

Université de Montréal

Effects of intense and unpredictable perturbations during gait training in individuals
with hemiparesis due to cerebrovascular accident at the chronic phase

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Cette thèse intitulée :

Effects of intense and unpredictable perturbations during gait training in individuals with hemiparesis due to cerebrovascular accident at the chronic phase

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Résumé

Chez des personnes présentant une hémiparésie à la suite d'un accident vasculaire cérébral (AVC), les carences de l'équilibre dynamique pendant la marche sont fréquentes en raison de l'altération des réponses posturales réactives et anticipées. Toutefois, les interventions traditionnelles basées sur la réalisation de mouvements volontaires ne visent pas l'amélioration de ces réponses qui sous-tendent l'amélioration de l'équilibre dynamique. Des études portant sur l'application spécifique de perturbations imprévisibles de la marche ont rapporté des améliorations limitées des capacités de marche et d'équilibre chez cette population. Par ailleurs, en raison de l'utilisation concomitante d'autres interventions ou de l'absence d'un groupe témoin dans ces études, il n'est pas possible d'attribuer les changements rapportés spécifiquement aux perturbations imprévisibles de la marche. D'un autre côté, nos connaissances sur les mécanismes sous-jacents à l'amélioration de l'équilibre dynamique chez les individus ayant subi un AVC en phase chronique sont peu développées. Les principaux objectifs de cette thèse sont donc : 1) de comparer les effets de perturbations intenses et imprévisibles de la marche sur l'équilibre et les capacités de marche avec une intervention contrôle incluant uniquement de la marche sur un tapis roulant à double courroie ; et 2) de comparer les déterminants biomécaniques de l'équilibre dynamique entre un groupe de participants sains ($n=15$) et deux groupes de participants présentant une hémiparésie en phase chronique à la suite d'un AVC [les groupes AVC rapide (vitesse au sol ≥ 1 m/s, $n=20$) et AVC lent (vitesse au sol < 1 m/s, $n=18$)] ainsi qu'entre les groupes d'AVC. Pour atteindre le premier objectif, 18 participants ont été recrutés et assignés par

randomisation avec équilibre des co-variables (“covariate adaptive randomization”) au groupe expérimental (n=10) ou au groupe de comparaison (n=8) dans un essai pilote contrôlé randomisé. Les participants du groupe de comparaison marchait simplement sur un tapis roulant. Les deux groupes ont reçu neuf sessions d’entraînement réparties sur trois semaines. L’amélioration de l’équilibre dynamique (évaluée par le biais du MiniBESTest) était la seule différence statistiquement significative observée entre le groupe expérimental et le groupe de comparaison à la suite de l’intervention. Pour atteindre le deuxième objectif, les déterminants biomécaniques de l’équilibre dynamique ont été comparés à six moments du cycle de marche entre le groupe sain, le groupe AVC rapide et le groupe AVC lent. Les déterminants biomécaniques étaient la longueur et la largeur de la base de support (BOS), en plus des positions relatives du centre de pression (COP), du centre de masse (COM) et du COM extrapolé (XCOM) dans les axes antéropostérieur et latéral de la BOS. Les résultats indiquent que les participants présentant une hémiparésie à la suite d’un AVC en phase chronique présentent des variables biomécaniques altérées par rapport aux participants sains, surtout lors de la phase d’appui unipodal, suggérant une stratégie pour maintenir leur équilibre dynamique. Dans l’ensemble, les résultats suggèrent que l’intervention expérimentale a amélioré l’équilibre dynamique pendant la marche, probablement en raison de la normalisation de ses déterminants biomécaniques chez les individus ayant subi un AVC en phase chronique.

Mots-clés : Perturbations imprévisibles, équilibre dynamique, mobilité, vitesse de marche, base de support, centre de pression, centre de masse, biomécanique

Abstract

In individuals with hemiparesis following a cerebrovascular accident (CVA) at the chronic phase, the deficits of balance during gait are common due to the impairment of the reactive and anticipatory postural responses. However, traditional interventions based on voluntary movements do not target the improvement of these responses for the improvement of dynamic balance. Studies involving the applications of unpredictable gait perturbations reported limited improvements in balance and gait abilities in this population. Furthermore, due to the concomitant use of other interventions or the absence of a control group in these studies, the attribution of the reported changes of these studies specifically to unpredictable gait perturbations is not possible. On the other hand, our knowledge about the underlying mechanisms of improvement of dynamic balance in individuals at the chronic phase post-stroke is limited. Thus, the main objectives of this thesis were: 1) to compare the effects of intense and unpredictable gait perturbations on balance and gait abilities with a control intervention including walking-only on a split-belt treadmill; and 2) to compare biomechanical determinants of dynamic balance between a group of healthy participants ($n=15$) and two groups of hemiparetic participants following CVA at the chronic phase [stroke-fast group (overground gait speed ≥ 1 m/s, $n=20$) and stroke-slow group (overground gait speed < 1 m/s, $n=18$)], as well as between stroke groups. To achieve the first objective, 18 participants were recruited and assigned through covariate adaptive randomization to the experimental group ($n=10$) or the comparison group ($n=8$) in a randomized controlled pilot trial. The participants in the comparison

group walked merely on the treadmill. Both groups received nine training sessions over three weeks. Improvement of dynamic balance (assessed by the MiniBESTest) was the only statistically significant difference observed between the experimental and comparison groups. To reach the second objective, the biomechanical determinants of dynamic balance were compared at six time points of the gait cycle between the healthy group, stroke-fast group and stroke-slow group. The biomechanical determinants were the length and width of the base of support (BOS) in addition to the relative positions of the center of pressure (COP), the center of mass (COM) and the extrapolated COM (XCOM) along the anteroposterior and lateral axes of the BOS. The results indicate that participants with hemiparesis due to CVA at the chronic phase showed altered biomechanical variables compared to healthy participants, particularly at the single support phase of gait, suggesting a strategy to maintain their dynamic balance. Altogether, the findings suggest that the experimental intervention improved dynamic balance during gait probably through the normalization of its biomechanical determinants in individuals in the chronic phase post-stroke.

