML OE= BBS (r=-0.13 NS). TUG (r= 0.36 NS). FIM (r= -0.14 NS). Age (r= -0.23 NS)/ CoP ML CE = BBS (r=-0.34 NS). TUG (r=0.5.p =0.05). Age (r= -0.19 NS). FIM (r=-0.28 NS). CoP surf OE= BBS (r=-0.47.p= 0.05). TUG (r=0.33 NS). FIM (r=-0.29 NS). Age (r=-0.2 NS)/ CoP surf CE = BBS (r=-0.7.p:=0.05). TUG (r=0.58. p:0.05). FIM (r=-0.29 NS). Age (r=-0.05 NS)	

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Ferreira et al. 2016	RCT (6/10)	12/59.2 (10.4)	11/1	6/6 (203.3 (78.21))	8/60.3 (13.3)	5/3	6/2 (161.6 (57.3))				Kistler. model 9286 BA	Barefoot /with habitual shoes/ with habitual shoes and insoles (postural or placebo).	standing-30-EO/EC		18.07 (4.3)					22.4 (9.6)				10.52 (5.19)					10.42 (7.01)					
Nardone et al. 2009	CS (7/10)	15/68.1 (7.6)	10/5	5/10 (309.38 (306.7))							(Medicapteurs. France)	Feet were placed at an angle of 30°. Distance between the heels was 2 cm.	standing-51-EO/EC (2)		16.7 (10.9)	364.3 (279.1)				12.7 (12.5)	1091.8 (364.3)													
Nardone et al. 2001	CS (4/10)	14/56.6 (13.5)		6/8 (36.6 (41.7))							(Kistler model 9281 B).	Barefoot Feet were parallel. spaced 10 cm apart.	standing-52-EO/EC			891.2 (461)					2107.8 (1167.1)													
Milczarek et al. 1993	CO (6/10)	14/59.9 (12.7)	8/6	4/10 (23.1 (24.4))							Kistler force platform	NA	standing-10-EO (3)		154 (135)																			

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Laufer et al. 2003	CS (10/10)	19/73 (6)	11/8	19/0	31/73.3 (7)	19/12	0/31 (3.71 (0.5))				Tetrax Ltd.. Ramat Gan. Israel	Barefoot Feet at a 30° angle to each other. with 15 cm between the heels.	standing-10-EO/EC (1)	41.6 (12.1)				47.7 (7.8)					44.4 (13.1)				46.7 (10.3)						WBA OE = neglect (r =0.53; p =0.01)/hypoesthesia (r=0.54; p=0.01)/ motor weakness (r=0.47; p=0.03)/ Bell test (r=0.31; p=0.15)/ line bisection (r=0.21; p=0.35) / PASS (r=0.51; p=0.035) / gait independence (r=0.70; p=0.001)/ SCP (r=0.36; p=0.01) /LBA (r=0.52; p=0.02) / SVV (r =0.41; p =0.074)	

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Stevenson et al. 1996	CS (4/10)	24/68.8 (7.7)	18/6	13/11 (438 (321.2))							NA	Heels parallel and approximately l0cm apart. feet rotated to comfort	standing-20-EO(5)				8.5 (3.6)																	
Winstein et al. 1989	CS (6/10)	21/51.9 (3.4)	16/5	6/15 (7.7 (1))	21/53.8 (3.2)	10/11	09/12 (6.3 (0.7))				NA	2,5 cm apart	standing-30-EO	30	7.1 (0.8)		22.4 (3.5)						28	5.9 (0.7)		18.9 (2.9)								
Paillex et al. 2003	CS (6/10)	6/53.3 (3)	3/3	2/4 (152.1 (129.9))							NA	Barefoot. appart 8cm angle 30°	standing-64-EO/EC (5)		0.6 (0.3)					0.8 (0.2)														
Le Liepvre et al. 2012	CS (5/10)	15/62		5/10 (<26.07)							double force-plate	Standart position	standing-52-EO	36.9 (13.9)		303.9 (183.8)																		

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Caldwell et al. 1986	CS (4/10)	10/57.12 (47-70)	NA	NA (>26)							(Timex Healthcheck Digital Scale. Timex Medical Products Corp.. Waterbury. Connecticut 06720).	NA	standing-NA-EO	35.8 (10.7)																				
Leroux et al. 2006	CS (8/10)	10/63.9 (10.3)	5/5	3/7 (516.24 (578.78))							Matscan system (Tekscan. Inc.)	Double legged stance	standing-20-EO	42.5 (7.5)	9.4 (4.4)																			
Saggini et al. 2011	CS (8/10)	20/54	9/11	NA (chronic stage)							NA	Heels spaced about 1 cm and alignment plantar stance at 30°	standing-51.2-EO/EC			240.9 (97.78)					262.4 (119.82)													

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Lim et al. 2012	RCT (6/10)	10/55.21 (3.6)	6/4	6/4 (76.86 (8.6))	11/56.3 (1.9)	7/4	7/4 (63.17 (9))				Balance performance monitor (SMS Health care Inc. England)	10cm distance apart	standing-30-EO (3)			1138.6 (705.8)	148.3 (70)								967.5 (738.6)	160.7 (110.4)								
Yasuda et al. 2017	RCT (5/10)	9/63.6 (12.6)	9/0	4/5 (177.14 (253.57))	8/66.5 (11)	4/4	6/2 (148.14 (174.28))				Balance Mat; SanwaKako. Kyoto. Japan ;	Barefoot	standing-30-EO (3)		2.8 (2.1)		1 (1.5)							0.1 (0.9)		1.5 (4.7)								
Song et al. 2015	RCT (5/10)	20/51.4 (40.6)	10/10	9/11	20/50.8 (5.5)	11/9	11/9 (58.22 (35.6))				(AP1153 BioRescue. RM Ingenierie. Rodez. France)	NA	standing-NA-EO	45.9 (1.2)									41.3 (2)											
Kim et al. 2017	CO (5/10)	11/57.08 (7.2)	10/1	7/4 (64.3 (26.5))	10/52.92 (8.2)	9/1	7/3 (169.11 (138.7))				BioRescue. Rodez. France	NA	standing-30-EO	38.48 11.73)									36.55 (11.08)											
Song et al. 2015	RCT (5/10)	10/52.4 (4.6)	4/6	2/8 (46.9 (26.5))	10/50.8 (5.5)	6/4	4/6 (58.22 (35.6))	10/50.8 (5.5)	7/3	3/7 (58.22 (35.6))	(AP1153 Biorescue. France)	NA	standing-NA	45.9 (1.2)									41.3 (2)									WBA OE=42.8 (1.5)		

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)			
Jung et al. 2014	RCT (5/10)	15/57.2 (3.9)	8/7	6/9 (58.6 (21.1))	15/55.6 (4.3)	8/7	6/9 (59.9 (17.3))				Good balance system	NA	standing-30-EC									10.4 (6.3)									9.9 (4.5)			
Gim et al. 2015	RCT (5/10)	11/58.7 (15.1)	11/0	8/3 (110.3 (53.8))	11/62.6 (10.7)	11/0	10/1 (97.3 (69.9))	11/57.5 (10.1)	11/0	8/3 (132 (71.6))	BT4 force platform (Hur Laps Oy. Tampere. Finland)	NA	standing-60-EO/EC (2)		22.8 (16.3)	521.3 (397.6)				22.6 (13.9)	528.1 (497.4)			21.0 (14.8)	602.5 (594.1)				21.3 (21.8)	580.4 (510.3)		CoP ML OE = 20.8 (20.8) / CoP Surf OE = 570 (346.5) / CoP ML EC = 21.3(21.8) / CoP Surf EC = 758.1 (635.9)		

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/ delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Bonan et al. 2016	CO (5/10)	35/54.1 (10.6)	NA	17/18 (13.03 (5.6))							Technoconcept	NA	standing-50-EO		RBD =30.2 (29.9) / LBD= 13.8 (14.7)																			
Rodriguez et al. 2002	RCT (6/10)	9/NA (36-78)	3/6	NA (2-8)							NA	Without shoes	standing-300-EO	39.9 (8)																				
Ju et al. 2014	CO (6/10)	20/57.6 (11.1)	18/2	NA (122.01 (77.7))							Two force plates (AMTI. Newton. MA. USA)	NA	standing-30-EO				81 (5)																	
Yoo et al. 2006	CO (6/10)	3/60.3 (12.6)	3/0	0/3 (52.14 (41.7))							Limloader (Model LLD-2000. SAKAI Medical Co.. Tokyo. Japan)	NA	standing-30-EO(3)	26.3 (5)	24.6 (13)																			
Peurala et al. 2005	RCT (6/10)	15/53.3 (8.9)	13/2	9/6 (135.57 (125.14))	15/51.2 (7.9)	13/2	8/7 (125.14 (135.57))	15/52.3 (6.8)	11/4	5/10 (208.57 (302.42))	a force plate	With their feet apart with patients' shoes	standing-40-NA				11.5 (17.1)									8.7 (5.3)								

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Mehdizadeh et al. 2015	CO (6/10)	19/51.5 (12.2)	9/10	11/8 (144.8 (88))							Bertec Corporation. Columbus. OH. USA	Barefoot	standing-35-EO/EC (3)			32.8 (27.1)	10.7 (2.2)				39.3 (32.7)	11.6 (3.6)												
Negahban et al. 2017	CO (6/10)	22/55.8 (7.9)	15/7	NA (133.9 (183.3))							dual plate Bertec 4060-10. Columbus. Ohio. USA)	Barefoot	standing-60-EO		4 (2)	35.4 (39.3)	24.2 (5.7)																	
Park et al. 2014	RCT (6/10)	15/71.2 (3.4)	12/3	10/5 (80.2 (10.4))	14/71.14 (3.8)	8/6	8/7 (80.6 (7.56))				Good Balance (Metitur Ltd. Finland. 2008)	NA	standing-30-EO/EC (3)				24.99 (7.17)					29.57 (10.53)				22.36 (10.01)					30.02 (18.44)			
Lee et al. 2011	RCT (5/10)	15/55.6 (9.4)	8/7	6/9 (NA)	15/55.06 (10.08)	8/7	6/9				Good Balance system	NA	standing-30-EO/EC (3)		8.39 (5.4)					10.25 (6.27)				7.89 (3.49)					11.91 (5.7)					
Baek et al. 2014	RCT (6/10)	15/56.5 (7.5)	8/7	9/6 (NA)	15/55.1 (6.1)	7/8	10/5				biofeedback. AP1153; BioRescue. France	NA	standing-60-EO				0.7 (0.3)									0.7 (0.3)								
Lim et al. 2016	RCT (6/10)	10/66.8 (5.7)	5/5	6/4 (667.4 (297))	9/61.11 (6.6)	5/4	5/4 (688.28 (328))				FIT. 1821 Bertec Corp.. USA	With shoes	standing-60-EO		10.85		83.94 (42.1)							11.72 (5.4)		84.24 (45)								

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Sohn et al.2015	CO (6/10)	27/57 (12)	17/10	14/13 (9.2 (8.2))							Biodex Medical Systems Inc.. Shirley. NY. USA	NA	standing-NA-EO	No sling = 25.2 / Bobath sling = 16.7(68.4) / standra sling =28.8(57.7)																				
Seo et al. 2014	RCT (5/10)	15/59.3 (3.2)	8/7	7/8 (162 (27.8))	15/61.7 (3.6)	10/5	6/9 (123.4 (23))				AP1153 BioRescue. France	Angle of 30°	standing-60-EO	41 (6.1)									51.6 (14.4)											
Lee et al. 2016	CS (5/10)	25/62.8 (8.1)	9/16	11/14 (128.6 (64.3))							Wii Balance Board (WBB) (Nintendo. Kyoto. Japan)	NA	standing-NA-EO (3)				33 (07)																	
Hong et al. 2013	CO (5/10)	25/52.9 (18.5)	19/6	11/14 (43.5 (5.4-515.2))							BioRescue (RM Ingenierie. Rodez. France).	Barefoot and heels 9 cm apart with 30°	standing-60-EO	RBD =49.8 (14.7); LBD=51.4 (15.3)		RBD=334.4 (573.6) / LBD=397.2 (755.1)	RBD=7 (7) / LBD=6 (4)																	

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Lee et al. 2013	RCT (5/10)	12/60.6 (8.8)	4/8	10/2 (>26.07)	10/63.7 (4.7)	2/8	6/4 (>26.07)				Good Balance System (Metitur Ltd. Finland. 2008)	patients sitting on the force plate with their feet approximately shoulder width apart	sitting-30-EO/EC (3)				3 (1.2)					3.45 (1.6)				3.24 (1.37)					3.59 (2.38)			
Jang et al. 2015	CO (6/10)	16/65.2 (9.3)	5/11	7/9 (43.19 (8.25))							NA	NA	standing-NA-EO(2)	without AFO 75.8 (13)																				

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Krukowska et al. 2016	RCT (6/10)	72/53.7 (20-69)	32/40	38/34 (>26.07)							ALFA balance platform	Barefoot on the platform in the free position	standing-30-EO			population 1 = 169.8 (45.6); population 2 =218.53 (42.2); population 3= 128.46 (31.21); population 4= 264.34 (48.51)																		
Lewek et al. 2014	CS (6/10)	39/56.7 (10.5)	23/16	17/22 (234.6 (260))							Bertec Corp. Columbus. OH	Feet at shoulder width	standing-60						45 (8)															

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Parsons et al. 2016	CS (10/10)	52/64.2 (13.6)	35/17	26/26 (2.44 (2.4))							Advanced Medical Technology Inc.. Watertown. MA. USA	0.17 m between the mid-heels and a foot angle of 14 degrees to the mid-sagittal plane.	standing-30-EO/EC	45.9 (9.2)	4.5 (2.9)					6.8 (6.4)														
Naghdi et al. 2013	CS (9/10)	18/56 (8.9)	13/5	10/8 (143.3 (122.9))							(Kistler Instrumente AG. Eulachstrasse 22. 8408 Winterthur. Switzerland)	Barefoot on the force platform with heels 9 cm apart and toes at 30° out and arms along the body sides.	standing-20-EO/EC (3)		3.3 (1.2)	41.8 (57.3)	30.3 (5.1)			3.9 (1.7)	45.4 (28)	33.9 (4.8)												
Mansfield et al. 2011	CR (5/10)	1 1/68	1/0	0/1 (7.4)							NA	NA	standing-1-EO	75																				

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Mitsutake et al. 2017	RCT (6/10)	14/70.6 (7.4)	10/4	7/7 (2.6)	35/69.6 (9)	23/12	14/21 (4.7)				Anima G-620. Tokyo. Japan	Barefoot with their feet oriented at 30°separate 9 cm between the heels	standing-60-EO/EC				21.5					26.6				23.5					34.7			
Kim et al. 2009	RCT (8/10)	12/52.4 (10)	6/6	6/6 (112.5 (39))	12/51.7 (7)	7/5	7/5 (105.3 (38.7))				NA	NA	standing-30-EO	45 (10)		479.08 (336.3)	45.50 (20.36)						47.48 (4.25)		298.33 (177.80)	67.50 (84.86)								
Betker et al. 2006	CS (5/10)	1 1/68	1/0	0/1 (NA)							FSA software	15.24 cm apart	standing-20-EO/EC		4																			
In et al. 2016	RCT (5/10)	13/57.3 (10.5)	8/5	6/7 (54.3 (17.8))	12/61.5 (9.3)	7/5	7/5 (58.6 (22.5))				PDM Multifunction Force Measuring Plate. Zebris. Germany	Barefoot with their feet comfortable situated.	standing-30-EO/EC (3)		354.1 (33.1)					501.8 (56.9)				347.8 (37.4)					526.5 (135.6)					
Cho et al. 2012	RCT (5/10)	11/65.26 (8.3)	8/3	1/10 (54.4 (11.21))	11/63.13 (6.8)	6/5	3/8 (54.8 (11))				Good balance force platform system (Metitur Ltd. Finland)	20 cm appart	standing-30-EO/EC (3)				11.4 (2.24)					16.78 (2.25)				9.92 (1.28)					14.41 (3.59)			

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)			
Barcala et al. 2013	RCT (7/10)	10/65.2 (12.5)	5/5	4/6 (53.44 (30.85))	10/63.5 (14.5)	4/6	3/7 (66.94 (28.6))				Medicapteurs®. Fusyo® model	Barefoot	standing-30-EO/EC		45.5 (5.5)					54 (5.1)				43 (16.9)					51.7 (20.7)					
Kitamura et al. 1996	CS (4/10)	19/51 (37-69)	12/7	5/14 (13-34)							NA	NA	standing-60-EO	28.4 (10.1)																				
Adegoke et al. 2012	CS (7/10)	53/58.8 (9.2)	35/18	NA (59 (61.3))							Two bathroom weighing scales (Hana. Germany)	10 cm apart	standing-NA-EO (3)	39.6 (7.36)																				
Tessem et al. 2007	CS (7/10)	21/55	15/6	10/11 (77)	21/55	15/6					SMS Healtcare. Harlow. Essec. UK	NA	Sitting/standing-NA	0.201 (0.034) (sitting)									0.04 (0.022)										CoP ML standing / sitting r=0,17 NS	
Laufer et al. 2000	CO (6/10)	15/72 (7.6)		9/6 (8.9 (7))							Tetrax Ltd. 56 Miryam Street. Ramat Gan. Israel).	10 cm apart at a 30°	standing-24-EO	41.5 (9.1)																				

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm^2)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm^2)	CoP velocity EC (SD) (mm/s)			
Bohannon et al. 1991	CS (6/10)	20/63.2 (10.1)	NA	NA (NA)							(Model HS-I0. North American Phillips Corp.. High Ridge Park. Stamford. CT 06904)	20cm apart at 10°	standing-NA-EO	24.7 (8.9)																				
Shaw et al. 2011	CS (5/10)	14/73.4 (48-88)	8/6	10/4 (136.5)							(BPM) (SMS technologies. Harlow. Essex. UK)	NA	standing-30-EC					RBD 52 (6) / LBD 48.6 (7)																
Gasq et al. 2010	CS (7/10)	20/49.7 (15)	14/6	11/9 (44.7 (4-160))							Win-Posturo. Medicapteurs. Toulouse. France	Barefoot iheels 3 cm apart and toes pointed out at an angle of 30°	standing-51.2-EO/EC		10.7 (9.9)	438.3 (229.2)	7.6 (3.1)			14.1 (11.6)	558.6 (324)	10.7 (5.8)											CoP Surf OE = BBS-K(r=-0.9.p=0.05); FIM (r=-0.8; p=0.05)	

		Population 1			Population 2			Population 3			Characteristics			Population 1									Population 2									Population 3	Correlation	
Author/Date	Design/quality	Nb/age (Y)	M/F	R/L/Both side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Nb/age (Y)	M/F	R/L/Both Side of stroke/delay stroke (W)	Brand	Feet position	Sitting/standing - Duration (s)/ EO/EC (nb of tests)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)	WBA OE (SD) (%)	CoP ML OE (SD) (mm)	CoP surface OE (SD) (mm²)	CoP velocity OE (SD) (mm/s)	WBA EC (SD) (%)	WBA Total (SD) (%)	CoP ML EC (SD) (mm)	Cop Surface EC (SD)(mm²)	CoP velocity EC (SD) (mm/s)			
Hwang et al. 2016	RCT (5/10)	14/68.2 (1.3)	5/9	6/8 (79.9 (19.5))							AccuGait®. Advanced Mechanical Technology Inc.. MA. USA).	NA	standing-30-EO		343.8 (163.4)		22.8 (11)																	
Yatar et al. 2015	RCT (5/10)	15/62.8 (10.8)	6/9	8/7 (192.9 (229.4))	15/56.6 (16.42)	7/8	7/8 (220.8 (243.4))				Wii Balance Board (WBB).	NA	standing-NA-NA						44.04 (7.47)									47.54 (10.16)						

Annexe 1 : Appendix B : Quality of methodology of the articles included in the systematic review and meta-analysis.

Table 1 : Quality of methodology of randomized control trails and cross-over trials with Pedro scale *(1/ the eligibility criteria were specified, 2/ subjects were randomly allocated to groups, 3/ allocation was concealed, 4/ the groups were similar at baseline regarding the most important prognostic indicators, 5/ there was blinding of all subjects, 6/ there was blinding of all therapists who administered the therapy, 7/ there was blinding of all assessors who measured at least one key outcome, 8/ measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups, 9/ all subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analyzed by "intention to treat", 10/ the results of between-group statistical comparisons are reported for at least one key outcome, 11/ the study provides both point measures and measures of variability for at least one key outcome)*

Title	**Author**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**
A virtual reality-cycling training system for lower limb balance improvement	Yin et al.	X	0	0	0	0	0	0	1	1	0	1	3
Balance and steadiness correction of the upright posture of patients having withstood an ischemic stroke with the help of stabilographic rehabilitation training equipment with biofeedback	Bredikhina et al.	X	0	0	1	0	0	0	1	1	0	1	4
Effect of eye movements and proprioceptive neuromuscular facilitation on balance and head alignment in stroke patients with neglect syndrome	Park et al.	X	1	0	0	0	0	0	1	1	0	1	4
Compelled weightbearing in persons with hemiparesis following stroke: the effect of a lift insert and goal-directed balance exercise	Aruin et al.	X	1	0	0	0	0	0	1	1	1	1	5
Effects of Trunk Stabilization Exercises on Different Support Surfaces on the Cross-sectional Area of the Trunk Muscles and Balance Ability	Bae et al.	X	1	0	0	0	0	0	1	1	1	1	5
The effect of optokinetic and galvanic vestibular stimulations in reducing post-stroke postural asymmetry	Bonan et al.	X	0	0	1	0	0	0	1	1	1	1	5
Changes in postural sway according to footwear types of hemiparetic stroke patients	Cho et al.	X	0	0	1	0	0	0	1	1	1	1	5
Virtual-reality balance training with a video-game system improves dynamic balance in chronic stroke patients	Cho et al.	X	1	0	1	0	0	0	1	1	0	1	5
Effect of training with whole body vibration on the sitting balance of stroke patients	Choi et al.	X	1	0	1	0	0	0	0	1	1	1	5
The effect of olfactory stimuli on the balance ability of stroke patients	Gim et al.	X	1	0	0	0	0	0	1	1	1	1	5
The effects of visual and haptic vertical stimulation on standing balance in stroke patients	Hong et al.	X	0	0	1	0	0	0	1	1	1	1	5
Feasibility of Using Tetrax Biofeedback Video Games for Balance Training in Patients With Chronic Hemiplegic Stroke	Hung et al.	X	1	0	1	0	0	0	1	0	1	1	5
Whole body vibration may have immediate adverse effects on the postural sway of stroke patients	Hwang et al.	X	1	0	1	0	0	0	1	1	0	1	5
Reduced sway during dual task balance performance among people with stroke at 6 and 12 months after discharge from hospital	Hyndman et al.	X	0	0	1	0	0	0	1	1	1	1	5
Effects of visual feedback with a mirror on balance ability in patients with stroke	In et al.	X	1	0	0	0	0	0	1	1	1	1	5
Virtual Reality Reflection Therapy Improves Balance and Gait in Patients with Chronic Stroke: Randomized Controlled Trials	In et al.	X	1	0	1	0	0	0	1	1	0	1	5
The effect of obstacle training in water on static balance of chronic stroke patients	Jung et al.	X	1	0	0	0	0	0	1	1	1	1	5
The Effect of Action Observation Training on Balance and Sit to Walk in Chronic Stroke: A Crossover Randomized Controlled Trial	Kim et al.	X	1	0	1	0	0	0	1	0	1	1	5
Functional electrical stimulation with exercises for standing balance and weight transfer in acute stroke patients: a feasibility randomized controlled trial.	Kunkel et al.	X	1	1	0	0	0	0	1	0	1	1	5
The Effects of Exercising on Unstable Surfaces on the Balance Ability of Stroke Patients	Lee et al.	X	1	0	0	0	0	0	1	1	1	1	5
The effects of visual feedback training on sitting balance ability and visual perception of patients with chronic stroke	Lee et al.	X	1	0	1	1	0	0	1	0	0	1	5
Postural Balance of Stroke Survivors in Aquatic and Land Environments	Park et al.	X	1	0	0	0	0	0	1	1	1	1	5
The effects of stair gait exercise on static balance ability of stroke patients	Seo et al.	X	1	0	0	0	0	0	1	1	1	1	5
Effect of virtual reality games on stroke patients' balance, gait, depression, and interpersonal relationships	Song et al.	X	1	0	0	0	0	0	1	1	1	1	5
The effect of a rehabilitational sliding machine and conventional neurological physical therapy on the balance of patients with hemiplegia	Song et al.	X	1	0	0	0	0	0	1	1	1	1	5
The effect of modified bridge exercise on balance ability of stroke patients	Song et al.	X	1	0	0	0	0	0	1	1	1	1	5
Effects of a program on symmetrical posture in patients with hemiplegia: a single-subject design	Wu et al.	X	0	0	1	0	0	0	1	1	1	1	5
Effects of real-time auditory stimulation feedback on balance and gait after stroke: A randomized controlled trial	Yang et al.	X	1	0	1	0	0	0	1	0	1	1	5

Title	Author	1	2	3	4	5	6	7	8	9	10	11	Total
The effect of a haptic biofeedback system on postural control in patients with stroke: An experimental pilot study	Yasuda et al.	X	0	0	1	0	0	0	1	1	1	1	5
Wii Fit balance training or progressive balance training in patients with chronic stroke: a randomised controlled trial	Yatar et al.	X	1	0	1	0	0	0	1	0	1	1	5
Compelled body weight shift approach in rehabilitation of individuals with chronic stroke.	Aruin et al.	X	1	0	1	0	0	0	1	1	1	1	6
Dual-afferent sensory input training for voluntary movement after stroke: A pilot randomized controlled study	Bae et al.	X	1	0	1	0	0	0	1	1	1	1	6
Effects of Lower-Leg Kinesiology Taping on Balance Ability in Stroke Patients with Foot Drop	Bae et al.	X	1	0	1	0	0	0	1	1	1	1	6
The effects of horse riding simulation training on stroke patients' balance ability and abdominal muscle thickness changes	Baek et al.	X	1	0	1	0	0	0	1	1	1	1	6
Immediate effect of lateral-wedged insole on stance and ambulation after stroke	Chen et al.	X	1	0	1	0	0	0	1	1	1	1	6
Effects of Game-Based Constraint-Induced Movement Therapy on Balance in Patients with Stroke: a Single-Blind Randomized Controlled Trial	Choi et al.	X	1	0	1	0	0	0	1	1	1	1	6
Stabilometric analysis of the effect of postural insoles on static balance in patients with hemiparesis: a randomized, controlled, clinical trial	Ferreira et al.	X	1	0	0	1	0	0	1	1	1	1	6
Postural responses to unilateral arm perturbation in young, elderly, and hemiplegic subjects	Garland et al.	X	1	0	1	0	0	0	1	1	1	1	6
Effects of visual biofeedback therapy on postural balance of stroke patients	Ghomashchi et al.	X	1	0	1	0	0	0	1	1	1	1	6
Sit-to-stand in people with stroke: Effect of lower limb constraint-induced movement strategies	Gray et al.	X	1	0	1	0	0	0	1	1	1	1	6
Effects of Balance Training with Various Dual-Task Conditions on Stroke Patients	Her et al.	X	1	0	1	0	0	0	1	1	1	1	6
The influence of an ankle foot orthosis on the percentage of weight loading during standing tasks in stroke patients	Jang et al.	X	1	0	1	0	0	0	1	1	1	1	6
The Effect of Somatosensory and Cognitive-motor Tasks on the Paretic Leg of Chronic Stroke Patients in the Standing Posture	Ju et al.	X	1	0	1	0	0	0	1	1	1	1	6
Effect of constrained weight shift on the static balance and muscle activation of stroke patients	Kang et al.	X	1	0	1	0	0	0	1	1	1	1	6
Effects of limb loading on gait initiation in persons with moderate hemiparesis	Ko et al.	X	1	0	1	0	0	0	1	1	1	1	6
The influence of NDT-Bobath and PNF methods on the field support and total path length measure foot pressure (COP) in patients after stroke	Krukowska et al.	X	1	0	1	0	0	0	1	1	1	1	6
Effects of one-point and four-point canes on balance and weight distribution in patients with hemiparesis	Laufer et al.	X	1	0	1	0	0	0	1	1	1	1	6
Weight-bearing shifts of hemiparetic and healthy adults upon stepping on stairs of various heights	Laufer et al.	X	1	0	1	0	0	0	1	1	1	1	6
Effects of vibration on the bearing asymmetry walking in chronic stroke patients	Leblong-Lecharpentier et al.	X	1	0	1	0	0	0	1	1	1	1	6
Effects of sling exercise on postural sway in post-stroke patients	Lee et al.	X	1	0	1	0	0	0	1	1	1	1	6
Effects of virtual reality-based training and task-oriented training on balance performance in stroke patients	Lee et al.	X	1	0	1	0	0	0	1	1	1	1	6
The Effect of a Bridge Exercise Using the Abdominal Drawing-in Maneuver on the Balance of Chronic Stroke Patients	Lim et al.	X	1	0	1	0	0	0	1	1	1	1	6
The effects of Pilates exercise training on static and dynamic balance in chronic stroke patients: a randomized controlled trial	Lim et al.	X	1	0	1	0	0	0	1	1	1	1	6
The effects of a short-term memory task on postural control of stroke patients	Mehdizadeh et al.	X	1	0	1	0	0	0	1	1	1	1	6
Standard and four-footed canes: Their effect on the standing balance of patients with hemiparesis	Milczarek et al.	X	1	0	1	0	0	0	1	1	1	1	6
Transient Effects of Gaze Stability Exercises on Postural Stability in Patients With Posterior Circulation Stroke	Mitsutake et al.	X	1	0	1	0	0	0	1	1	1	1	6
Compelled Body Weight Shift Technique to Facilitate Rehabilitation of Individuals with Acute Stroke	Mohapatra et al.	X	1	0	1	0	0	0	1	1	1	1	6
Effects of perceptual learning exercises on standing balance using a hardness discrimination task in hemiplegic patients following stroke: a randomized controlled pilot trial	Morioka et al.	X	1	1	1	0	0	0	1	0	1	1	6
The effects of cognitive versus motor demands on postural performance and weight bearing asymmetry in patients with stroke	Negahban et al.	X	1	0	1	0	0	0	1	1	1	1	6
The effects of exercise with TENS on spasticity, balance, and gait in patients with chronic stroke: a randomized controlled trial.	Park et al.	X	1	1	1	0	0	0	1	0	1	1	6
The effectiveness of body weight-supported gait training and floor walking in patients with chronic stroke	Peurala et al.	X	1	1	1	0	0	0	1	0	1	1	6

Title	Author	1	2	3	4	5	6	7	8	9	10	11	Total
The effect of shoe wedges and lifts on symmetry of stance and weight bearing in hemiparetic individuals	Rodriguez et al.	X	1	0	1	0	0	0	1	1	1	1	6
Effects of Motor Imagery Combined with Repetitive Task Practice on Sitting Balance of Hemiplegic Patients	Saito et al.	X	1	0	1	0	0	0	1	1	1	1	6
Effects of Combined Exercise Training on Balance of Hemiplegic Stroke Patients	Shin et al.	X	1	0	1	0	0	0	1	1	1	1	6
The Effects of Shoulder Slings on Balance in Patients With Hemiplegic Stroke	Sohn et al.	X	1	0	1	0	0	0	1	1	1	1	6
Effect of dual tasks on balance ability in stroke patients	Song et al.	X	1	0	1	0	0	0	1	1	1	1	6
Assessment of the interest of inhibitory repetitive transcranial magnetic stimulation (rTMS) on unaffected motor cortex in balance disorders in chronic stroke patients	Vignon et al.	X	1	0	1	0	0	0	1	1	1	1	6
The effect of visual feedback plus mental practice on symmetrical weight-bearing training in people with hemiparesis	Yoo et al.	X	1	0	1	0	0	0	1	1	1	1	6
Visual biofeedback balance training using Wii Fit after stroke: a randomized controlled trial	Barcala et al.	X	1	0	1	0	0	1	1	1	1	1	7
Clinical feasibility of the Nintendo Wii for balance training post-stroke: a phase II randomized controlled trial in an inpatient setting	Bower et al.	X	1	1	1	0	0	1	1	0	1	1	7
Effect of treadmill training based real-world video recording on balance and gait in chronic stroke patients: a randomized controlled trial	Cho et al.	X	1	1	1	0	0	1	1	0	1	1	7
Preliminary study on efficiency of repetitive specific postural tasks and walking protocol on subacute stroke patient	Elleuch et al.	X	1	0	1	0	0	1	1	1	1	1	7
Is hydrokinesitherapy effective on gait and balance in patients with stroke? A clinical and baropodometric investigation.	Furnari et al.	X	1	0	1	0	0	1	1	1	1	1	7
Effects of sensorimotor foot training on the symmetry of weight distribution on the lower extremities of patients in the chronic phase after stroke	Goliwas et al.	X	1	0	1	0	0	1	1	1	1	1	7
Randomized comparison trial of balance training by using exergaming and conventional weight-shift therapy in patients with chronic stroke	Hung et al.	X	1	1	1	0	0	1	1	0	1	1	7
Effect of a local vibration stimulus training programme on postural sway and gait in chronic stroke patients: a randomized controlled trial.	Lee et al.	X	1	1	1	0	0	1	1	0	1	1	7
Acupuncture stimulation improves balance function in stroke patients: a single-blind controlled randomized study	Liu et al.	X	1	0	1	0	0	1	1	1	1	1	7
Immediate effects of two attention strategies on trunk control on patients after stroke. A randomized controlled pilot trial	Mückel et al.	X	1	1	1	0	0	1	1	0	1	1	7
Immediate effects of ankle eversion taping on dynamic and static balance of chronic stroke patients with foot drop	Shin et al.	X	1	0	1	0	0	1	1	1	1	1	7
Effect of the cognitive-motor dual-task using auditory cue on balance of surviviors with chronic stroke: a pilot study	Choi et al.	X	1	1	1	0	0	1	1	1	1	1	8
Cranial nerve non-invasive neuromodulation improves gait and balance in stroke survivors: A pilot randomised controlled trial	Galea et al.	X	1	1	1	0	0	1	1	1	1	1	8
Cognitive Dual-Task training improves balance function in patients with stroke.	Jiejiao et al.	X	1	1	1	1	0	1	1	0	1	1	8
Use of virtual reality to enhance balance and ambulation in chronic stroke: a double-blind, randomized controlled study	Kim et al.	X	1	0	1	1	0	1	1	1	1	1	8
Randomized comparison trial of gait training with and without compelled weight-shift therapy in individuals with chronic stroke	Sheikh et al.	X	1	1	1	0	0	1	1	1	1	1	8
Balance outcomes after additional sit-to-stand training in subjects with stroke: a randomized controlled trial	Tung et al.	X	1	1	1	0	0	1	1	1	1	1	8

Table 2 = JBI Critical Appraisal Checklist for Case Series

1/ Were there clear criteria for inclusion in the case series? 2/ Was the condition measured in a standard, reliable way for all participants included in the case series? 3/ Were valid methods used for identification of the condition for all participants included in the case series? 4/ Did the case series have consecutive inclusion of participants? 5/ Did the case series have complete inclusion of participants? 6/ Was there clear reporting of the demographics of the participants in the study? 7/ Was there clear reporting of clinical information of the participants? 8/ Were the outcomes or follow up results of cases clearly reported? 9/ Was there clear reporting of the presenting site(s)/clinic(s) demographic information? 10/ Was statistical analysis appropriate?