Keywords: Unpredictable perturbations, dynamic balance, mobility, gait speed, base of support, center of pressure, center of mass, biomechanics

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List of abbreviations and glossary of terms

6-ABC scale: 6-item Activity Specific Balance Confidence scale

6-MWT: Six-minute Walking Test

10-MWT: Ten-Meter Walking Test

m/s: meter per second

m/s²: meter per second square

ms: milliseconds

ABC scale: Activity-specific Balance Confidence scale

ADL: activities of daily living

AP: values in anteroposterior direction (along the anteroposterior axes)

AXONE : Group de loisirs après-AVC du grand Montréal

BAR-TM: Balance-assessment robot and an instrumented treadmill

BBS: Berg Balance Scale

BOS: base of support

CIUSSS: Centre intégré universitaire de santé et de services sociaux

CNS: central nervous system

COM: center of mass

COP: center of pressure

CONSORT: Consolidated Standards of Reporting Trials

CMSA: Chedoke-McMaster Stroke Assessment

CRIR: Center of Interdisciplinary Research in Rehabilitation of Great Montreal

ES: effect size

FAC: Functional Ambulatory Category

fMRI: functional magnetic resonance imaging

FSST: Four-Step Square Test

GRFs: ground reaction forces

Hz: Hertz

IRGLM : Institut de réadaptation Gingras-Lindsay-de-Montréal

LHC: left heel contact

LMS: left midstance

LTO: left toe-off

MCID: Minimal clinically important difference

Mini-BESTest: Mini-Balance Evaluation Systems Test

ML: values mediolateral direction (along the lateral axes)

MOS: margin of stability

NHP: Nottingham Health Profile

NParetic: Non-paretic

RNLI: Reintegration to Normal Living Index

ROM: range of motion

RHC: right toe-off

RMS: right midstance

RTO: right toe-off

SCI: spinal cord injury

SFQ-Mp: Short Feedback Questionnaire, modified for perturbations

TIDieR: Template for Intervention Description and Replication

TIS: Trunk Impairment Scale

TUG: Timed Up and Go

XCOM: extrapolated COM

Glossary of terms:

Faster-belt perturbations: perturbations applied by increasing the speed of one of the belts of a split-belt treadmill to simulate trips

Comparison group: Name of the control group where participants received the gait training program without perturbation in the first part

Experimental group: Name of the experimental group where participants received the gait perturbation training program

Slip: perturbations which lead to backward loss of balance

Slower-belt perturbations: perturbations applied by decreasing the speed of one of the belts of a split-belt treadmill to simulate slips

Stroke-fast group: Name of the stroke group including individuals post-stroke with an overground speed faster than 1 meter per second

Stroke-slow group: Name of the stroke group including individuals post-stroke with an overground speed slower than 1 meter per second

Trip: trips which lead to forward loss of balance

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Chapter 1 General introduction

1-1 General problem

Stroke is defined as a neurological deficit due to a loss of blood flow (Canadian Stroke Best Practice, 2018). There are two main subtypes of stroke, hemorrhagic and ischemic with 20% and 80% of prevalence respectively (Ojaghiahaghghi, Vahdati, Mikaeilpour, & Ramouz, 2017). Sixty-two thousand new strokes occur each year in Canada, on average one per nine minutes, which leads to 400,000 persons who currently live with long-term stroke-related sequels (Heart and Stroke Canada, 2018). Stroke is the primary cause of adult disability (Lavados et al., 2007).

Stroke can lead to motor, sensory, cognitive, and perceptual deficits (Arya, Pandian, Agarwal, Chaudhary, & Joshi, 2021; Tasseel-Ponche, Yelnik, & Bonan, 2015). Muscle weakness after stroke (paresis) (Arene & Hidler, 2009) with a high prevalence of 65% (Wist, Clivaz, & Sattelmayer, 2016) happens due to neurophysiological and structural impairments (Jeon, Kim, Lee, & Kim, 2013). Stroke also frequently leads to somatosensory impairments (Smania, Montagnana, Faccioli, Fiaschi, & Aglioti, 2003) including a loss or altered superficial tactile sense and proprioception (deep sensory signals of joints and muscles) (Kessner et al., 2019).

All these motor and sensory impairments potentially impact walking abilities (Lamontagne, Stephenson, & Fung, 2007) and control of balance during gait (de Oliveira, de Medeiros, Frota, Greters, & Conforto, 2008). Dynamic balance during gait is defined as maintaining the mass of the body over the base of support which is

limited to one foot or both feet during normal gait without any assistive device like a cane (Pollock, Eng, & Garland, 2011). Using a cane, crutch or walker enhances the base of support (Maguire et al., 2012). A specific definition of dynamic balance and its biomechanical determinants are described in detail in section 2.3. Reduced balance abilities are associated with a reduced level of ambulation, the inability to perform activities of daily living (ADL), limited participation in social activities (Tsang, Liao, Chung, & Pang, 2013) and an increased risk of falls (Tyson, Hanley, Chillala, Selley, & Tallis, 2006).

Association between poor balance and multiple fall incidence in individuals at the chronic phase post-stroke (Chumacero-Polanco & Yang, 2017; Lubetzky-Vilnai & Kartin, 2010) underscores the need to identify effective balance training interventions during rehabilitation. So far, the majority of traditional rehabilitation programs aiming to improve the dynamic balance of individuals post-stroke have focused on voluntary movements like gait training or bodyweight shifting (Handelzalts et al., 2019). Voluntary movements lead to the recruitment of anticipatory postural adjustments (Horak, Wrisley, & Frank, 2009; Lee et al., 2018). However, to maintain balance after an unpredictable external perturbation, the reactive postural responses must be activated (Horak et al., 2009). Thus, the traditional interventions have probably a limited impact on delayed reactive postural responses of individuals post-stroke required to maintain balance after a perturbation (Mansfield, et al., 2015b). Addressing impaired muscular reactions using unpredictable perturbations with enough intensity (as a function of acceleration and displacement of the support

surface) and repetition is necessary for effective balance training in this population (Lamontagne & Fung, 2004; Punt et al., 2019).

Furthermore, our knowledge regarding the interaction between altered biomechanical variables affecting dynamic balance and their correlations with scores of clinical measures in individuals at the chronic phase post-stroke is limited. Understanding the underlying mechanisms of dynamic balance during gait by studying the interaction between altered biomechanical variables and clinical variables is important for improving rehabilitation programs. For example, although we know the advantages of intense and unpredictable gait perturbations, we do not know how this kind of intervention affects the determinants of dynamic balance. In light of these considerations, this thesis aimed the following objectives:

- 1) to measure the effects of intense and unpredictable gait perturbation on balance and gait abilities in individuals at the chronic phase post-stroke;
- 2) to study the characteristics of the determinants of dynamic balance during the gait cycle and their relationships with the gait speed and scores of clinical measures in this population.