Title	Author	1	2	3	4	5	6	7	8	9	10	Total
Anatomo-clinical study of postures using electronic baropodometer	Rizzi et al.	0	0	1	0	0	1	0	1	0	0	3
Effect of ankle-foot orthosis (AFO) on body sway and walking capacity of hemiparetic stroke patients	Mojica et al.	0	1	0	0	0	0	0	1	0	1	3
Motion analysis in the movements of standing up from and sitting down on a chair. A comparison of normal and hemiparetic subjects and the differences of sex and age among the normals	Yoshida et al.	0	0	1	0	0	0	0	1	0	1	3
Restoration of standing, weight-shift and gait by multichannel electrical stimulation in hemiparetic patients	Malezic et al.	0	0	1	0	0	0	0	1	0	1	3
A single session of open kinetic chain movements emphasizing speed improves speed of movement and modifies postural control in stroke	Gray et al.	0	0	1	0	0	1	0	1	0	1	4
Anterior ankle-foot orthosis effects on postural stability in hemiplegic patients	Chen et al.	0	0	1	0	0	1	0	1	0	1	4
BalanceReTrainer: A new standing-balance training apparatus and methods applied to a chronic hemiparetic subject with a neglect syndrome	Matjačić et al.	0	0	1	0	0	1	1	0	0	1	4
Deliberately Light Interpersonal Touch as an Aid to Balance Control in Neurologic Conditions	Johannsen et al.	0	0	1	0	0	1	0	1	0	1	4
Determinants and predictors of the maximum walking speed during computer-assisted gait training in hemiparetic stroke patients	Suzuki et al.	1	0	1	0	0	0	0	1	0	1	4
Differences in Leg Length Discrepancy and Weight Distribution between the Paretic and Non-paretic Sides of Chronic Hemiplegic Stroke Patients	Jeon et al.	1	0	1	0	0	1	0	0	0	1	4
Effect of thyrotropin-releasing hormone (TRH) on motor performance of hemiparetic stroke patients	Nakamura et al.	0	0	1	0	0	1	0	1	0	1	4
Effects of a single session of transcranial direct current stimulation on static balance in a patient with hemiparesis: a case study	Dumont et al.	0	0	1	0	0	1	0	1	0	1	4
Effects of modified bridging exercises on static postural control of a poststroke hemiplegic patient who had received surgery for lumbar spinal stenosis: a case report	Kim et al.	0	0	1	0	0	1	0	1	0	1	4
Electromyographic responses of distal ankle musculature of standing hemiplegic patients to continuous anterior-posterior perturbations during imposed weight transfer over the affected leg	Dickstein et al.	0	0	1	0	0	1	0	1	0	1	4
Lower extremity weight bearing under various standing conditions in independently ambulatory patients with hemiparesis	Bohannon et al.	0	0	1	0	0	0	1	1	0	1	4
Quantitative evaluation of stance balance performance in the clinic using a novel measurement device	Dickstein et al.	0	0	1	0	0	1	0	1	0	1	4
Relationships among walking performance, postural stability, and functional assessments of the hemiplegic patient	Dettmann et al.	0	0	1	0	0	1	0	1	0	1	4
Stance control is not affected by paresis and reflex hyperexcitability: The case of spastic patients	Nardone et al.	0	1	1	0	0	0	0	1	0	1	4
Standing balance during internally produced perturbations in subjects with hemiplegia: Validation of the balance scale	Stevenson et al.	0	1	0	0	0	1	0	1	0	1	4
Symmetry of weight distribution in normals and stroke patients using digital weigh scales	Caldwell et al.	1	0	1	0	0	0	0	1	0	1	4
Visual influence on contact pressure of hemiplegic patients through photoelastic sole image	Kitamura et al.	0	0	1	0	0	1	0	1	0	1	4

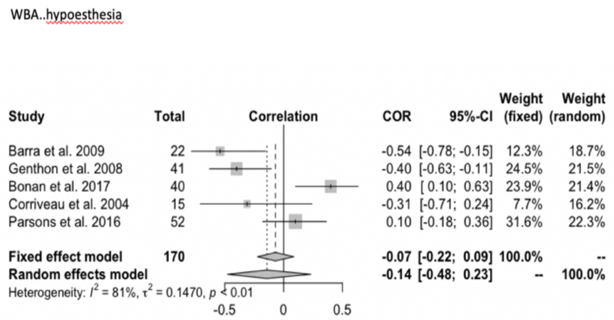
Title	Author	1	2	3	4	5	6	7	8	9	10	Total
Automatic and voluntary lateral weight shifts in rehabilitation of hemiparetic patients	Dickstein et al.	0	1	1	0	0	1	0	1	0	1	5
Combining ambulatory and laboratory assessment of rollator use for balance and mobility in neurologic rehabilitation in-patients	Tung et al.	0	1	1	0	0	1	0	1	0	1	5
Comparison of upper-extremity balance tasks and force platform testing in persons with hemiparesis	Fishman et al.	1	0	1	0	0	1	0	1	0	1	5
Differences in weight-bearing distribution during upright stance measured by digital scales in subjects with or without hemiparesis	Martins et al.	1	0	1	0	0	0	1	1	0	1	5
Effects of eye movement with functional electrical stimulation on balance in stroke patients with neglect syndrome	Park et al.	0	1	1	0	0	1	0	1	0	1	5
Evolution of hemiplegic patient's postural stability parameters during function rehabilitation	Carette et al.	0	1	1	0	0	1	0	1	0	1	5
Influence of light touch using the fingertips on postural stability of poststroke patients	Lee et al.	1	0	1	0	0	1	0	1	0	1	5
Is it correct to always consider weight-bearing asymmetrically distributed in individuals with hemiparesis?	Martins et al.	1	0	1	0	0	1	0	1	0	1	5
Posturography in patients with stroke: Estimating the percentage of body weight on each foot from a single force platform	Genthon et al.	0	1	1	0	0	1	0	1	0	1	5
Reliability of center of pressure measures within and between sessions in individuals post-stroke and healthy controls.	Gray et al.	0	1	1	0	0	1	0	1	0	1	5
Reliability of the measures of weight-bearing distribution obtained during quiet stance by digital scales in subjects with and without hemiparesis	de Araujo-Barbosa et al.	1	0	1	0	0	1	0	1	0	1	5
Static disorders in hemiplegic patients: Evaluation on dual-plate force platform	Le Liepvre et al.	1	1	1	NA	NA	0	0	1	0	1	5
The effects of trunk kinesio taping on balance ability and gait function in stroke patients	Lee et al.	1	0	1	0	0	1	0	1	0	1	5
Training rapid stepping responses in an individual with stroke.	Mansfield et al.	0	1	1	0	0	1	0	1	0	1	5
Video game-based exercises for balance rehabilitation: a single-subject design	Betker et al.	0	1	1	0	0	1	0	1	0	1	5
What is the relationship between weight-bearing asymmetry and subjective visual vertical (SVV) following stroke?	Shaw et al.	1	0	1	0	0	1	0	1	0	1	5
Body balance in standing position in people after cerebral stroke on the basis of posturographic examinations	Jasińska et al.	1	1	1	0	0	1	0	1	0	1	6
Effect of horseback riding simulation machine training on trunk balance and gait of chronic stroke patients	Kim et al.	1	1	1	0	0	1	0	1	0	1	6
Femoral neck bone mineral density change is associated with shift in standing weight in hemiparetic stroke patients	Chang et al.	0	0	1	1	1	1	0	1	0	1	6
Impaired ability to shift weight onto the non-paretic leg in right-cortical brain-damaged patients	Ishii et al.	1	0	1	1	0	1	0	1	0	1	6
Measurements of Weight Bearing Asymmetry Using the Nintendo Wii Fit Balance Board Are Not Reliable for Older Adults and Individuals With Stroke	Liuzzo et al.	0	0	1	0	0	1	1	1	1	1	6
Posturo-respiratory synchronization: Effects of aging and stroke	Manor et al.	1	1	1	1	0	0	0	1	0	1	6
Relationship between clinical and instrumental balance assessments in chronic post-stroke hemiparesis subjects	Sawacha et al.	1	1	1	0	0	1	0	1	0	1	6
Reliability of the Good Balance System (R) for Postural Sway Measurement in Poststroke Patients	Ha et al.	1	1	1	0	0	1	0	1	0	1	6
Standing balance training: effect on balance and locomotion in hemiparetic adults	Winstein et al.	1	1	1	0	0	1	0	1	0	1	6
Standing posture of adults: Effects of a stroke	Paillex et al.	1	1	1	0	0	1	0	1	0	1	6
The relationship between spatiotemporal gait asymmetry and balance in individuals with chronic stroke	Lewek et al.	1	1	1	0	0	1	0	1	0	1	6
Weightbearing during comfortable stance in patients with stroke: Accuracy and reliability of measurements	Bohannon et al.	0	0	1	0	0	1	1	1	1	1	6
Asymmetric standing posture after stroke is related to a biased egocentric coordinate system	Barra et al.	0	1	1	0	0	1	1	1	1	1	7

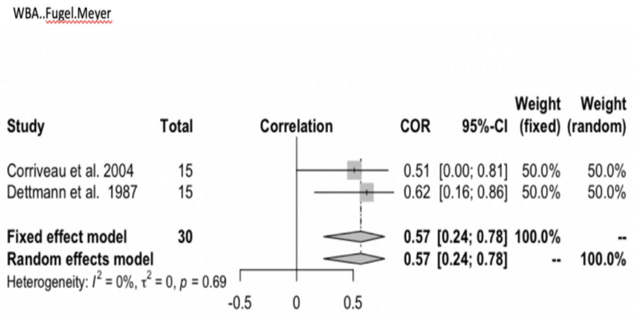
Title	Author	1	2	3	4	5	6	7	8	9	10	Total
Balance Confidence Is Related to Features of Balance and Gait in Individuals with Chronic Stroke	Schinkel-Ivy et al.	1	0	1	1	0	1	1	1	0	1	7
Balance evaluation with stabilometric platform on hemiplegic patients in a neurological rehabilitation center	Samaniego et al.	1	1	1	1	0	1	0	1	0	1	7
Correlation between clinical assessment and force plate measurement of postural control after stroke	Frykberg et al.	1	1	1	1	0	1	0	1	0	1	7
Correlations between force plate measures for assessment of balance	Karlsson et al.	1	1	1	1	0	1	0	1	0	1	7
Differences between left- and right-sided neglect revisited: A large cohort study across multiple domains	Ten Brink et al.	1	0	1	1	1	1	0	1	0	1	7
Effects of Dual-task Performance on Postural Sway of Stroke Patients with Experience of Falls	Shim et al.	1	1	1	1	0	1	0	1	0	1	7
Effects of weight-shift training on balance control and weight distribution in chronic stroke: A pilot study	Tsaklis et al.	1	1	1	1	0	1	0	1	0	1	7
Exercise-induced muscle fatigue in the unaffected knee joint and its influence on postural control and lower limb kinematics in stroke patients	Park et al.	1	1	1	1	0	1	0	1	0	1	7
Gait asymmetry, ankle spasticity, and depression as independent predictors of falls in ambulatory stroke patients	Wei et al.	1	1	1	1	0	1	0	1	0	1	7
Impact of Spasticity on Balance Control during Quiet Standing in Persons after Stroke	Rahimzadeh Khiabani et al.	1	0	1	0	0	1	1	1	1	1	7
Instrumented static and dynamic balance assessment after stroke using Wii Balance Boards: Reliability and association with clinical tests	Bower et al.	1	0	1	0	0	1	1	1	1	1	7
Measuring lateropulsion following stroke in the clinical setting: A feasibility study using Wii technologies	Birnbaum et al.	1	0	1	0	0	1	1	1	1	1	7
Performance in the stability limits test during rehabilitation following stroke	Goldie et al.	1	1	1	0	1	1	0	1	0	1	7
Physical factors associated with fatigue after stroke: An exploratory study	Hoang et al.	1	1	1	1	1	0	0	1	0	1	7
Postural control of individuals with chronic stroke compared to healthy participants: TUG, FRT and center of pressure movement	Portnoy et al.	1	0	1	0	0	1	1	1	1	1	7
Relationship between Postural Sway and Dynamic Balance in Stroke Patients	Cho et al.	1	0	1	0	0	1	1	1	1	1	7
Stabilometry is a predictor of gait performance in chronic hemiparetic stroke patients	Nardone et al.	0	1	1	0	0	1	1	1	1	1	7
Weight bearing asymmetry and functional ambulation performance in stroke survivors	Adegoke et al.	1	1	1	1	0	1	0	1	0	1	7
Weight distribution in standing and sitting positions, and weight transfer during reaching tasks, in seated stroke subjects and healthy subjects.	Tessem et al.	1	0	1	1	1	1	0	1	0	1	7
What stabilometric parameters are the most pertinent for evaluating stability in the vascular hemiplegic? HemiStab study	Gasq et al.	1	1	1	1	0	1	0	1	0	1	7
A Retrospective Analysis of Post-Stroke Berg Balance Scale Scores: How Should Normal and At-Risk Scores Be Interpreted?	Patterson et al.	1	1	1	1	1	1	0	1	0	1	8
Activity of thigh muscles during static and dynamic stances in stroke patients: A pilot case-control study	Wen et al.	1	1	1	0	0	1	1	1	1	1	8
Ambulatory level and asymmetrical weight bearing after stroke affects bone loss in the upper and lower part of the femoral neck differently: Bone adaptation after decreased mechanical loading	Jorgensen et al.	1	1	1	1	1	1	0	1	0	1	8
Ankle-foot orthoses in stroke: effects on functional balance, weight-bearing asymmetry and the contribution of each lower limb to balance control	Simons et al.	1	1	1	1	0	1	1	1	0	1	8
Changes in Postural Sway According to Surface Stability in Post-stroke Patients	Yu et al.	1	1	1	0	0	1	1	1	1	1	8
Changes in the standing posture of stroke patients during rehabilitation	Paillex et al.	1	1	1	1	1	1	0	1	0	1	8

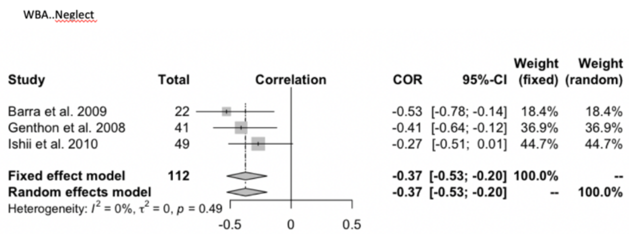
Title	Author	1	2	3	4	5	6	7	8	9	10	Total
Contribution of each lower limb to upright standing in stroke patients	Genthon et al.	1	1	1	0	0	1	1	1	1	1	8
Curved walking in hemiparetic patients	Godi et al.	1	1	1	0	0	1	1	1	1	1	8
Difference between individuals with left and right hemiparesis in the effect of gluteus medius vibration on body weight shifting	Bonan et al.	1	1	1	0	0	1	1	1	1	1	8
Do measures of reactive balance control predict falls in people with stroke returning to the community?	Mansfield et al.	1	0	1	1	0	1	1	1	1	1	8
Evaluation of postural stability in the elderly with stroke	Corriveau et al.	1	1	1	0	0	1	1	1	1	1	8
Instrumenting gait assessment using the Kinect in people living with stroke: Reliability and association with balance tests	Clark et al.	1	1	1	0	0	1	1	1	1	1	8
Long lasting reduction of postural asymmetry by prism adaptation after right brain lesion without neglect	Hugues et al.	1	1	1	0	0	1	1	1	1	1	8
Normal functional balance does not necessarily imply recovered standing balance control, as measured with posturography in individuals with stroke	Patterson et al.	1	0	1	1	0	1	1	1	1	1	8
On the relative contribution of the paretic leg to the control of posture after stroke	Roerdink et al.	1	1	1	0	0	1	1	1	1	1	8
Postural control of healthy elderly individuals compared to elderly individuals with stroke sequelae	Alfieri et al.	1	1	1	1	0	1	0	1	1	1	8
Posturographic assessment of sitting balance recovery in the subacute phase of stroke	Van Nes et al.	1	1	1	0	0	1	1	1	1	1	8
Reaching-lifting-placing task during standing after stroke: Coordination among ground forces, ankle muscle activity, and hand movement	Kusoffsky et al.	1	1	1	0	0	1	1	1	1	1	8
Relationships between standing balance and symmetry measurements in patients following recent strokes (3 weeks or less) or older strokes (6 months or more)	Pyöriä et al.	1	1	1	1	1	1	0	1	0	1	8
Relationships of balance, gait performance, and functional outcome in chronic stroke patients: A comparison of left and right lesions	Lopes et al.	1	1	1	0	0	1	1	1	1	1	8
Stabilometer test for the quantified evaluation of equilibrium function in stroke patients with hemiplegia	Lei et al.	1	1	1	1	1	1	0	1	0	1	8
Task-oriented intervention in chronic stroke: Changes in clinical and laboratory measures of balance and mobility	Leroux et al.	1	1	1	0	0	1	1	1	1	1	8
Task-oriented physical exercise using postural re-alignment with body weight support in chronic stroke	Saggini et al.	1	1	1	1	1	1	0	1	0	1	8
Between-limb synchronization for control of standing balance in individuals with stroke	Mansfield et al.	1	0	1	1	1	1	1	1	1	1	9
Clinical Correlates of Between-Limb Synchronization of Standing Balance Control and Falls During Inpatient Stroke Rehabilitation	Mansfield et al.	0	1	1	1	1	1	1	1	1	1	9
Determinants and consequences for standing balance of spontaneous weight-bearing on the paretic side among individuals with chronic stroke	Mansfield et al.	1	0	1	1	1	1	1	1	1	1	9
Force Plate Assessment of Quiet Standing Balance Control: Perspectives on Clinical Application Within Stroke Rehabilitation	Mansfield et al.	0	1	1	1	1	1	1	1	1	1	9
Relationships between fear of falling, balance confidence, and control of balance, gait, and reactive stepping in individuals with sub-acute stroke	Schinkel-Ivy et al.	1	1	1	1	1	1	0	1	1	1	9
The short-term effects of plantar vibration therapy on the balance of patients after stroke	Naghdi et al.	1	1	1	1	0	1	1	1	1	1	9
Between-day reliability of centre of pressure measures for balance assessment in hemiplegic stroke patients	Gasq et al.	1	1	1	1	1	1	1	1	1	1	10
Disturbances of spatial reference frame and postural asymmetry after a chronic stroke	Jamal et al.	1	1	1	1	1	1	1	1	1	1	10
Influence of treatment with botulinum toxine after stroke to control posture	Trappier et al.	1	1	1	1	1	1	1	1	1	1	10

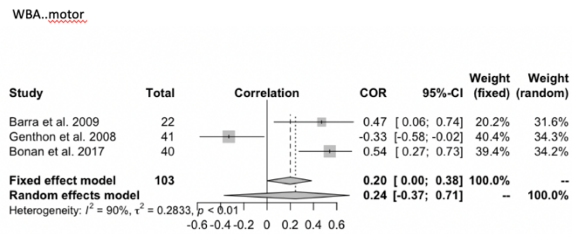
Title	Author	1	2	3	4	5	6	7	8	9	10	Total
Is the recovery of functional balance and mobility accompanied by physiological recovery in people with severe impairments after stroke?	Peters et al.	1	1	1	1	1	1	1	1	1	1	10
Post-Stroke Lower Limb Spasticity Alters the Interlimb Temporal Synchronization of Centre of Pressure Displacements Across Multiple Timescales	Singer et al.	1	1	1	1	1	1	1	1	1	1	10
Recovery of Standing Balance and Functional Mobility after Stroke	Garland et al.	1	1	1	1	1	1	1	1	1	1	10
Recovery of standing balance in postacute stroke patients: A rehabilitation cohort study	De Haart et al.	1	1	1	1	1	1	1	1	1	1	10
Relationship between asymmetry of quiet standing balance control and walking post-stroke	Hendrickson et al.	1	1	1	1	1	1	1	1	1	1	10
Short-term effect of neck muscle vibration on postural disturbances in stroke patients	Leplaideur et al.	1	1	1	1	1	1	1	1	1	1	10
Standing balance and functional recovery of patients with right and left hemiparesis in the early stages of rehabilitation	Laufer et al.	1	1	1	1	1	1	1	1	1	1	10
The relationship of plantar cutaneous sensation and standing balance post-stroke	Parsons et al.	1	1	1	1	1	1	1	1	1	1	10

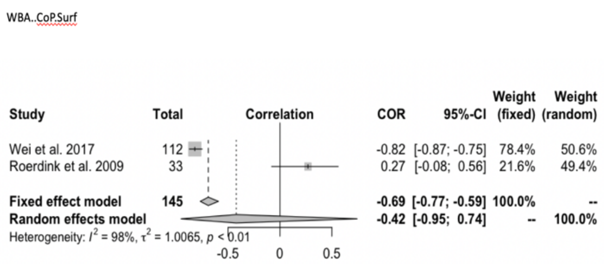
Annexe 1 : Appendix C = Figures of the meta-analysis of the correlation between postural asymmetry / postural sway and the characteristics of hemiplegia, balance and gait function. (Antero-posterior (AP), Berg Balance Scale (BBS), Center of Pressure (CoP), Clinical Outcome Variables Scale (COVS), Clinical Test for Sensory Interaction on Balance (CTSIB) Double Limb Support (DLS), Emory Functional Ambulation Profile (E-FAP), Functional Standing Balance (FSB), Functional Independence Measure (FIM), Functional Reach Test (FRT), Longitudinal Body Axis (LBA), Limit od stability (LOS), Medio-Lateral (ML), Open eyes (OP), Postural Assessment Scale for Stroke (PASS), Scale for Contraversive Pushing (SCP), Single Limb Support (SLS) Subjective Straight Ahead (SSA), Subjective Visual Vertical (SVV), Surface (Surf), Time Up and Go (TUG), Velocity (Vel), Weight bearing asymmetry (WBA))

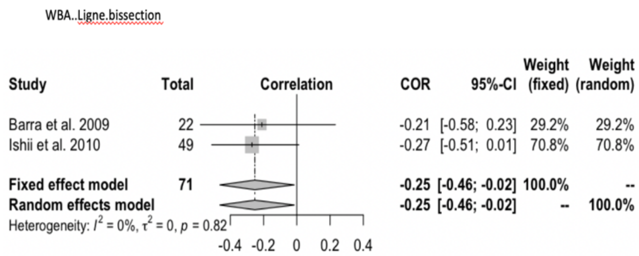


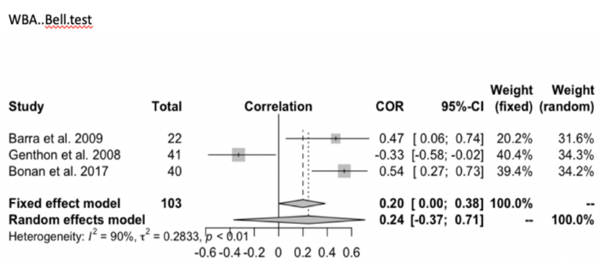


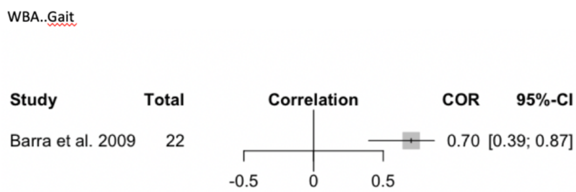




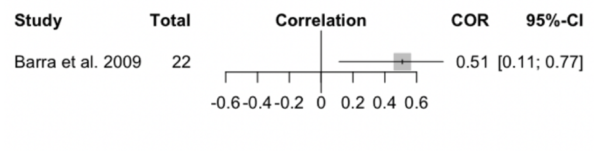








WBA..PASS



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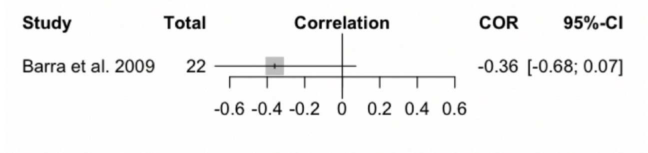
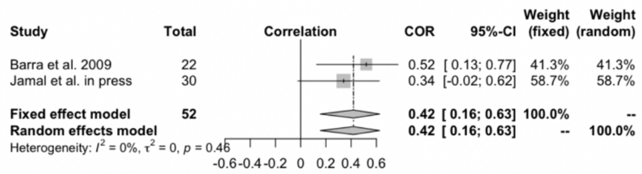


WBA..LBA



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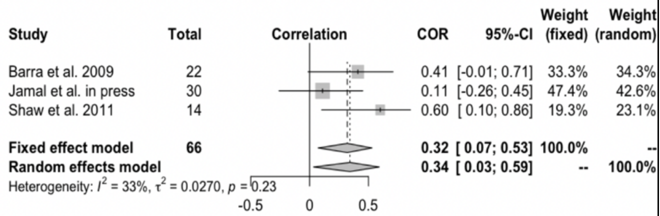
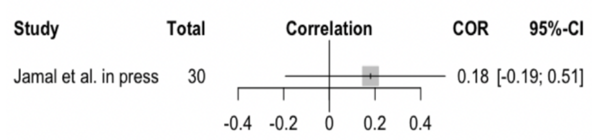
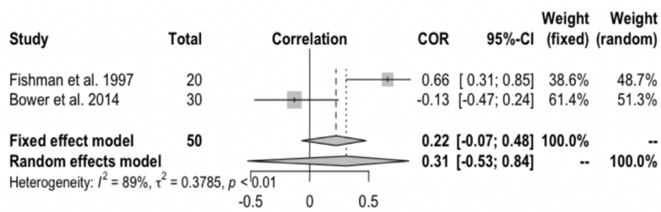


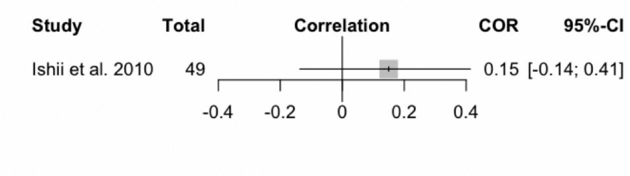
WBA..SSA



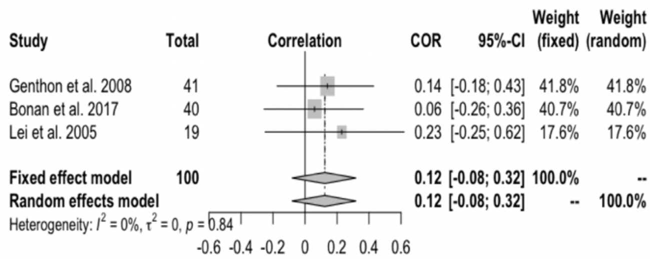
WBA...FRT



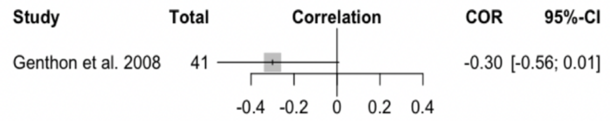
WBA...Anosognosia



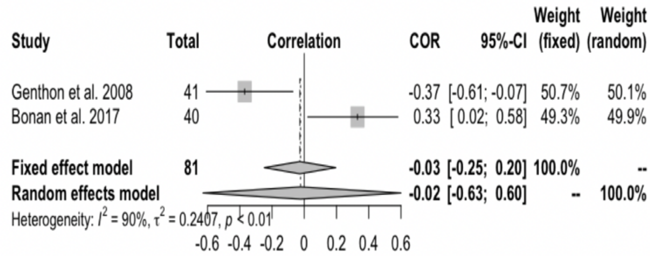
WBA..Age



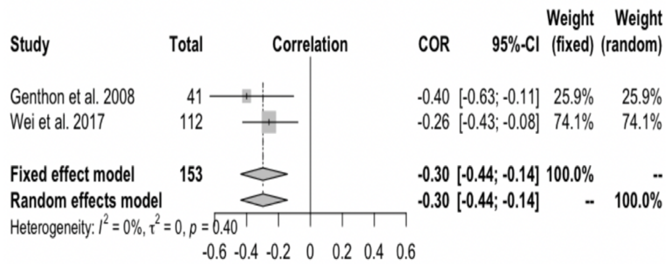
WBA..Lesion.size



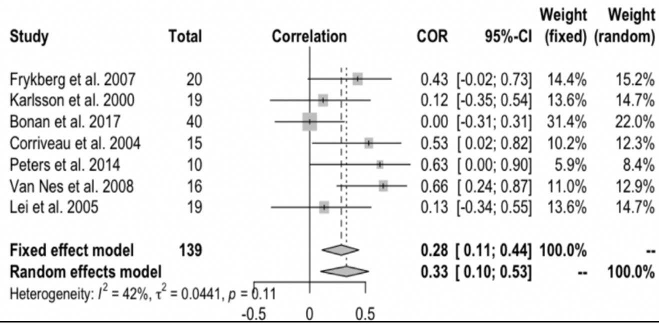
WBA..Delay.post.stroke



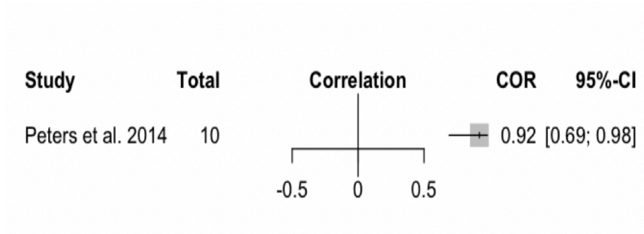
WBA..Spasticity



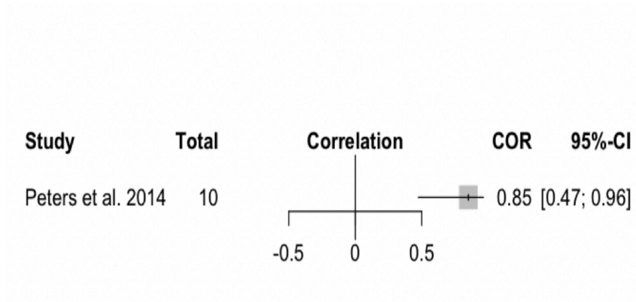
WBA..BBS



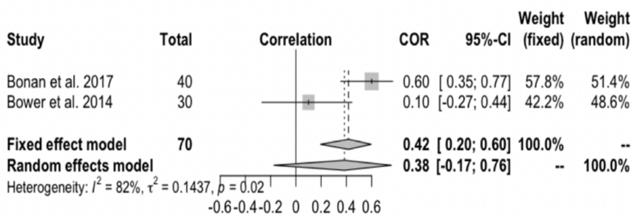
WBA..COVS



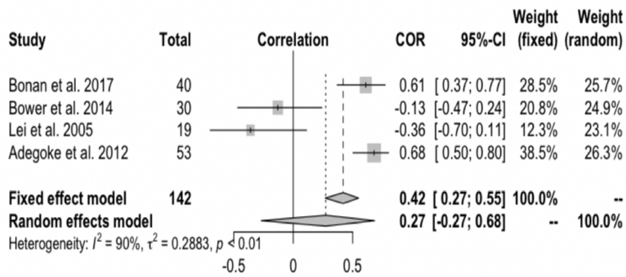
WBA..Chedoke



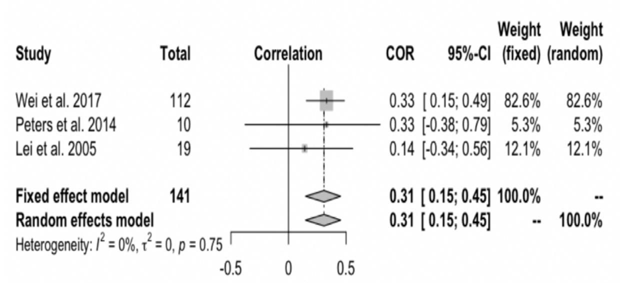
WBA..T10m



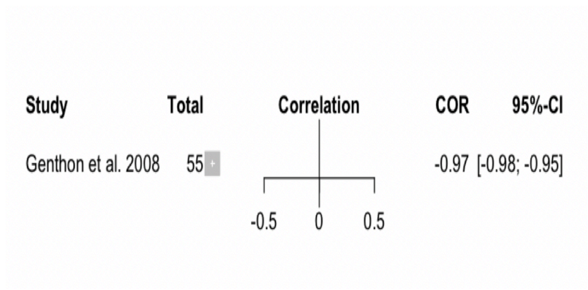
WBA..TUG



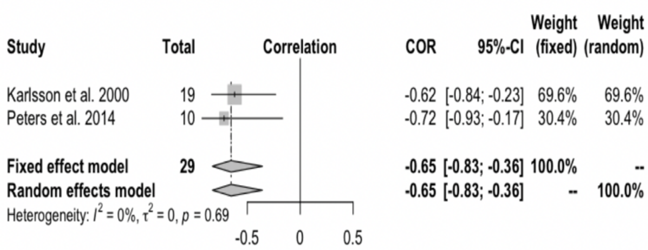
WBA..FIM



WBA...CoP.ML.OE



WBA..CoP.Vel.OE



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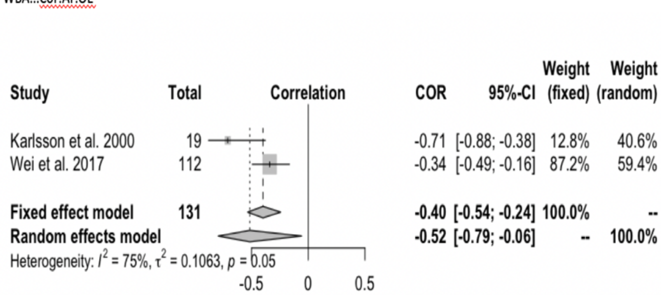
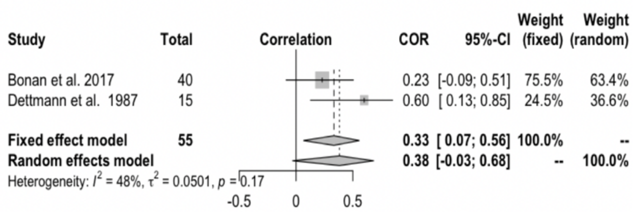
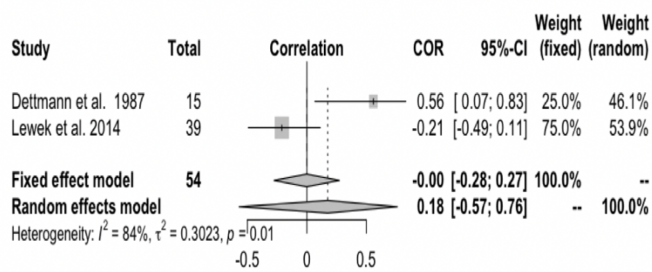