1-2 Organization of the thesis

The second chapter of the thesis is the literature review. The literature review first explains the characteristics of gait and dynamic balance in healthy individuals. Then, the characteristics of gait and dynamic balance in individuals post-stroke are described. Based on the characteristics of impaired dynamic balance, the specific features of an effective intervention for the improvement of dynamic balance in

participants with stroke at the chronic phase are explained. Then, the impairments of individuals post-stroke in response to unpredictable perturbations during gait are explained. Finally, the characteristics of the previous studies that applied unpredictable gait perturbations in individuals at the chronic phase post-stroke and their findings are described. The thesis included two studies. Chapter 3 presents the main objectives and hypotheses of the thesis, as well as the specific objectives and hypotheses of each of the two studies described in this thesis. The first study is referred as the “randomized controlled trial” and the second study is referred as the “biomechanical study” which is a descriptive and correlational study. Chapter 4 describes the methods used to reach the objectives of the thesis. The results of the two studies are presented in chapter 5. Chapter 6 is the general discussion, where the results of the studies are synthesized and discussed relative to the literature review. Chapter 7, the conclusion, restates the main ideas and arguments of the thesis. Finally, the appendices include consent forms of the studies linked to the thesis, questionnaires used in the studies and published abstracts related to this thesis.

Chapter 2 Literature review

2-1 Gait characteristics in healthy individuals

2-1-1 Definition of gait and its subphases

Gait is defined as a cyclic event that is selected by a person during locomotion (Kang et al., 2021). Swing, stance and double support are the three main phases of gait (Figure 1) (Iosa et al., 2013). The stance phase in non-pathologic gait is defined between heel strike and toe-off, i.e. when one foot is in contact with the floor (Gouelle & Megrot, 2017). The swing phase is defined between toe-off and heel strike, i.e. when the foot is moving forward. Double support phases are defined as the two periods of bilateral contact with the ground, at the beginning and the end of the stance phase (Han, Sun, Suk, & Park, 2019). Sixty to sixty-two percent of each gait cycle is the stance phase, the first and last 10% of that belong to the two double support phases and 38% to 40% represent the swing phase (Schmeltzpfenning & Brauner, 2013).

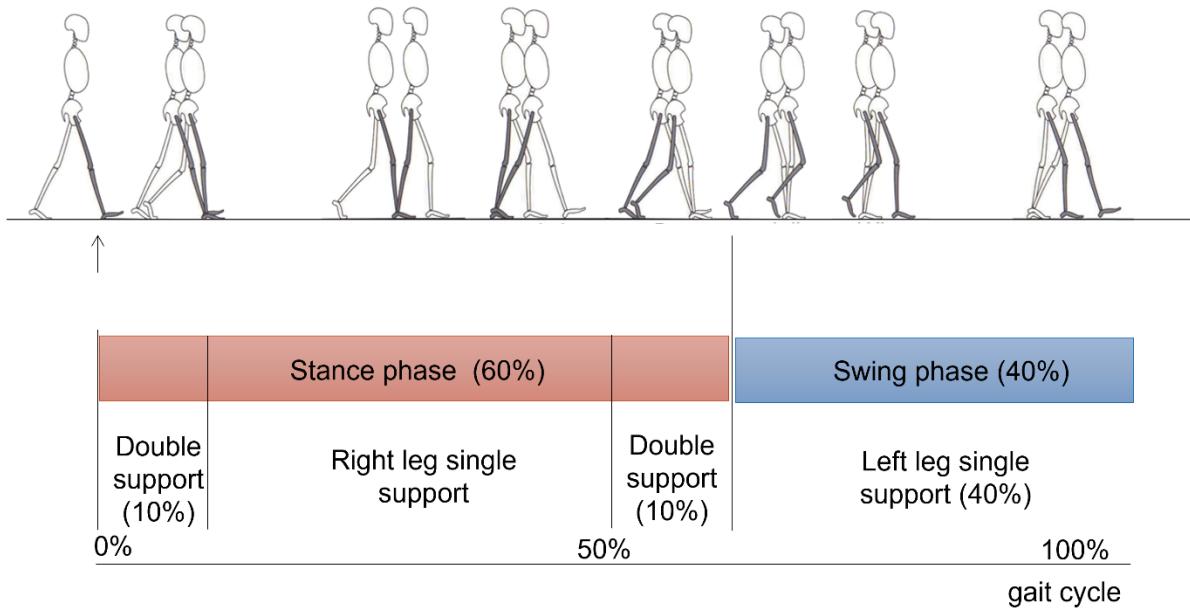


Figure 1. Subphases of a stride (gait cycle). (Betschart, 2016)

2-1-2 Neuromusculoskeletal control of gait

Coordinated control of all segments of the body and optimal function of the musculoskeletal system is essential for a smooth gait progression, its maximal performance and dynamic balance (Kuo & Donelan, 2010). This coordinated control leads to a successful repetitive symmetrical transfer of weight between lower extremities (Nolan & Yarossi, 2011). Additionally, the coordination between the movements of the eyes, which follow the head movements, and other parts of the body is established through postural responses (Takakusaki, 2017). Accurate sensory information is critical for the perception of the parameters of a goal-directed movement (like appropriate foot placement after an unpredictable perturbation) (Deshpande & Patla, 2007). The postural responses are discussed in section 2-3 of the

thesis. Muscles produce the required force for moving different parts of the body with specific mass and regulate the movement of interacting segments and provide support for body weight (Beyaert, Vasa, & Frykberg, 2015). Coordinated segmental rotations at joints (Shemmell et al., 2007) during interaction of arms, trunk, pelvis and lower extremities regulate local forces at each body segment to provide dynamic balance (Beyaert et al., 2015; Brockett & Chapman, 2016; Son & Kim, 2015).

To understand the importance of the control of this coordinated segmental rotation, it is notable that the three factors of the path of movement of the lower limb, speed of the movement and angle between joints of both sides affect the relationship between joints and the muscles attaching them (Shemmell et al., 2007). Ankle joints and muscles around them bear the important responsibility of absorbing shocks at heel contact (Bonnefoy-Mazure & Armand, 2015) and providing enough force for the propulsion of the body (Olney & Richards, 1996). Normal timing and excursion of hip and knee flexion followed by knee extension and ankle dorsiflexion (Moore, Schurr, Wales, Moseley, & Herbert, 1993) should be achieved repeatedly and reciprocally to progress forward with appropriate clearance (Schmid, Schweizer, Romkes, Lorenzetti, & Brunner, 2013). To avoid collision with other objects on the ground, sufficient clearance during the swing phase is necessary (Okubo et al., 2018).