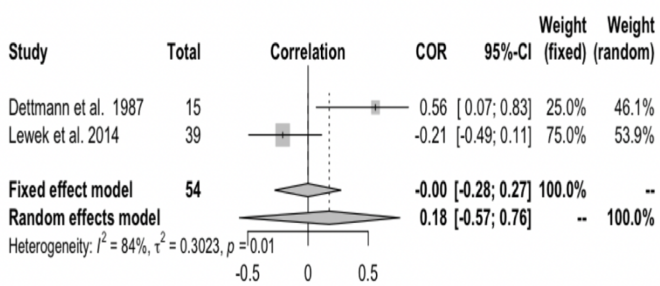
WBA...Barthel



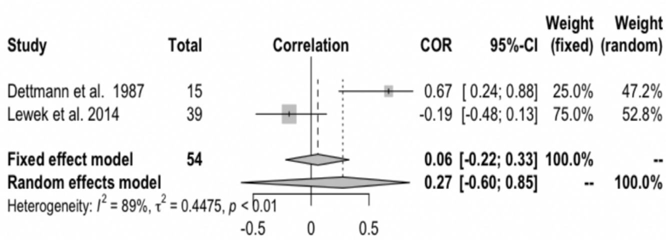
WBA...Stride.lenght



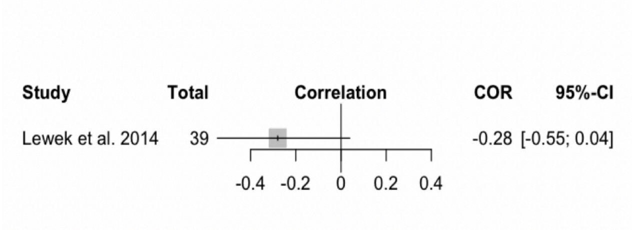
WBA...Stride.lenght.paretic.side



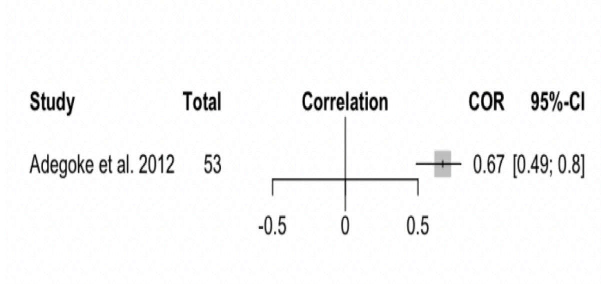
WBA...Swing.ratio



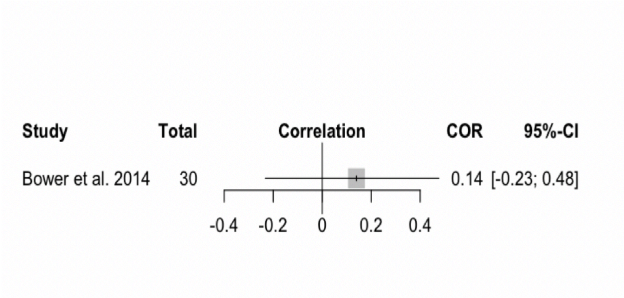
WBA..Stance



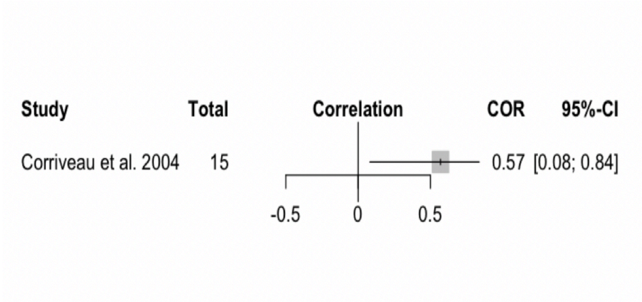
WBA..E.FAP



WBA..Step.test



WBA..Tinetti



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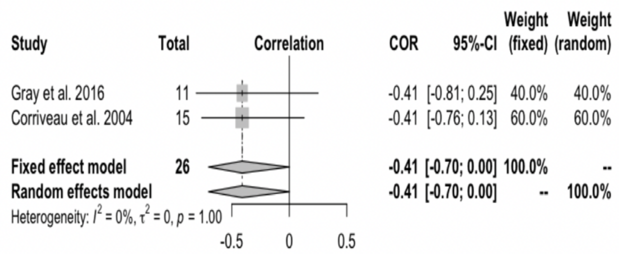
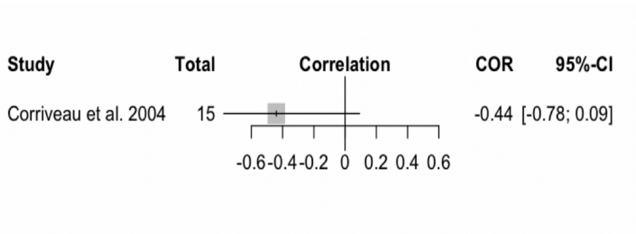
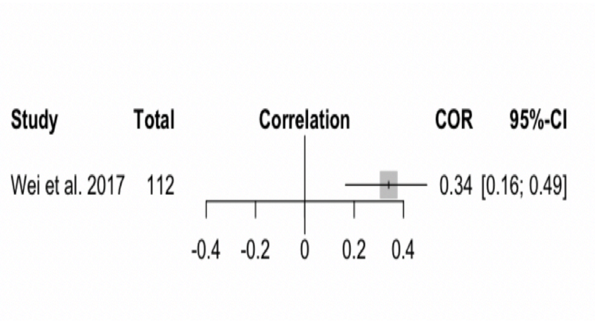


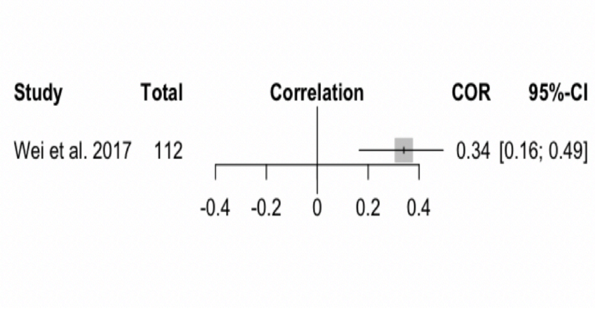
WBA..REACTI



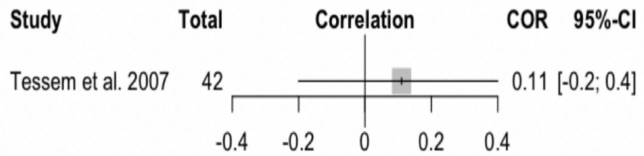
WBA...Gait.cadence



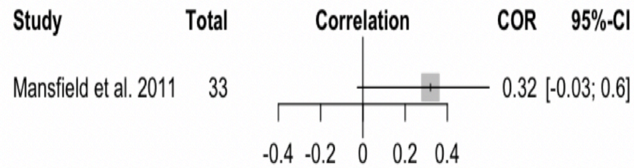
WBA...Gait.velocity



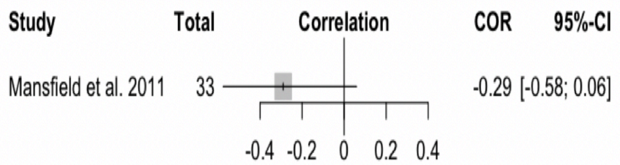
WBA...Standing.sitting



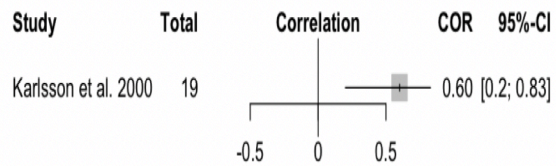
WBA..AP.synchronisation



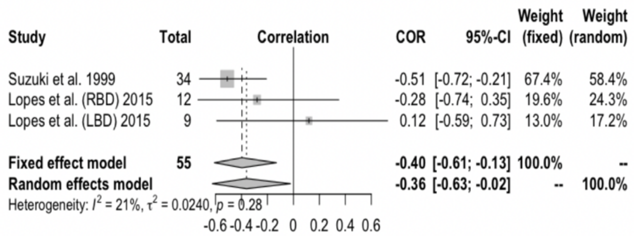
WBA..ML.synchronisation



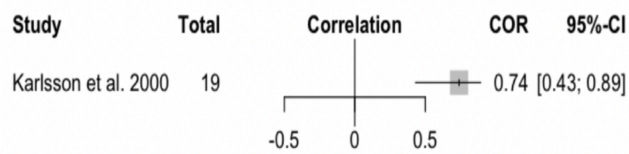
CoP.VeL...CoP.VeL.AP



CoP.VeL..Motor



CoP.VeL...CoP.AP.OE



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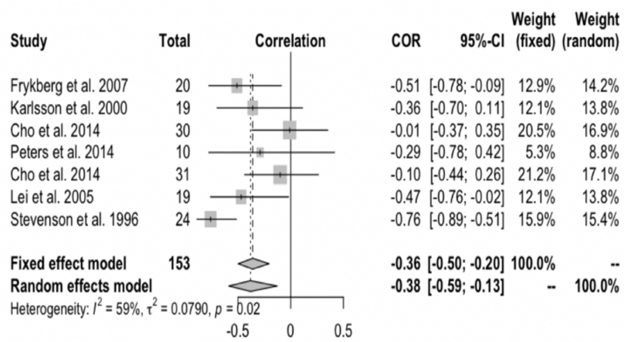

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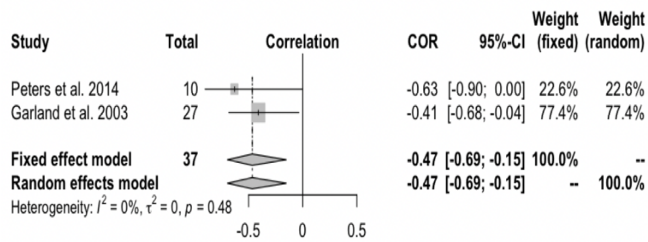

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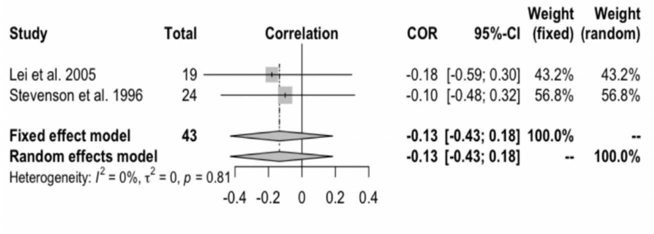

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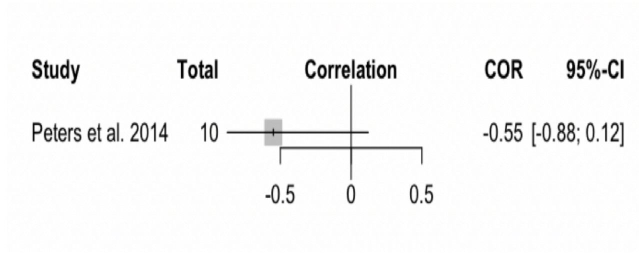
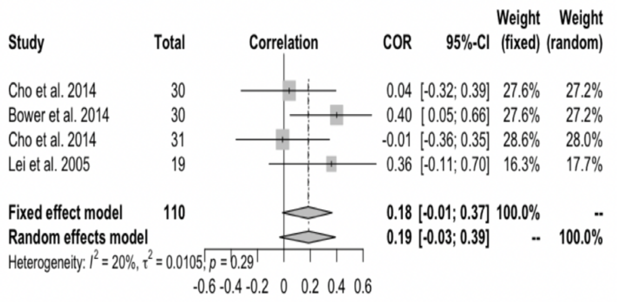
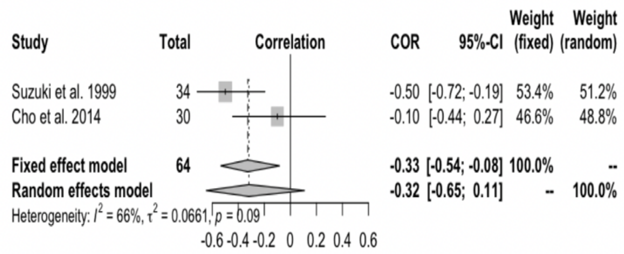


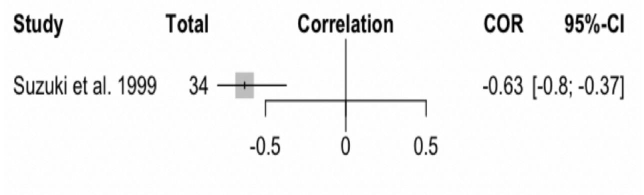
CoP.VeL..TUG



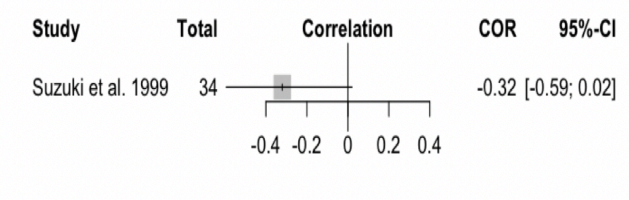
CoP.VeL..Gait.speed



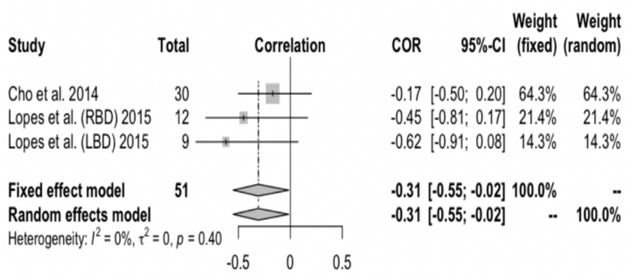
CoP.VeL..LOS.R.L



CoP.VeL..LOS.AP



CoP.VeL..Gait.cadence



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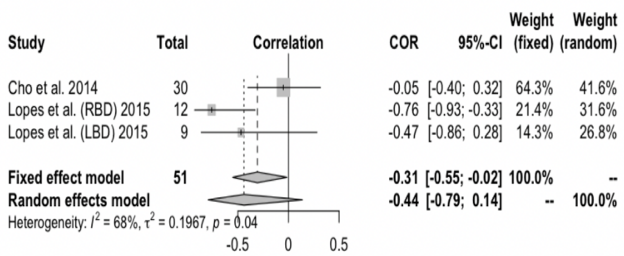

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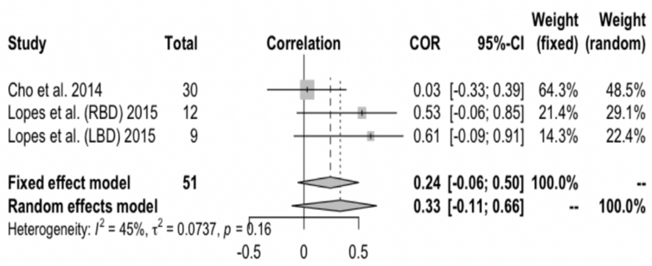

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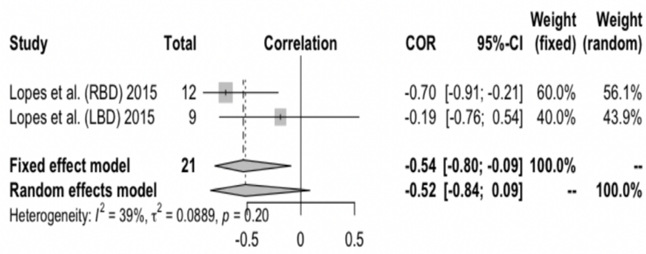

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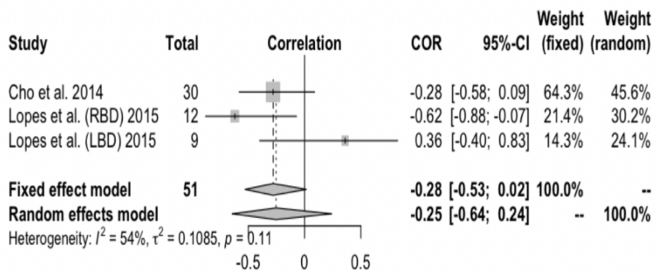
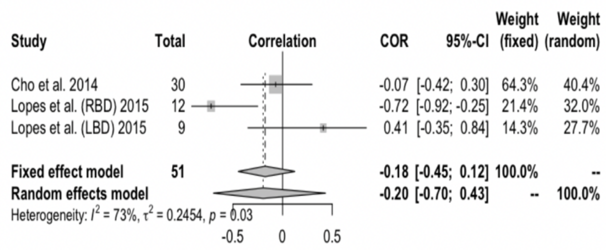
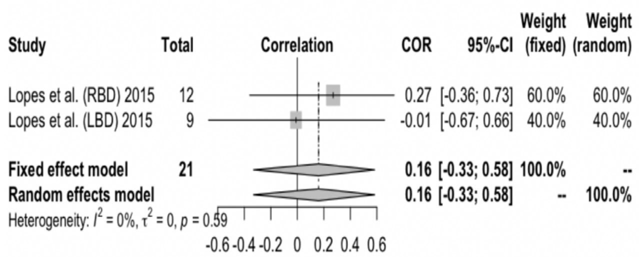


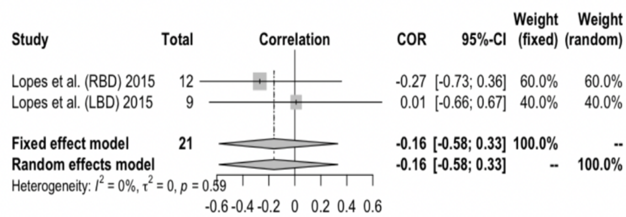
CoP.VeL..Gait.stride.lenght



CoP.VeL...Stance.phase



CoP.VeL...swing.phase



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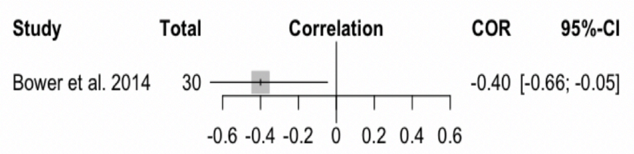
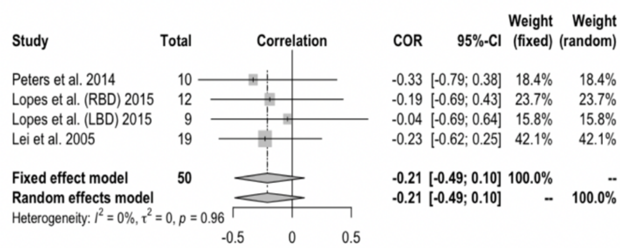
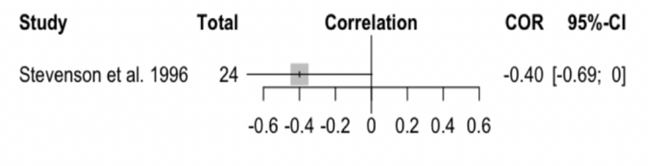


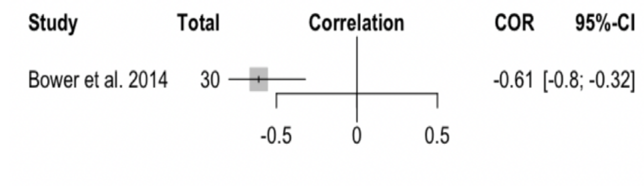
CoP.VeL..FIM



CoP.VeL..Delay.post.stroke



CoP.VeL..FRT



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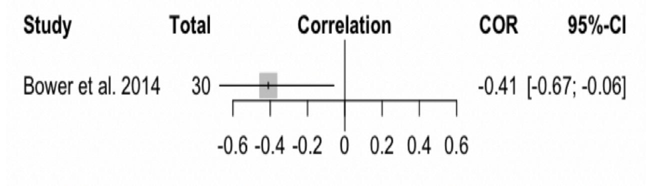

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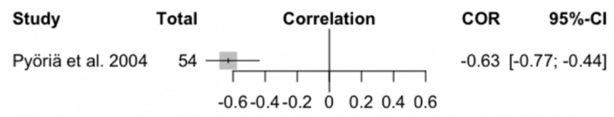
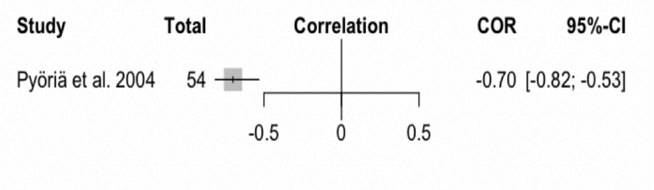
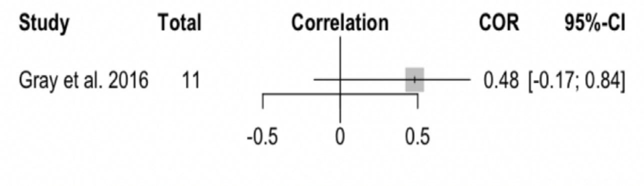


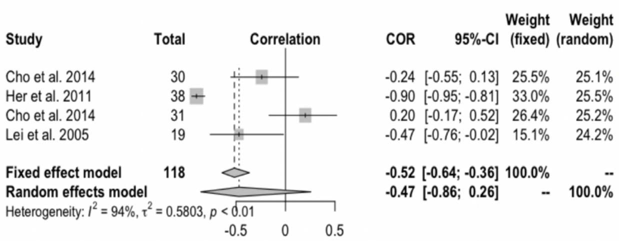
CoP.VeL...FSB.without.mouvement



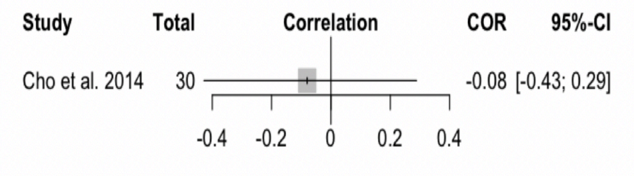
CoP.VeL.Arm.acceleration

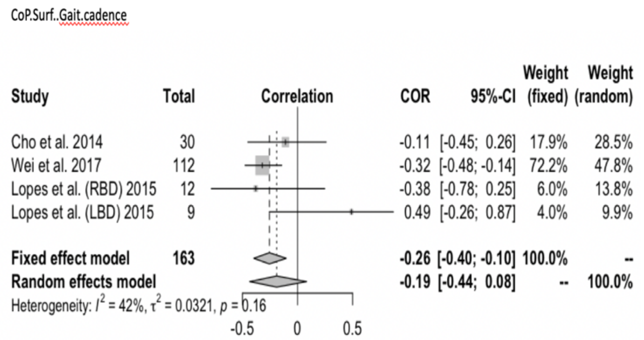


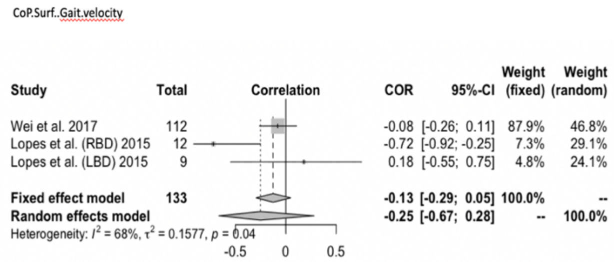
CoP.surf..BBS

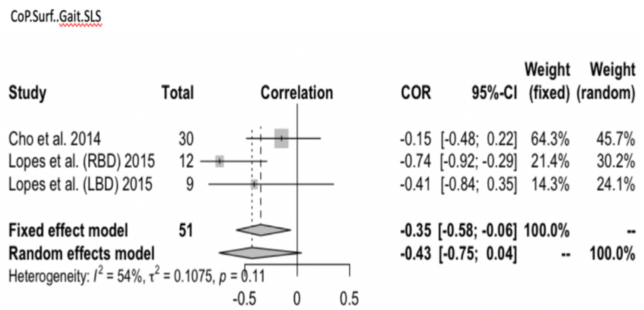


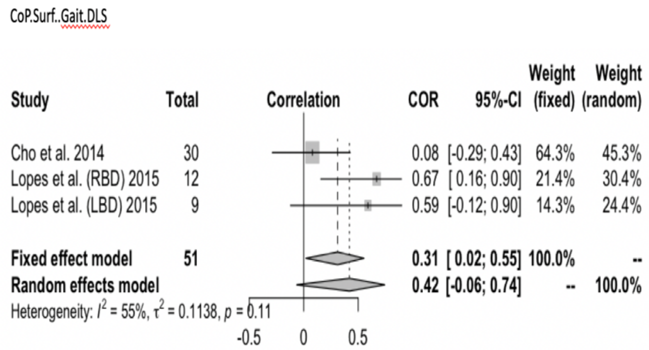
CoP.Surf..Gait.speed

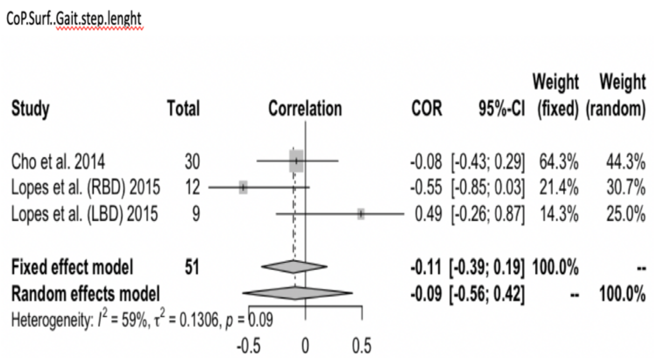


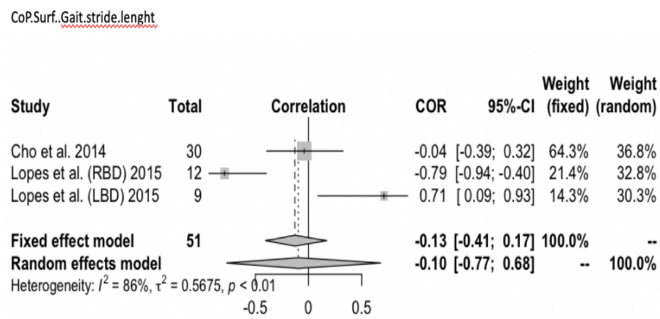

CoP.Surf..Gait.cadence
Study Total Correlation COR 95%-CI Weight (fixed) Weight (random)
Cho et al. 2014 30 -0.11 [-0.45; 0.26] 17.9% 28.5%
Wei et al. 2017 112 -0.32 [-0.48; -0.14] 72.2% 47.8%
Lopes et al. (RBD) 2015 12 -0.38 [-0.78; 0.25] 6.0% 13.8%
Lopes et al. (LBD) 2015 9 0.49 [-0.26; 0.87] 4.0% 9.9%
Fixed effect model 163 -0.26 [-0.40; -0.10] 100.0% --
Random effects model -0.19 [-0.44; 0.08] -- 100.0%
Heterogeneity: I^2 = 42%, τ^2 = 0.0321, p = 0.16
-0.5 0 0.5

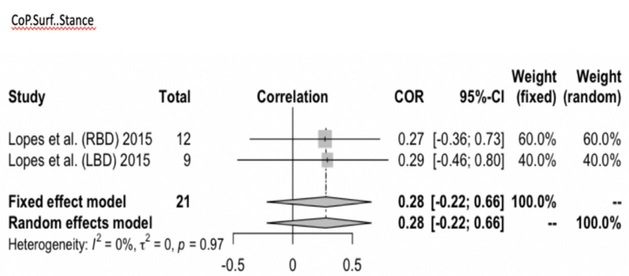

CoP.Surf..Gait.velocity
Study Total Correlation COR 95%-CI Weight (fixed) Weight (random)
Wei et al. 2017 112 -0.08 [-0.26; 0.11] 87.9% 46.8%
Lopes et al. (RBD) 2015 12 -0.72 [-0.92; -0.25] 7.3% 29.1%
Lopes et al. (LBD) 2015 9 0.18 [-0.55; 0.75] 4.8% 24.1%
Fixed effect model 133 -0.13 [-0.29; 0.05] 100.0% --
Random effects model -0.25 [-0.67; 0.28] -- 100.0%
Heterogeneity: I^2 = 68%, τ^2 = 0.1577, p = 0.04
-0.5 0 0.5

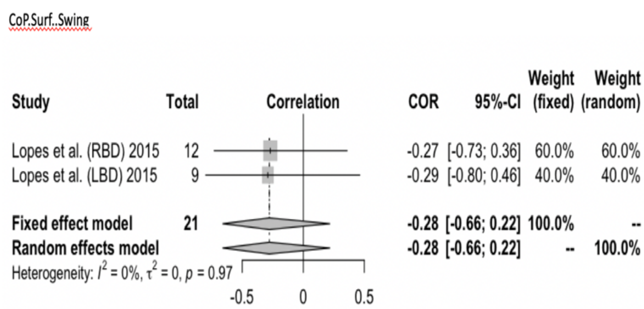

CoP.Surf..Gait.SLS
Study Total Correlation COR 95%-CI Weight (fixed) Weight (random)
Cho et al. 2014 30 -0.15 [-0.48; 0.22] 64.3% 45.7%
Lopes et al. (RBD) 2015 12 -0.74 [-0.92; -0.29] 21.4% 30.2%
Lopes et al. (LBD) 2015 9 -0.41 [-0.84; 0.35] 14.3% 24.1%
Fixed effect model 51 -0.35 [-0.58; -0.06] 100.0% --
Random effects model -0.43 [-0.75; 0.04] -- 100.0%
Heterogeneity: I^2 = 54%, τ^2 = 0.1075, p = 0.11
-0.5 0 0.5


CoP.Surf..Gait.DLS
Study Total Correlation COR 95%-CI Weight (fixed) Weight (random)
Cho et al. 2014 30 0.08 [-0.29; 0.43] 64.3% 45.3%
Lopes et al. (RBD) 2015 12 0.67 [0.16; 0.90] 21.4% 30.4%
Lopes et al. (LBD) 2015 9 0.59 [-0.12; 0.90] 14.3% 24.4%
Fixed effect model 51 0.31 [0.02; 0.55] 100.0% --
Random effects model 0.42 [-0.06; 0.74] -- 100.0%
Heterogeneity: I^2 = 55%, τ^2 = 0.1138, p = 0.11
-0.5 0 0.5

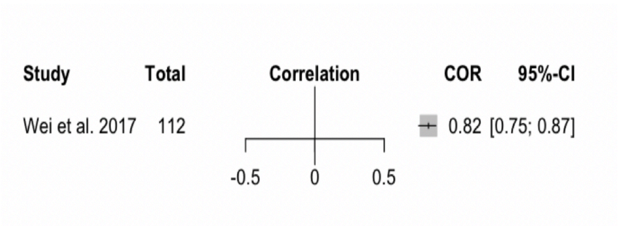

CoP.Surf..Gait.step.lenght
Study Total Correlation COR 95%-CI Weight (fixed) Weight (random)
Cho et al. 2014 30 -0.08 [-0.43; 0.29] 64.3% 44.3%
Lopes et al. (RBD) 2015 12 -0.55 [-0.85; 0.03] 21.4% 30.7%
Lopes et al. (LBD) 2015 9 0.49 [-0.26; 0.87] 14.3% 25.0%
Fixed effect model 51 -0.11 [-0.39; 0.19] 100.0% --
Random effects model -0.09 [-0.56; 0.42] -- 100.0%
Heterogeneity: I^2 = 59%, τ^2 = 0.1306, p = 0.09
-0.5 0 0.5


CoP.Surf..Gait.stride.lenght
Study Total Correlation COR 95%-CI Weight (fixed) Weight (random)
Cho et al. 2014 30 -0.04 [-0.39; 0.32] 64.3% 36.8%
Lopes et al. (RBD) 2015 12 -0.79 [-0.94; -0.40] 21.4% 32.8%
Lopes et al. (LBD) 2015 9 0.71 [0.09; 0.93] 14.3% 30.3%
Fixed effect model 51 -0.13 [-0.41; 0.17] 100.0% --
Random effects model -0.10 [-0.77; 0.68] -- 100.0%
Heterogeneity: I^2 = 86%, τ^2 = 0.5675, p < 0.01
-0.5 0 0.5

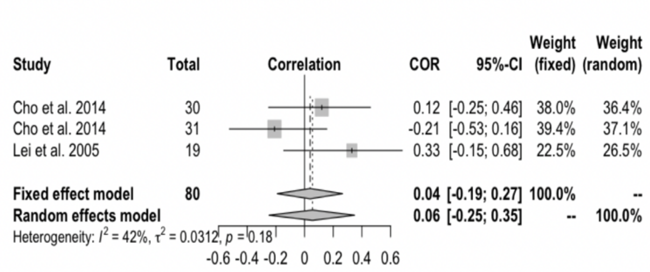

CoP.Surf..Stance
Study Total Correlation COR 95%-CI Weight (fixed) Weight (random)
Lopes et al. (RBD) 2015 12 0.27 [-0.36; 0.73] 60.0% 60.0%
Lopes et al. (LBD) 2015 9 0.29 [-0.46; 0.80] 40.0% 40.0%
Fixed effect model 21 0.28 [-0.22; 0.66] 100.0% --
Random effects model 0.28 [-0.22; 0.66] -- 100.0%
Heterogeneity: I^2 = 0%, τ^2 = 0, p = 0.97
-0.5 0 0.5


CoP.Surf..Swing
Study Total Correlation COR 95%-CI Weight (fixed) Weight (random)
Lopes et al. (RBD) 2015 12 -0.27 [-0.73; 0.36] 60.0% 60.0%
Lopes et al. (LBD) 2015 9 -0.29 [-0.80; 0.46] 40.0% 40.0%
Fixed effect model 21 -0.28 [-0.66; 0.22] 100.0% --
Random effects model -0.28 [-0.66; 0.22] -- 100.0%
Heterogeneity: I^2 = 0%, τ^2 = 0, p = 0.97
-0.5 0 0.5

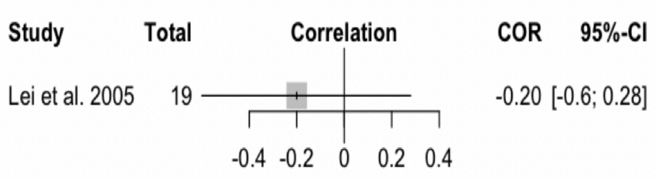
CoP.Surf...CoP.AP.OE



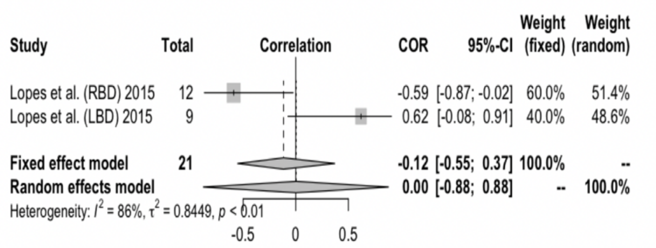
CoP.Surf..TUG



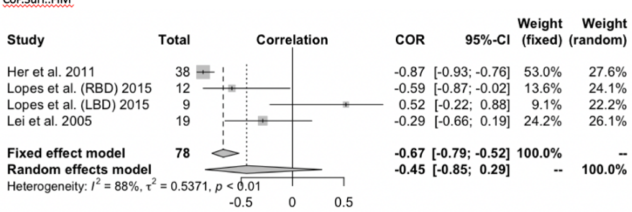
CoP.Surf..Age



CoP.Surf..Motor



CoP.Surf..FIM



Annexe II :

Article 5: Characterization and understanding of the mechanisms of balance disorders in a seated position following a stroke: a cohort study; Karim Jamal, Armel Cretual, Sébastien Cordillet, Aurélie Veislinger, Bruno Laviolle, Florian Bidet, Stéphanie Leplaideur, Isabelle Bonan.