The central nervous system (CNS) integrates sensory information of visual, vestibular, and proprioceptive to adjust generated force by muscles and to correct body position depending on the purposes of the gait (Duyseens, Clarac, & Cruse, 2000; Takakusaki, 2017). The accuracy of the signals from the sensory receptor is critical for adjusting the appropriate intensity and duration of the activation of extensor

muscles and suppression of the antagonistic muscle during gait (Duysens et al., 2000). The complete picture of the position of the body and its movement in the three-dimensional space for precise control of movement at CNS relies on the integration of intact information from all types of sensory afferents (Marigold, Eng, Tokuno, & Donnelly, 2004). The integration occurs at different levels like the spinal cord, brainstem, cerebellum, and cortex. At the spinal level, automatic rhythmic motor commands are generated by central pattern generators to produce flexible cyclic patterns of muscle activities (Masani, Kouzaki, & Fukunaga, 2002). The brainstem is responsible for the initiation and execution of movements (Stieltjes et al., 2001). The reticular formation at the brainstem level superimposes the motor commands of the cortex to establish appropriate posture during gait on different terrains (Drew, Prentice, & Schepens, 2004). The cortex is largely engaged in voluntary complex movements (Mihara et al., 2012; Woollacott & Shumway-Cook, 2002). Modification of trajectories of limbs according to the specific tasks is possible by changing muscle activity via a “time-varying pattern” of motor commands from the motor cortex (Omrani, Kaufman, Hatsopoulos, & Cheney, 2017). In other words, some authors have suggested that basic and stereotypic patterns like muscle synergies responsible for gait at a comfortable speed on the level ground are generated at the spinal level and mediated at the brainstem level. However, fine-tuning the movements according to the characteristics of the task and the environment is managed at the cortical level (Li, Francisco, & Zhou, 2018; Verma, Arya, Sharma, & Garg, 2012).

The interaction between neural and mechanical factors determines the overall pattern of gait (Beyaert et al., 2015) through circuits that generate rhythm at the CNS

level (Duysens et al., 2000). The normal pattern of gait is guaranteed by appropriate joint angles and force generation to support and propel the mass of the body (Li et al., 2018) with the minimum amount of energy (Kao, Srivastava, Agrawal, & Scholz, 2013). The pattern is also characterized by spatiotemporal parameters (Gouelle & Megrot, 2017).

2-1-3 Spatiotemporal parameters

Spatiotemporal gait variables describe the placement of feet and their relative timing during a gait cycle (Wonsetler & Bowden, 2017). The parameters include step length, stride length, cadence, and duration of the stance phase (including single limb support and double limb support) and the swing phase (Rozanski, Wong, Inness, Patterson, & Mansfield, 2019; Tanaka et al., 2019). The spatial parameters determine the base of support (BOS). The BOS is defined as the area limited to feet, including the area between the feet at the double support phase or a single foot at the single support phase during gait (Hof, Gazendam, & Sinke, 2005; Van Meulen et al., 2016). Using assistive devices in pathologic conditions like amputation changes the BOS based on the structure of the assistive device (Maguire et al., 2012). The BOS changes continuously during different phases of gait (Leroux, Pinet, & Nadeau, 2006). The presence of equal spatial and temporal parameters at the right and left sides during gait is called symmetry (Verma et al., 2012).

2-2 Balance in healthy individuals

2-2-1 Definition of balance

Balance is a widespread term without a universal definition (Pollock, Durward, Rowe, & Paul, 2000). Different studies used the terms balance control, balance reaction, postural reaction, postural control, posture, and equilibrium to address the common concept of balance without an agreement on the definition of balance (Tyson et al., 2006). Practically, balance is defined as the ability to maintain or restore a specific body position relative to the supporting surface while performing a task or following any balance-threatening event like external perturbations (Arienti, Lazzarini, Pollock, & Negrini, 2019; de Kam, Geurts, Weerdesteyn, & Torres-Oviedo, 2018; Niam, Cheung, Sullivan, Kent, & Gu, 1999; Pollock et al., 2000).

2-2-2 Biomechanical aspects of balance

Dynamic balance is summarized as continuous antigravity support of the body along with anteroposterior (AP) and mediolateral (ML) axes (Beyaert et al., 2015) based on anticipation, planning, and continuous adaptation to the environment (Moe-Nilssen, Nordin, & Lundin-Olsson, 2008). The following section defines some of the biomechanical parameters necessary for explaining the interaction between the biomechanical parameters and their role in dynamic balance during gait.

2-2-2-1 Definition of center of pressure (COP) and center of mass (COM)

The point of action of the forces resulting from contact of the foot with the surface, i.e., ground reaction forces (GRFs), to the foot at each moment during gait is

called the center of pressure (COP) (De Cock, Vanrenterghem, Willems, Witvrouw, & De Clercq, 2008; Roerdink et al., 2006). COP moves along AP and ML axes and its excursion is limited to the supporting surface (Hof et al., 2005). To analyze the movement of a mass like the human body, it is possible to substitute the whole body with a point which is called the center of mass (COM) (Erdmann, 2018). Thus, COM is a specific virtual point. To calculate the global COM of the body first, the COM of each segment of the body is calculated. Then the global COM is calculated using the COM of the different segments of the body.

Dynamic balance during gait is mainly maintained by controlling the acceleration of the COM by the position of the COP (Hof, 2007; Hof, Vermerris, & Gjaltema, 2010; Jian, Winter, Ishac, & Gilchrist, 1993; van Duijnhoven et al., 2018; Winter, 1995), particularly during weight transfer in the ML direction (Nolan, Yarossi, & McLaughlin, 2015). One of the biomechanical models which explain the interaction between COP and COM is the inverted pendulum model.

The inverted pendulum model is used to explain the mechanism of control of dynamic balance through the coupling of two multi-segment lower limbs (Figure 2) (Winter, 1995). In this model, the COM is at the top of an inverted pendulum and the body is modelled as a stick that touches the ground at the point of the COP, the point represents the forces resulting from the contact of the foot with the ground (Hof, van Bockel, Schoppen, & Postema, 2007). When the COM is at the highest position, the COP is exactly under it. With the forward movement of the body mass, the heel of the leading foot will touch the ground and will provide a new COP to control the acceleration of the falling COM (Adamczyk & Kuo, 2009). During the double support

phase, the COP which is located under the leading foot (Figure 2) decelerates the COM (Jian et al., 1993). This deceleration contributes to smooth weight transfer from the trailing limb to the leading limb (Jian et al., 1993).

In ML direction (along ML axes), the foot placement which determines the position of the COP is postulated to have the greatest effect on dynamic balance (Balasubramanian, Neptune, & Kautz, 2010). Foot symmetry relative to the pelvis at heel contact guarantees the equal distance of the COM from the COP at both feet at the beginning of the double support phase (Balasubramanian et al., 2010). A smooth gait with normal spatiotemporal characteristics which guarantees normal displacement of the COP establishes conditions for the coordinated displacement of COM (Lin, Gfoehler, & Pandy, 2014; Orendurff et al., 2004).

The trajectories and events related to the biomechanical components repeat rhythmically during gait cycles with low variability as a characteristic of normal gait (Winter, 1995). It indicates that the kinematic and kinetic characteristics of normal gait are consistent between strides (Laroche, Cook, & Mackala, 2012). The controlling effect of the GRFs, which are represented by the position of COP, on the acceleration of COM is the main mechanism of dynamic balance and is established through normal gait.