Caractérisation et compréhension des mécanismes de perturbations posturales en position assise suite à un accident vasculaire cérébral

Ce protocole a fait l'objet d'une soumission dans le journal *« BMJ Open »*.

Characterization and understanding of the mechanisms of balance disorders in a seated position following a stroke: protocol of a cohort study

This article has been submitted to the journal "*BMJ Open*"

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Abstract

Introduction : One of the causes of disability in stroke patients is postural disturbances which can result in a disturbance of balance in the sitting position. To date, the mechanisms of these postural disturbances in the seated position in stroke patients have not been fully set out. To add, sitting posture disorders only benefit from few instrumental measurement tools outside of clinical measurement scales. The objective of this study is to characterize the disorders of the patient's sitting posture via a new evaluation device and to relate the results obtained to the characteristics of hemiplegia and disorders of spatial representation.

Methods and Analysis: 16 stroke patients (8 right and 8 left) with less than 3 months of delay post-stroke with a seated balance disorder will be tested alongside 16 age-matched healthy subjects. Sitting balance disorders will then be accessed using a sensor pad associated with head and trunk measurements via inertial measurement units and the Optitrack device® and will conclude 4 tests; 2 with open eyes and 2 with closed eyes each with a duration of 30 seconds. The data on sitting balance disorders will be associated to the characteristics of hemiplegia (motor skills, sensitivity, spasticity, pushing syndrome, hemineglect) and the perception of the spatial representation of the body (straight ahead, longitudinal axis, visual vertical) by a multivariate variance analysis.

Key words : stroke, sitting balance, sensor pad, inertial measurement units

Ethics and dissemination : This study was approved by the "Comité de protection des Personnes , France (number CPP 1-19-081 SI 544)

Registration : Clinicaltrial.gov NCT04152616

Strengths and limitations of this study

- This study will help to better understand these postural disturbances in the seated position in stroke patients and in particular its relation with spatial cognition.
- To characterize the disorders of the patient's sitting posture via a new evaluation device composed of a sensor pad and two inertial measurement units.
- To validate the reproducibility of this new evaluation device in measuring postural disturbance in the seated position.
- Our count of stroke patients in each group may however not be enough, thus suggesting to carry out a second test and this time with a larger population.
- The reproducibility of the tools will be performed with the same researchers and Inter-examiner reproducibility will be confirmed.

Introduction

One of the causes of disability in stroke patients is postural disturbances [1].These postural disturbances cause a greater risk of falls and are a source of loss of autonomy for these patients [2]. In the standing position, during an evaluation on a force platform, these balance disorders can be characterized by postural asymmetry [3] which results in a greater displacement of the center of pressure on the lesion side and thus providing a greater percentage of support on the lower non-paretic limb (Weight-Bearing Asymmetry (WBA)). Today, the mechanisms of balance disorders in standing position are better understood. Indeed, in addition to sensory and motor deficits [4–6], spatial cognitive disorders also contribute to these postural disturbances, particularly in right brain damage stroke [7,8]. Many authors agree on a localization of spatial cognition and in particular the mental elaboration of the representation of the body in space according to the different types of spatial frame at the level of the right cerebral hemisphere [9,10]. This would be the reason why patients with right brain damage have a more precarious and time-consuming balance to rehabilitate rather than patients with lesions located in the left hemisphere [7,11].

Postural disturbances can also result in a disturbance of balance in the sitting position. The persistence of these disorders in a sitting position is a poor prognosis for the recovery of transfers, standing and walking [12–14]. Thus far, the mechanisms of these postural disturbances in the seated position in stroke patients have not been fully described. To this effect many discrepancies are observed in the literature. Although it appears that for a majority of authors [13,15,16], stroke patients have greater sitting asymmetry than healthy subjects, not all are unanimous [17]. Moreover, amongst these authors, highlighting this asymmetry in the sitting position, some found a more pronounced lateral plane [18] while others find a more pronounced imbalance in the antero-posterior plane [13]. Apart from the motor and sensory deficit, the postural asymmetry found in the sitting position could also be due to a spatial cognitive disorder. Additionally, the authors Au-Yeung *et al.* [15] showed a more pronounced deviation in patients with a localized stroke in the right hemisphere. This result in agreement with the relationship between posturography data from the sitting position and the postural vertical suggests the involvement of spatial cognition in balance disorders in the sitting position [19]. Contrarily, given that the authors Van Nes *et al.* [18] did not find identical results in their study, it suggests that this hypothesis still remains to be confirmed.

Unlike standing posture disorders, which are commonly assessed on the force platforms in rehabilitation, sitting posture disorders benefit only from a few instrumental measurement tools outside clinical measurement scales [20]. Also, in the literature, a wide variety of evaluation methods by instrumental measures are proposed, but sadly not validated [13,15–18,21]. In some cases, the patient was placed directly on the force platform [13,16,17,21], while in others the choice to sit the patient on a chair positioned on the platform was preferred [18]. At the outset, the sensor pad is typically used to adapt the bases for patients with pressure ulcers but may also be help to quantify the postural base [22]. However, when the involvement of the head and trunk in the sitting posture are apparent, the details are well documented in the literature [15] which leads to assume that for the addition of an assessment, the trunk and head appear to be essential. To our knowledge, few authors have studied the sitting balance disorders in a quantified manner by taking into account both the posture of the trunk associated with the head and measurement of postural asymmetry [23].

Thus the purpose of this study is to characterize the disorders of the patient's sitting posture using a new evaluation device. Combining hemiplegia clinical data and spatial representation disorders, this study will improve knowledge about the sitting balance disabilities after stroke. The expected hypothesis is a varied typology of sitting posture disorders after stroke (compared to healthy subjects) and a more pronounced disorder in right brain damage patients, due in part, to spatial cognitive disorders.

The objectives are :

- To compare the sitting posture of the stroke patient with that of a healthy subject.
- To characterize the involvement of the head and trunk in a sitting posture in stroke patients and healthy subjects.
- To compare the sitting posture by taking into consideration the head and trunk data between stroke patients and healthy subjects and between right and left stroke patients.
- To relate sitting posture data to hemiplegia characteristics, spatial representation disorders and clinical scales.
- To relate the head and trunk data to hemiplegia characteristics, spatial representation disorders and clinical scales.
- To validate tools (sensor pad and Inertial measurement units) in correlation with the Optitrack® device.

Methods and Analysis

Patients

The participants will be recruited among stroke patients hospitalized in the Physical and Rehabilitation Medical department of the University Hospital of Rennes. All patients will receive information concerning the protocol and will have to sign the consent form before inaugurating the protocol. The inclusion criteria will be a right or left brain unique sustentoriel damage, less than 3 months after stroke, and be under 80 years old. The patients will have to be able to sit for 30 seconds with eyes closed without support so as to perform the assessment on the sensor pad. A score under 23/36 for the functional test PASS (postural assessment of scale of stroke) will be required in order to exclude the standing patients of the inclusion. Patients will not been included if the stroke is located in the brain stem and if they have a medical history with another symptomatic stroke, orthopaedic or rheumatological pathology affecting the distribution center of pressure when sitting. Patients with a visual disability that will not allow assessment, and those with major comprehension disorders will be excluded.

A preliminary study on 11 healthy subjects showed an average pressure center shift value of -1mm+/-5. Thus the difference between healthy subjects and stroke patients, assuming a ratio of σ / δ =1 with α =0.05 and a power of β=80% in bilateral formulation would estimate an inclusion of 32 subjects, i.e. 16 healthy subjects and 16 stroke patients. To facilitate the analysis of secondary criteria, ideally 8 patients with right and 8 with left strokes will be included. Patients will be included consecutively until the maximum number of evaluable patients is attained in each group (8 right and 8 left brain damage).

Evaluations

Instrumental evaluation of posture

- Sensor pad (figure1)

Postural assessment of the patient will be performed using a sensor pad (BodiTrak® Seat pressure mapping system) along with a thin mattress (size 32X32) made up of sensors usually used to adapt the bases of patients with pressure ulcers. The subject will be positioned in a sitting position on the pressure sheet with the legs hanging and the upper limbs relaxed on his knees. The percentage of the weight on the nonparetic limb (WBA), mean médiolateral (Xm), and anterolateral (Ym) position of the center of pressure (COP) (mm) and surface (mm^2) shall be calculated as the mean of four trials, each lasting 30 s – two with open eyes (OP) and two with closed eyes, with the patient wearing a blindfold (CE).

- Inertial measurement units (figure 2)

Trunk and head movements will be analyzed by inertial measurement units (IMU) (Xsens®) by estimating the variations in orientation between conditions. The IMUs estimate the orientation of the sensor in a land reference frame. The anatomical orientation of the segments is calculated after correction of the sensor orientation. This correction is quantified by a quick calibration procedure.

- Optitrack® device

The evaluation of posture (orientation of pelvis, trunk and head) will be measured using an optoelectronic system. The system includes 16 infrared cameras (Flex 3, Optitrack, Natural Point). To calculate the orientation of the marker segments, the markers are placed on anatomical markers in accordance with the recommendations of the International Society of Biomechanics. The 3D orientation of the pelvis/trunk/neck segments allows modeling the posture as a 3 rigid solids system connected by two joints with a 3 degrees variance of freedom. The angles are used to describe the movements of the trunk ; forward/backward tilt in the sagittal plane, inclination of the hemiplegic side or the healthy side in the frontal plane, torsional movements in the transverse plane. The measurement also makes it possible to describe the posture of the head in relation to the trunk at similar angles.

Instrumental evaluation of posture

- Scale for Lateropulsion (SCALA)[24]

With a score of 50, this scale evaluates the lateropulsion or resistance of the patient to the examiner who pushes him laterally to the side of his lesion in different positions (sitting, standing, walking).

- Postural Assessment Scale for Stroke (PASS; /36)[25]

This scale includes 12 items that assess the specific balance of stroke patients in the acute period. It is made up of two parts: the first five items (score /15) concern the maintenance of different postures in a sitting and standing position, the other seven (score /21) evaluate the control of balance during posture changes (turns, sitting-standing, picking up an object on the ground...). The total score is 36. PASS has been fully validated and is widely used clinically in PRM services, but also in scientific studies.

Evaluation of spatial representation

- Subjective Straight Ahead (SSA) haptic [26] (figure 3)

Evaluation of the SSA haptic will be carried out on a measuring table on which the patient will be required to move his hand while blindfolded. The table is graduated, and a one-degree angle corresponds to one linear cm. The midsagittal line coincides with the middle of the table with the head and trunk of the patient placed in strict alignment. From a starting position, in which the arm of the patient is placed by the examiner, patients will be instructed to point "straight ahead", so as to divide the space into two parts, with no imposed time limit in 10 starting positions in a randomized sequence (-10°/5°/-15°/10°/30°/-5°/-20°/15°/-30°/20°), with the right arm for RBD and the left arm for LBD patients. A positive sign corresponds to the ipsilesional side. The value (in degrees up to 0.5°) obtained shall consist of the mean (M) and standard deviation of 10 measurements (SD).

- The Longitudinal Body Axis (LBA) [27] (figure 4)

Evaluation of the LBA will be performed using a light strip in front of the patient in a supine position, in complete darkness, with the head, trunk, and lower limbs aligned and maintained by cushions. The rotation center of the light wand will be aligned with the patient's navel and the plumb line. The light wand will then be moved around its axis of rotation by the examiner from a starting position, with 10 starting positions, in a randomized sequence (-10°/5°/-15°/10°/30°/-5°/-20°/15°/-30°/20°). The patient shall be given the task of indicating when the strip is parallel to the axis of his body. No visual reference other than the wand will be available and there is no time limit. A positive sign corresponds to the ipsilesional side. The value (in degrees up to 0.5°) obtained shall consist of the M and SD of 10 measurements.

- Subjective Visual Vertical (SVV) (figure 5)

Evaluation of the SVV will be performed in a sitting position with the head fixed, using a virtual reality helmet (Oculus®, Virtualis). From an imposed starting position, the patient will be presented to a blue background with an oblique red line with 10 different starting positions in a random sequence (-10°/5°/-15°/10°/30°/-5°/-20°/15°/-30°/20°). No visual reference, other than the red line, will be available and there is no time limit. The patient shall be given the task of indicating when the line is aligned with the vertical axis and the position of the head will be monitored throughout the exercise. A positive sign corresponds to the ipsilesional side. The value (in degrees up to 0.5°) shall consist of the M and SD of 10 measurements.

Characteristics of hemiplegia

Clinical tests will be conducted, such as a motricity test (motricity index), which evaluates hip flexion, knee extension, and ankle dorsiflexion, with a score of 100 [28]; a spasticity test (Ashworth modified MAS) [29], which targets the sural triceps, quadriceps, and adductors; and a sensory test, consisting of two clinical examinations and the sum of the obtained results. The first sensory test will consist of tactile localization on the lower limb, while the second, an arthrokinetic sensitivity test on the knee, ankle, and toes. It is assumed that the rating for the different zones will be identical for both tests: 0 for anesthesia, 1 for disturbance, and 2 for normal sensitivity. Four tests of visuospatial neglect will also be conducted: the bell cancellation test [30], 20-cm line bisection [30], the Fluff test [31], and the OTA test, which will be performed to differentiate body-centered and stimulus-centered neglect [32]. Visuospatial neglect shall be considered if the patient had at least three of four positive tests. Finally, the presence or absence of homonymous hemianopia will be clinically tested with a confrontation visual field test on each quadrant using a ball.

Protocol

After a time of installation of the Optitrack® device's measurement sensors and two inertial measurement units (one placed on the subject's trunk facing the sternum fixed with a headband and the second at the level of the head also held with a headband), the subject will perform an evaluation of the balance sitting on the sensor pad; the movements of the head and trunk will be analyzed by the Optitrack® device and by the two Inertial measurement units. The subject will perform 4 tests , each consisting of 30-seconds, two with eyes open and two with eyes closed. A rest period may be taken between each assessment depending on the subjects physical status. After a rest period of 30 minutes, a new assessment of the sitting posture will be carried out to assess the reproducibility of the tools (sensor pad, Inertial measurement units, Optitrack®).

Statistical analysis

Statistical analysis will be performed using the SAS 9.3 Software. Clinical, postural asymmetry and spatial representation data for stroke patients will be compared to those of healthy subjects using a Student or Mann-Whitney test when the distribution is not normal for quantitative variables. In the case of qualitative variables, the $\chi 2$ test, or the Fisher test will be employed, if necessary.