Figure 2 explains the controlling role of the position of the COP (point of action of the ground reaction forces) on the acceleration of the COM during stance and double support phase of gait through the inverted pendulum model. The “PO” and “CO” represent the position of COP under the trailing foot and the leading foot respectively. When the weight of the body is on one leg, which is represented as the

“Pendulum” in this figure, the COP is directly under the COM. At the double support phase, which is represented as “Step-to-step transition”, the COP of the trailing leg and the leading leg control the acceleration of the COM.

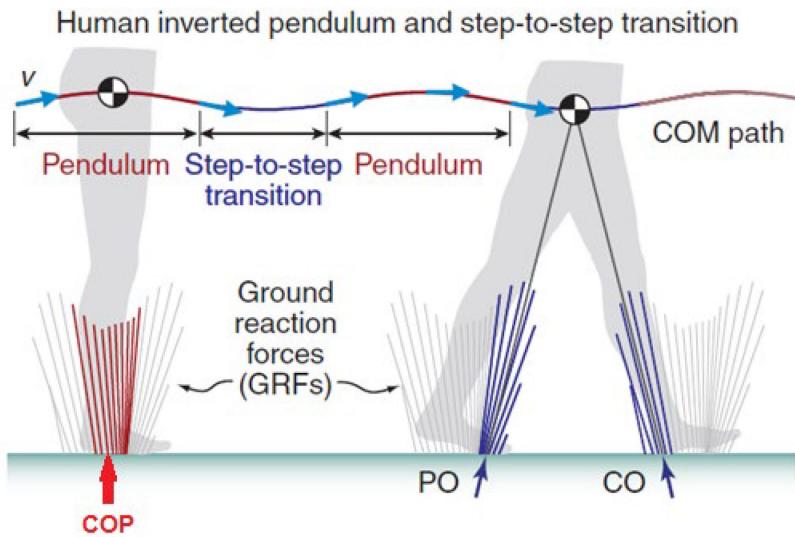


Figure 2. Inverted pendulum model, Adapted and slightly modified with permission from (Adamczyk & Kuo, 2009).

2-2-2-2 Extrapolated COM

Dynamic balance also necessitates considering the interplay between velocity and position of COM and the controlling role of the magnitude and direction of the velocity of the COM on its position over the BOS (Pai & Patton, 1997). A high magnitude of the horizontal velocity of the COM which is directed outward of the BOS may lead to falling even if the COM is within the BOS (Kao, Dingwell, Higginson, & Binder-Macleod, 2014). The GRFs (represented by COP) are limited to the BOS at each step. Consequently, their excursion cannot compensate for the

broader trajectory of a COM which is moving rapidly (Gazendam & Hof, 2007; Hof et al., 2005). To study this effect, Hof and colleagues suggested the concept of extrapolated COM (XCOM) (Figure 3) (Hof et al., 2005). The XCOM is also known as the velocity corrected position of the COM (Okubo et al., 2018). The velocity of COM (V_{com}) is divided by the square root of the acceleration of gravity (g) divided by the effective length of the pendulum (l) and is added to the position of the vertical projection of COM ($Pos(com)$) (Hof, 2008).

$$XCOM = Pos(com) + \frac{V_{com}}{\sqrt{g/l}}$$

A horizontal velocity of COM of enough magnitude should be directed toward the BOS to bring the position of COM within the BOS and to keep it within the boundary of BOS during gait (Pai & Patton, 1997). In the ML direction, the further the distance between the lateral border of BOS and XCOM, the faster the process of redirecting the COM toward the opposite side and consequently the faster the redirection of body movement to the opposite side and taking the contralateral step (Haarman et al., 2017). To consider both XCOM and BOS at the same time the margin of stability (MOS) is introduced. The distance between the XCOM and the limit of the BOS is called the margin of stability (Bierbaum, Peper, Karamanidis, & Arampatzis, 2011; Mohamed Refai, van Beijnum, Buurke, & Veltink, 2019). Based on its definition, the variable is calculated in both AP and ML directions. In this thesis, we used the relative positions of COP, the projection of COM, XCOM and dimensions of BOS in AP and ML directions as “determinants of dynamic balance”.

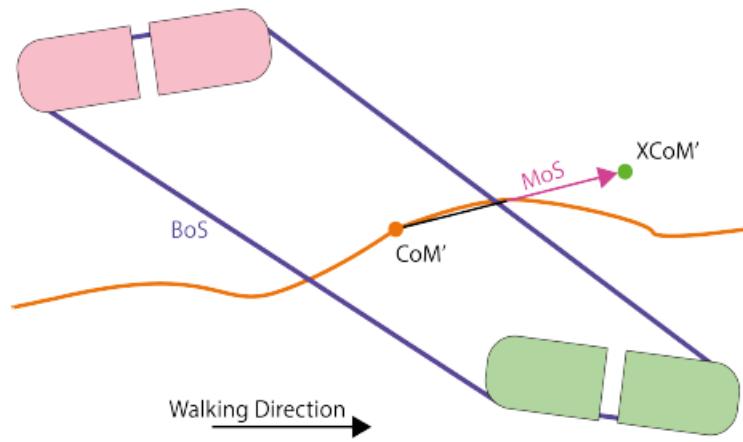


Figure 3. Vertical projections of the center of mass (COM) and extrapolated center of mass (XCOM) on the ground. The figure also illustrates the base of support (BOS) and the margin of stability (MOS). (Mohamed Refai et al., 2019).

2-3 Anticipatory and reactive postural responses

Anticipation and reaction are two important underlying mechanisms of control of balance during the execution of different tasks (Aruin, 2016). Anticipatory postural responses consist of preprogrammed active displacements evoked by anticipation of a change in posture during a voluntary movement from one position to another (Horak et al., 2009; Lee et al., 2018). For example, anticipatory postural responses contribute to the early activation of postural muscles before the voluntary movement of the arm (Patla, Ishac, & Winter, 2002). The anticipatory postural adjustments are controlled by cortical regions like supplementary motor areas (Maki & McIlroy, 1999). Reactive postural responses are used to keep balance in reaction to unpredictable perturbations (Horak et al., 2009). These responses are activated based on sensory signals generated

after mechanical disturbances (McCrum, Gerards, Karamanidis, Zijlstra, & Meijer, 2017). They include rapid limb movements to take the step(s) or to reach and grasp an object by hands during gait to maintain dynamic balance following an external perturbation (Handelzalts et al., 2019).

Reactive postural responses can occur following a perturbation during voluntary movements and lead to more adjustment of body movements and gait patterns while considering the constraints of the environment (Beyaert et al., 2015). The reactions are managed at different levels of the CNS (Bolton, Williams, Staines, & McIlroy, 2012; Maki & McIlroy, 1999). They include components with short, medium, and long latencies of muscle activation (Jacobs & Horak, 2007). The short-latency components of the reactive postural responses are mediated at the spinal level, medium latency ones at the midbrain level and the long latency responses at the cortical level (Jacobs & Horak, 2007). The reactions are recruited frequently to react against unstable situations (Maki & McIlroy, 1997). So, the compensatory reactions are important for keeping balance during the gait when it is challenged by unpredictable events occurring during daily activities (Pollock et al., 2011). Failure to react promptly and in an effective manner to unexpected perturbations leads to falling.

To maintain balance, continuous correction and optimization of the interaction of biomechanical variables are done via feedback and feedforward mechanisms (Huang, Lu, Chen, Wang, & Chou, 2008). The feedback mechanisms consist of a continuous update of motor commands using sensory information (Kannan, Vora, Varas-Diaz, Bhatt, & Hughes, 2020). However, the feedforward mechanisms include the voluntary release of preprogrammed signals to regain stability because of the

prediction of a destabilizing situation (Liu, Macedo, & Finley, 2018; Maki & McIlroy, 1999). Repetition of perturbations leads to adaptive and continuous use of sensory signals for updating the sensory representation at the CNS level (Pai & Bhatt, 2007). Feedback provided by the first unpredictable perturbation leads to a pure reactive postural response. However, the first experience affects fundamentally the upcoming responses to normal ordinary gait and unpredictable perturbations due to the adjustments based on feedforward mechanisms (Marigold, Bethune, & Patla, 2003a). Collectively, both feedback and feedforward mechanisms contribute to the improvement of motor control achieved by adequate reactive and anticipatory responses.

2-4 Gait characteristics of individuals post-stroke

As damaged regions of the brain following a stroke are unique for each person, each individual post-stroke shows a unique level of impairments, including impaired kinetics and kinematics of lower extremities (Kim et al., 2016), uncoordinated movements of lower extremities (do Carmo, Kleiner, & Barros, 2015), poor endurance and reduced adaptability to task and environment, and reduced speed (Lamontagne et al., 2007). The following sections describe the effects of stroke on dynamic balance during unperturbed gait, recovery from gait perturbations and gait speed. Comparing the gait of healthy participants (explained in previous sections) and the deficits of individuals with stroke provides an opportunity to find out the characteristics of an effective balance training intervention.

2-4-1 Deficits of dynamic balance during gait in individuals post-stroke

Balance impairments in standing and during gait are common among individuals with stroke, with a prevalence rate of about 83% (Lakhani, Mansfield, Inness, & McIlroy, 2011; Li et al., 2019). A combination of impairments of muscle strength, joint range of motion (ROM), muscle tone, sensory organization (Bonan et al., 2004), integration at the CNS level (Oliveira et al., 2011), cognitive processes and perception of vertical position (Verma et al., 2012) can lead to balance deficits after stroke. Impaired activation of muscles at several segments of the body and reduced ability of rapid and selective muscle contraction are of special importance for balance maintenance during gait in individuals with stroke at the chronic phase (Sharafi, Hoffmann, Tan, & Y, 2016). The impairments after stroke contribute to abnormal gait and reduce the smoothness of gait and weight transfer explained in the previous sections as the requirement of dynamic balance.

Impaired kinematics and kinetics of the lower extremity after stroke are the factors with the most serious effects on gait and disability (Nolan et al., 2015). The active ROM of joints are essential for normal kinematics and kinetics of gait and their impairments affect the rhythmic events of gait (Schmid et al., 2013) and reduce dynamic balance during gait due to impaired weight acceptance and weight transfer (Nolan et al., 2015). Ankle, knee, and hips are the primary joints involved in gait and the joints located in the pelvic region are the secondary joints (Kim et al., 2016). In individuals post-stroke, the active ROM of the primary joints is usually restricted, but the ROM of secondary joints is exaggerated during gait (Kim et al., 2016). Impaired

function of the lower limbs and pelvic girdle affects the interactions between the COP and the COM (Zadravec et al., 2020).

The tendency of shifting the weight of the body toward the nonparetic side in the ML direction leads to the placement of the COM outside of the BOS on the paretic single support phase (Weerdesteyn, de Niet, van Duijnhoven, & Geurts, 2008). This reduces the dynamic balance in the ML direction. Consequently, the majority of the individuals with stroke fall on the side (Matjačić, Zadravec, & Olenšek, 2017). The situation increases the distance between COM and COP on the paretic single support phase (Hsiao, Gray, Creath, Binder-Macleod, & Rogers, 2017). This alteration theoretically interrupts the controlling effect of the COP on the acceleration of the COM on the paretic single support phase. Additionally, slower gait speed leads to a wider excursion of COM in and a wider BOS (Orendurff et al., 2004). The altered muscular activity also changes the excursion of the COP (Garland, Gray, & Knorr, 2009). A longer excursion of COP along the AP axis, greater variability of the COP and along the ML axis on the nonparetic side in addition to the absence of COP at the forefoot has been reported in individuals post-stroke (Chisholm, Perry, & McIlroy, 2011). Altogether, the alterations reduce the normal interplay between the COP and the COM during gait and reduce the effectiveness of the main mechanisms involved in maintaining dynamic balance.

The inability of individuals post-stroke for maintaining COM near the midline (the virtual line which divides the body into two halves) (Devetak, Bohrer, Rodacki, & Manffra, 2019), leads to a closer position of the COM to the lateral border of the BOS, compared to the healthy individuals. Considering the method of calculation of XCOM, the position of COM affects the position of the XCOM in the BOS. Compared

to the healthy individuals, the position of the XCOM relative to the midline in the ML direction is more latterly located in the individuals post-stroke (Buurke, Liu, Park, den Otter, & Finley, 2020). A reduced distance between more laterally located XCOM and the lateral border of the BOS in the ML direction is an indicator of reduced dynamic balance in the ML direction (Buurke et al., 2020). In summary, the biomechanical determinants of dynamic balance are altered after stroke (Zadravec et al., 2020). The alteration contributes to the reduced dynamic balance (Haarman et al., 2017).

2-4-2 Effect of stroke on strategies of recovery from perturbations

Perturbations including slips and trips are concomitant to gait. Slips and trips are perturbations that lead to backward and forward loss of balance, consecutively (Bhatt, Wang, Yang, & Pai, 2013). In healthy participants, the type of the strategies in reaction to the perturbations depends on the direction and intensity of the perturbation and the gait speed (Matjačić et al., 2017). Stepping strategy, ankle strategy and inertial strategy contribute to the recovery from perturbation during gait (Zadravec et al., 2020). Stepping strategy is the most effective strategy to maintain dynamic balance during gait by increasing the step length and step width. Ankle strategy is defined as changing the location of the COP under stance foot for restoring dynamic balance without taking a step. As explained COP controls the acceleration of the COM (Hof et al., 2010; Jian et al., 1993; Winter, 1995). Hip strategy modulates the horizontal GRFs through rotation of different segments of the kinematic chain (Zadravec et al., 2020). The ankle strategy and the inertial strategy together are called the in-stance strategy (Zadravec et al., 2020).