Postural asymmetry data (obtained by the sensor pad) and changes in head/trunk and trunk/basin angle of stroke patients (obtained by both accelerometers as well as by the Optitrack® device) will be related to the characteristics of hemiplegia (age, sex, stroke delays, motor, sensitivity, spasticity, hemineglect, PASS and SCALA) as well as spatial representation disorders (SSA, LBA and SVV) on both patient groups (right and left stroke) by linear regression or ANOVA when the distribution is normal or by ANOVA on the rank otherwise. A multivariate model will then be performed by selecting the significant parameters at 0.20 in univariate or clinically relevant, thereafter a stepwise top-down selection will be performed. The reproducibility will be analyzed by an intra-class correlation test. All tests will be carried out bilaterally. All tests will be conducted at a significance level of $p = 0.05$.

Ethics and dissemination

This study was approved by Comité de Protection des Personnes (number CPP 1-19-081 SI 5441) and registered on clinicaltrial.gov NCT04152616.

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Authors' contributions

KJ, AC, BL, SL and IB designed the experimental protocol. KJ, AV, IB conducted the ethics and dissemination. KJ, AC, SC, FB will ran the study. KJ, AC, SC, FB, BL will analyze the data and KJ, AC, SC, FB, SL and IB will interpret the data. KJ, AC, SC, FB, SL and IB will be involved in writing the article. All authors have reviewed and agreed to the final protocol submission

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Competing interests statement.

None declared

Figure 1: sensor pad (BodiTrak® Seat pressure mapping system) (http://boditrak.com)

Figure 2 : inertial measurement units (IMU) (Xsens®) (https://www.xsens.com/products/mtw-development-kit-lite/)

Figure 3 : Subjective Straight Ahead (SSA)

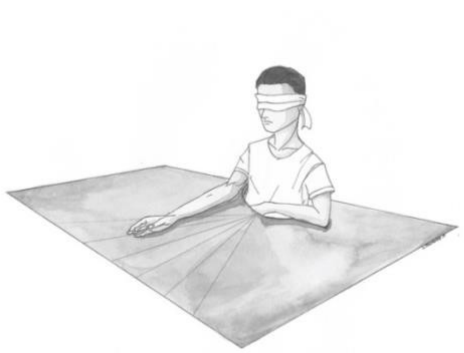
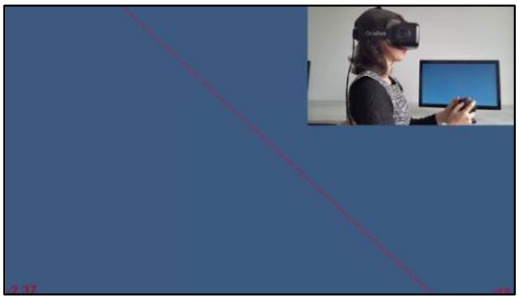


Figure 4 : The Longitudinal Body Axis (LBA)

Figure 5 : Subjective Visual Vertical (SVV)



Annexe III : Valorisation des travaux de thèse

PUBLICATIONS

Articles publiés dans une revue internationale avec comité de lecture (n=6)

1er Auteur (n=3)

1) Disturbances of spatial reference frame and postural asymmetry after a chronic stroke. **Jamal K,** Leplaideur S, Rousseau C, Chochina L, Moulinet-Raillon A, Bonan I. Exp Brain Res. août 2018;236(8):2377-85. doi: 10.1007/s00221-018-5308-1.

2) The effects of neck muscle vibration on postural orientation and spatial perception: a systematic review. **Jamal K,** Leplaideur S, Leblanche F, Moulinet-Raillon A, Honoré T, Bonan I. Neurophysiol Clin.Nov 2019

3) The effects of repetitive neck-muscle vibration on postural disturbances after a chronic stroke. Jamal K, Leplaideur S, Rousseau C, Cordillet S, Raillon AM, Butet S, et al. Neurophysiol Clin. mars 2020;doi : 10.1016/j.neucli.2020.01.005

Co-auteurs (n=3)

1) Effect of sensorial stimulations on postural disturbances related to spatial cognition disorders after stroke. Bonan, I., Chochina, L., Moulinet-Raillon, A., Leblong, E., **Jamal, K**., Challois-Leplaideur, S., 2015. Neurophysiol. Clin. Clin. Neurophysiol. 45, 297–303. doi: 10.1016/j.neucli.2015.09.006

2) Short-term effect of neck muscle vibration on postural disturbances in stroke patients. Leplaideur, S., Leblong, E., **Jamal, K**., Rousseau, C., Raillon, A.M., Coignard, P., Damphousse, M., Bonan, I., 2016. Exp. Brain Res. 1–9. doi: 10.1007/s00221-0

3) Difference between individuals with left and right hemiparesis in the effect of gluteus medius vibration on body weight shifting. Bonan, I., Butet, S., **Jamal, K**., Yelnik, A., Tasseel Ponche, S., Leplaideur, S., Neurophysiol. Clin. Neurophysiol. doi: 10.1016/j.neucli.2017.08.00

COMMUNICATIONS

Communications orales en congrès internationaux (n=4)

1er Auteur (n=2)

1) The long-lasting effects of repetitive neck muscle vibrations on postural disturbances in standing position and on spatial frame reference in chronic stroke. International Society Physical Rehabilitation Medicine (ISPRM) 2018, Paris (France)

2) Difference between neck muscle vibration and gluteus muscle vibration on standing balance in healthy subjects. **Jamal K,** Cretual A, Cordillet S, Rousseau C, Leplaideur S, Bonan I. Société Francophone Posture, Équilibre et Locomotion (SOFPEL) 2019 Montréal (Canada).

Co-auteur (n=2)

1) Amélioration de l'asymétrie posturale par stimulation sensorielle après Accident vaculaire Cérébral. Bonan I. **Jamal K.**, Challois-Leplaideur S, Chochina L., Raillon-Moulinet A-L. Société Francophone Posture, Équilibre et Locomotion (SOFPEL) 2019 Montréal (Canada).

2) L'application de vibration sur les muscles du cou peut-elle modifier l'exploration visuelle d'oeuvres d'art ? Duclos C., Bonan I., Duclos N., Poncet F., Verdugo P., **Jamal K.** Société Francophone Posture, Équilibre et Locomotion (SOFPEL) 2019 Montréal (Canada).

Communications orales en congrès nationaux (n=11)

1er Auteur (n=7)

1) Relation entre les perturbations de la représentation égocentrique et l'équilibres après un AVC **Jamal K.**, Challois-Leplaideur S., Leblond E., Chochina L., Raillon-Moulinet A-L, Bonan I. Société Francophone Posture, Équilibre et Locomotion (SOFPEL) 2015, Paris (France) (http://dx.doi.org/10.1016/j.neucli.2015.10.017)

2) Comparaison de l'effet de vibrations cervicales et de vibrations du muscle gluteus medius sur l'équilibre postural statique de sujets sains **Jamal K.**, Challois-Leplaideur S., Leblond E., Chochina L., Raillon-Moulinet A-L, Bonan I. Société Francophone Posture, Équilibre et Locomotion (SOFPEL) 2015, Paris (France) (https://doi.org/10.1016/j.neucli.2015.10.023)

3) The long-lasting effects of repetitive neck muscles vibrations on postural disturbances in standing position and on spatial frame of reference in chronic stroke. **Jamal K.**, Challois-Leplaideur S, Chochina L.,Raillon-Moulinet A-L, Bonan I. Société Française de Médecine Physique et Réadaptation (SOFMER) 2017 Nancy (France) (https://doi.org/10.1016/j.rehab.2017.07.021)

4) Disturbances of spatial reference frame and postural asymmetry after a chronic stroke. **Jamal K**, Challois-Leplaideur S, Chochina L., Raillon-Moulinet A-L, Bonan I Société Française de Médecine Physique et Réadaptation (SOFMER) 2017 Nancy (France)

5) The long-lasting effects of repetitive neck muscles vibrations on postural disturbances in standing position and on spatial frame of reference in chronic stroke. **Jamal K.**, Challois-Leplaideur S, Chochina L., Raillon-Moulinet A-L, Bonan I. Société Francophone Posture, Équilibre et Locomotion (SOFPEL) 2017 Montpellier (France)

6) Effets à long terme des vibrations répétés du muscle gluteus medius sur l'asymétrie posturale et sur la marche après un AVC chronique: étude pilote (résultats préliminaires) **Jamal K,** Lucas T, Leplaideur S, Butet S, Honoré T, Bonan I. Société Francophone Posture, Équilibre et Locomotion (SOFPEL) 2018 Amiens (France) DOI 10.1016/j.neucli.2018.10.020

7) Effets d'un programme de vibration des muscles du cou sur les troubles de l'équilibre du patient post-AVC **Jamal K,** Leplaideur S, Chochina L., Raillon-Moulinet A-L, Butet S, Bonan I. Journée Française de la Recherche en Santé (JFRS) 2019 Angers (France)

Co-auteur (n=4)

1) Effect of neck muscles gluteus medius vibrations on standing balance in healthy subjects. Leplaideur S, **Jamal K,** Leblong E, Chochina L, Bonan I. Société Française de Médecine Physique et Réadaptation (SOFMER) 2015 Montpellier (France) (https://doi.org/10.1016/j.rehab.2015.07.267)

2) Effects of vibration on the bearing asymmetry walking in chronic stroke patients. Leblong E, Cordillet S, Leplaideur S, Cretual A, Chochina L, **Jamal K**, Bonan I. Société Francophone Posture, Équilibre et Locomotion (SOFPEL) 2015, Paris (France) (http://dx.doi.org/10.1016/j.rehab.2015.07.367)

3) Le centre de masse, une variable posturale pertinente dans l'analyse d'une tâche dynamique d'évitement chez les patients post-AVC? Bethuel A, Cordillet S, **Jamal K**, Cretual A, Bonan I. Société Francophone Posture, Équilibre et Locomotion (SOFPEL) 2016 Nancy (France) (https://doi.org/10.1016/j.neucli.2016.09.023)

4) Effet de l'adaptation prismatique combinée ou non à des vibrations de muscles du cou sur l'asymétrie posturale après AVC récent: résultats préliminaires d'un essai randomisé contrôlé multicentrique. Leplaideur S, Bonan I, Boyer F, Chochina C, Yelnik A, Rode G, Rousseaux M, Paysant J, Perennou D, **Jamal K.** Société Française de Médecine Physique et Réadaptation (SOFMER) 2019 Bordeaux (France)

Communications affichées en congrès internationaux (n=7)

1er Auteur (n=6)

1) Disturbances of spatial reference frame and postural asymmetry after a chronic stroke, **Jamal K**., Challois-Leplaideur S, Chochina L., Raillon-Moulinet A-L, Bonan I. International Society Physical Rehabilitation Medicine (ISPRM) 2016 Buenos Aires (Argentine)

2) Effect of neck muscles vibration on spatial perception and postural balance: a scoping review. **Jamal k.,** Leplaideur S., Leblanche F, Moulinet-Raillon A., Honore T, Bonan I, International Society Physical Rehabilitation Medicine (ISPRM) 2018 Paris (France) DOI 10.1016/j.rehab.2018.05.811

3) Disturbances of spatial reference frame and postural asymmetry after a chronic stroke. **Jamal K**., Challois-Leplaideur S, Chochina L., Raillon-Moulinet A-L, Bonan I. International Society Physical Rehabilitation Medicine (ISPRM) 2018 Paris (France)

4) Difference between neck muscle vibration and gluteus muscle vibration on standing balance in healthy subjects. **Jamal K,** Cretual A, Cordillet S, Rousseau C, Leplaideur S, Bonan I. International Society Physical Rehabilitation Medicine (ISPRM) 2019, Kobe, (Japon)

5) The effects of repetitive neck-muscle vibration on postural disturbances after a chronic stroke. **Jamal K.,** Leplaideur S, Chochina L., Raillon-Moulinet A-L, Bonan I. International Society Physical Rehabilitation Medicine (ISPRM) 2019, Kobe, (Japon)

6) Postural asymmetry and hemiplegia post-stroke : a systematic review and meta-analysis. **Jamal K,** Leplaideur S, Lucas T, Butet S, Cogné M, Bonan I. Société Francophone Posture, Équilibre et Locomotion (SOFPEL) 2019, Montréal (Canada)

Co-auteur (n=1)

1) Cortical activity, body midsagittal representation there one or many egocentric space neural computation mechanism? Bonan I, Raillon-Moulinet A-L, Bannier E, Chochina L, **Jamal K**, Ferre J-C, Leplaideur S International Society Physical Rehabilitation Medicine (ISPRM) 2016 Buenos Aires (Argentine)

Communications affichées en congrès nationaux (n=5)

1er Auteur

1) Effet des vibrations des muscles du cou sur la perception spatiale et l'équilibre postural : revue de littérature. **Jamal k.,** Leplaideur S., Leblanche F, Moulinet-Raillon A., Honore T, Bonan I, Société Francophone Posture, Équilibre et Locomotion (SOFPEL) 2018 Amiens (France) DOI10.1016/j.neucli.2018.10.048

2) Difference between neck muscle vibration and gluteus muscle vibration on standing balance in healthy subjects. **Jamal K,** Cretual A, Cordillet S, Rousseau C, Leplaideur S, Bonan I. Société Française de Médecine Physique et Réadaptation (SOFMER) 2019, Bordeaux (France)

3) Postural asymmetry and hemiplegia post-stroke : a systematic review and meta-analysis. **Jamal K,** Leplaideur S, Lucas T, Butet S, Cogné M, Bonan I. Société Française de Médecine Physique et Réadaptation (SOFMER) 2019 Bordeaux (France)

4) Caractérisation et compréhension des mécanismes de troubles de l'équilibre en position assise suite à un Accident Vasculaire Cérébral. **Jamal K,** Cretual A, Cordillet S, Veisingler A, Laviolle B, Bidet F, Leplaideur S, Bonan I. Journée Française de la Recherche en Santé (JFRS) 2019 Angers (France)

5) L'asymétrie posturale et hémiplégie : une revue systématique et méta-analyse. **Jamal K,** Leplaideur S, Lucas T, Butet S, Cogné M, Bonan I. Journée Française de la Recherche en Santé (JFRS) 2019 Angers (France)

Titre : Effets des stimulations sensorielles par vibrations des muscles du cou sur les perturbations posturales secondaires aux troubles de la représentation spatiale.

Mots clés : accident vasculaire cérébral, perturbation posturale, représentation spatiale, vibration musculaire, muscles du cou,

Résumé : Une des causes de handicap chez le patient victime d'un AVC sont les perturbations posturales à l'origine d'un plus grand risque de chute. A ce jour, bien qu'un trouble de la représentation spatiale semble être impliqué dans ces mécanismes d'action, ceux-ci ne sont pas encore totalement compris. L'objectif de cette thèse est d'étudier l'implication de la représentation spatiale dans les troubles posturaux suite à un AVC et plus spécifiquement dans l'asymétrie d'appui puis d'évaluer l'effet de stimulations proprioceptives par vibration des muscles du cou à la fois sur l'asymétrie d'appui et sur la représentation spatiale afin de mieux appréhender les mécanismes d'action de cette stimulation sensorielle. Nos travaux confirment la présence d'asymétrie d'appui en phase aiguë mais également persistante en phase chronique avec un déficit légèrement plus marqué pour les patients AVC droit. Les troubles de la représentation spatiale semblent être plus impliqués dans les mécanismes de ce comportement postural que le déficit moteur et/ou sensitif. Nos travaux vont dans le sens du rôle de l'hémisphère droit dans la représentation spatiale. Ces résultats pourraient expliquer l'asymétrie d'appui plus marqué dans le groupe de patients avec une lésion au niveau de l'hémisphère droit dû à un trouble de la représentation spatiale. Les stimulations sensorielles par vibration musculaire constituent un outil intéressant dans le domaine de la rééducation de par leur action à la fois sur la posture et la représentation spatiale. L'application de stimulations sensorielles de façon répétée réduit l'asymétrie d'appui dans le groupe de patients AVC droit chroniques à la fin du programme de 10 sessions avec un léger maintien à distance, suggérant l'intérêt d'appliquer ces stimulations en rééducation et, notamment, dans la prise en charge de patients avec un trouble de l'équilibre secondaire à un trouble de la représentation spatiale.

Title : Effects of sensory stimulation by neck muscles vibrations on postural disturbances secondary to spatial representation disorders after a stroke.

Keywords : stroke, postural disturbance, spatial representation, muscle vibration, neck muscles,

One of the causes of disability in stroke patients is postural disturbances which increases the risk of falls. To date, even though a spatial representation disorder appears to be involved in these mechanisms of action, they are yet not fully understood. The objective of this thesis is to study the involvement of spatial representation in postural disorders following a stroke and more specifically in supporting asymmetry and then to evaluate the effect of proprioceptive stimuli by vibration of the neck muscles on both supporting asymmetry and spatial representation in order to better understand the mechanisms of action of this sensory stimulation. Our work confirms the presence of support asymmetry in the acute phase, but also persistent in the chronic phase with a slightly more pronounced deficit for patients with a right brain stroke. Disorders of spatial representation seem to be more involved in the mechanisms of action of this postural behavior rather than motor and/or sensory deficits. Our work supports the role of the right hemisphere in spatial representation; and these results could explain the more pronounced asymmetry of support in the group of patients with a lesion in the right hemisphere due to a spatial representation disorder. Sensory stimulation by muscle vibration is an interesting tool in the field of rehabilitation because of its action on both posture and spatial representation. The repeated application of sensory stimuli reduces the support asymmetry in the group of chronic right brain damage stroke patients at the end of the 10-sessions program, with a slight distance maintenance, which suggests the value of applying these stimuli in rehabilitation and particularly in the management of patients with a secondary balance disorder in a spatial representation disorder.