Delayed reactive responses and non-coordinated muscular contractions in individuals with stroke (Mansfield, et al., 2015b; Matjačić, Zadravec, & Olenšek, 2018) affect the three above-mentioned strategies required to maintain dynamic balance after gait perturbations. For example, the reaction of individuals post-stroke to the unpredictable gait perturbations that reproduced conditions like trips in the AP direction is delayed compared to the healthy participants (Sharafi et al., 2016). The downward fall of the COM after a perturbation should be redirected by a fast and appropriate step (Mansfield, Peters, Liu, & Maki, 2007). However, the delayed activation of muscles in individuals post-stroke may lead to falls (Bhatt, Dusane, & Patel, 2019) due to the inability of controlling the falling COM. Individuals post-stroke also showed a reduced ability of execution of reactive postural responses after external perturbations in ML direction (along lateral axes) (de Kam, Roelofs, Bruijnes, Geurts, & Weerdesteyn, 2017). The reduced ability has mainly resulted from the slow and weak activity of hip abductors on the paretic side (de Kam et al., 2017). To be effective, a balance training program should address the delayed and weak muscular reactions during unpredictable perturbations.

2-4-3 Reduced gait speed

Gait speed is the indicator of gait performance commonly used in studies (Verma et al., 2012). According to Beyaert et al. (2015), the average comfortable speed in low-functioning individuals with stroke is between .23 to .73 m/s, whereas it is between .78 and .95 m/s in high-functioning individuals post-stroke. Functionally, the speed of 1 m/s in individuals at the chronic phase post-stroke is important to reach a

safe and independent integration into the community (Bijleveld-Uitman, van de Port, & Kwakkel, 2013).

Gait speed after stroke is reduced due to a variety of kinetic, kinematic, and neural impairments (Mizuta et al., 2020) including impaired multi-joint coupling (Cruz & Dhaher, 2008), reduced strength of hip flexors, impaired postural adjustment of the paretic side and activity of antagonist muscles (Nadeau, Arsenault, Gravel, & Bourbonnais, 1999; Woolley, 2001) and sensory impairment of the paretic limb (Eng & Tang, 2007). Additionally, reduced speed is attributed to impairments of some of the spatial and temporal parameters. Generally, reduced step length (Wonsetler & Bowden, 2017), decrease in step frequency (Hak et al., 2013) in addition to the asymmetry of step length (Mizrachi, Treger, & Melzer, 2020; Patterson et al., 2008), swing time (Guzik et al., 2017) and stride duration are responsible for slower gait speed (Malone & Bastian, 2014; Titanova & Tarkka, 1995). Notably, gait speed correlated positively with balance confidence (Botner, Miller, & Eng, 2005; Rosen, Sunnerhagen, & Kreuter, 2005; Schinkel-Ivy, Wong, & Mansfield, 2017) and negatively with fear of falling in this population (Park & Yoo, 2014).

An increase of one or some of the spatiotemporal parameters including stride length, step length, cadence or paretic single support time were reported in several studies as mechanisms of improvement of gait speed in participants with stroke at the chronic phase (Wonsetler & Bowden, 2017). A significant positive correlation has been found between gait speed and dynamic balance evaluated with the MiniBESTest in this population (Madhavan & Bishnoi, 2017). A study recently reported similar tendencies of increasing speed and improvement of functional balance (evaluated by the Berg Balance Scale (BBS) in individuals at the chronic phase post-stroke (Lee,

Lee, & Song, 2018). Probably, it is possible to suggest that improvement of gait speed could contribute to the improvement of dynamic balance.

2-5 Unpredictable perturbations training in standing position in individuals at the chronic phase post-stroke

Here is a review of studies that applied unpredictable perturbations in standing position as a training intervention. These studies are done using a platform (Schinkel-Ivy, Huntley, Aqui, & Mansfield, 2019; van Duijnhoven et al., 2018), lean and release system (Mansfield, Inness, Lakhani, & McIlroy, 2012) or a treadmill (Pigman et al., 2019). In reaction to unpredictable perturbations in standing position, individuals with stroke usually take delayed stepping reactions (Schinkel-Ivy et al., 2019) characterized by several nonparetic steps to maintain their balance and prevent falling (Honeycutt, Nevisipour, & Grabiner, 2016; Mansfield, Inness, et al., 2012). The reactions are mostly done with only one limb without accompanying the other limb (Schinkel-Ivy et al., 2019).

Van Duijnhoven et al. (2018) evaluated the effects of ten training sessions over five weeks of perturbation training in standing position using a platform on reactive step quality in backward and forward directions. The assessments were done using a lean and release system. The reactive stepping quality was defined as the leg angle at the time of foot contact. The leg angle was defined as the angle between the line of the inclination of the leg and a vertical line (Hsiao & Robinovitch, 2001; Weerdesteyn, Laing, & Robinovitch, 2012). The authors additionally used a movable platform to assess reactive step quality in eight directions and improvement of side-

stepping along the ML axis. Relative to the center of the platform, the directions were anterior, posterior, right, left, and at the direction of angle bisectors of the four mentioned directions (van Duijnhoven et al., 2018). The improvement of side-stepping was defined as the percentage of steps taken along the lateral axis due to the perturbations in the same direction. BBS, Trunk Impairment Scale (TIS), 10 MWT, 6-item Activity Specific Balance Confidence (6-ABC) and TUG were used to assess clinically the effects of the intervention. The mentioned variables were evaluated before, immediately after and six weeks after training. The intervention led to improvement of the quality of reactive stepping on forward, backward, right and left sides. Additionally, compared to before training, both paretic and nonparetic steps were used more frequently in reaction to side perturbation after the intervention. The improvements were retained until six weeks after the training. The improvement in the scores of BBS and TIS were found immediately after the training and the improvement in the scores of TIS and 6-ABC were found six weeks after the training.

Pigman et al. (2019) applied trip perturbations in standing position training for individuals at the chronic phase post-stroke. The authors reported more successful recoveries along with the training session when reacting with either limb. Additionally, the progression to larger intensities of perturbations was found only when participants reacted with their paretic limb. They found that after training, when the paretic foot was used to react to the trip perturbations in standing position, it always placed more anterior relative to the projection of COM in the AP direction than before training. It means a longer paretic step length in reaction to the perturbations after training. The amount of forward rotation of the trunk in the AP

direction after training was less than this amount before training regardless of the side. The reduced amount of forward rotation of the trunk in the AP direction positively affects fall recovery.

Schinkel-Ivy et al. (2019) studied the effect of 6 weeks of unpredictable perturbation training applied by translation of the support surface in anterior, posterior, left and right directions. The authors also recruited another group of individuals post-stroke that received the traditional balance training like maintaining balance during voluntary movements. Both groups were evaluated using reactive stepping characteristics and timing. The number of extra steps along the AP and ML axes, stepping with paretic side and foot collision were variables used for evaluation of the reactive stepping characteristics. The delay between the onset of the perturbation and foot off as well as the swing time of the foot after perturbations were the parameters to evaluate the timing after perturbation. The mentioned variables were assessed before training, after training and six months after training. The training led to improvement of the reactive subscale of the Mini-BESTest, the reduction of the number of extra steps in the AP direction, no reduction of the number of lateral steps, and no effect on stepping with paretic side, foot collision and timing parameters. Collectively, the authors reported the training as a feasible and cost-effective intervention for the improvement of reactive stepping in this population. The studies in this section supported the contribution of unpredictable perturbation training in the improvement of stepping reactions in participants with stroke. However, task-specific unpredictable perturbation training is necessary to improve dynamic balance during gait.

2-6 Balance training during gait in individuals post-stroke

Impaired dynamic balance in individuals post-stroke frequently leads to fall and fall-related physical and psychological consequences. To reduce fall rates during gait, training must specifically target mechanisms of dynamic balance related to this task. The following section highlights the importance of applying unpredictable perturbations during gait training by offering the results of studies that used the specific intervention in this population.

2-6-1 Perturbations during gait training for rehabilitation of dynamic balance after stroke

Traditional mobility and balance training programs target balance maintenance using voluntary movements (Mansfield et al., 2018). These training programs are based on mobility exercises and do not impose external perturbations and therefore cannot trigger specifically the reactive postural responses for recovery of balance (McCrum et al., 2017). Both the anticipatory postural responses and reactive postural reactions in response to both self-induced and external perturbations are impaired after stroke (Weerdesteyn et al., 2008). The reason is the delayed and uncoordinated muscular activation (Mansfield, et al., 2015b; Matjačić et al., 2018; Weerdesteyn et al., 2008).

According to the task-specificity principle, to activate specifically reactive postural responses responsible for the effective reaction to gait perturbations, it is necessary to apply unpredictable perturbations that reproduce the same conditions like slips and trips during gait (Granacher, Muehlbauer, Zahner, Gollhofer, & Kressig, 2011; Lubetzky-Vilnai & Kartin, 2010; Shapiro & Melzer, 2010). Such a training

approach is more ecological than traditional mobility and balance interventions (Punt et al., 2019).

Enough intensity (according to the tolerance of each individual with stroke) and repetition are other important characteristics of a dynamic balance training program (Lamontagne & Fung, 2004; Punt et al., 2019). The improvement after such an intervention in this population may occur through the improvement of neuromuscular activation and speed of execution of compensatory stepping (Mansfield et al., 2011). Applying unpredictable gait perturbation using a split-belt treadmill to reduce fall rates in older adults has been shown practically effective (Gerards, McCrum, Mansfield, & Meijer, 2017; Pai & Bhatt, 2007). Decreasing reaction times, improvement of the perception of balance loss and speed of processing of sensory signals are potential factors that contribute to the improvement of the balance performance after unpredictable perturbations during gait training in older adults (McCrum et al., 2017).

An effective intervention for improving dynamic balance during gait must actively challenge both sides (Zadravec et al., 2020), particularly the paretic side (Mansfield et al., 2015). Due to the learned disuse of the paretic side, motor recovery of individuals at the chronic phase post-stroke reaches a plateau which interferes with the progression of recovery (Aruin, Hanke, Chaudhuri, Harvey, & Rao, 2000). The unpredictable gait perturbations which are characterized by improvement of reactive postural responses on the paretic side (Matjačić et al., 2018) can probably contribute to the break out of the plateau of the recovery process.

The CNS can reorganize its structure and function, a phenomenon known as neuroplasticity (Arya, Pandian, Verma, & Garg, 2011). In the sensorimotor sphere, neuroplasticity is defined as the ability of the nervous system to change its sensorimotor activity in response to intrinsic or extrinsic stimuli by reorganizing its structures, functions and connections. Generation of new structures and emergence of functions in the brain after enough repetitions probably contribute to relearning of a task after stroke while stroke individual executed the same task normally before the incidence of stroke (Chambers & Artermiadis, 2021). The proper reactive stepping also depends on the sensory information. Thus, the intervention should challenge the sensory system effectively.

2-6-2 Importance of multisensory stimulation by the interventions for improvement of dynamic balance

Sensory afferents contribute to the complex process of modification of motor outputs at different levels of the CNS based on the requirements of the environment to maintain dynamic balance (Arene & Hidler, 2009; Frost, Skidmore, Santello, & Artermiadis, 2015). The process of coordination between multiple motor outputs is based on the representation of the body in the three-dimensional space provided by sensory signals from different sources (Bonan, Marquer, Eskiizmirli, Yelnik, & Vidal, 2013).

Sensory stimulation including somatosensory, vestibular and visual stimulation has been reported to contribute to the normalization of postural deficits (Bonan et al., 2013). Previous studies stated that a compliant surface that destabilizes the body may lead to sensory conflict due to inadequate afferent

information from lower limbs (Smania, Picelli, Gandolfi, Fiaschi, & Tinazzi, 2008). Consequently, the CNS integrates potential sensory signals like vestibular signals to recover balance (Smania et al., 2008; Yelnik et al., 2008). Likewise, a sudden perturbation leads to uncertainty due to unusual sensory feedback and challenges the CNS to maintain balance and effective motor function using the unusual sensory feedback (Hsu et al., 2021). With repetition of the perturbations, the CNS must adapt using unusual sensory feedback for detection and correction of errors during the execution of a motor task relative to the environmental context and updating the sensory representation (Hsu et al., 2021; Pai & Bhatt, 2007). The updated sensory representation is also used for feedforward control after the perturbation (Frost et al., 2015; Pai & Bhatt, 2007; Punt et al., 2019). Altogether, based on the literature, it is possible to postulate that unpredictable perturbation training of enough intensity leads to the activation of several types of sensory inputs (Weerdesteyn et al., 2008). It contributes to more challenges for the sensorimotor system and faster muscular reaction to provide more efficient responses (Krasovsky, Lamontagne, Feldman, & Levin, 2013; Marigold et al., 2005). Therefore, the unpredictable perturbation can potentially facilitate more accurate execution of a task and more flexible control of tasks by the CNS despite the restrictions due to stroke (Hsu et al., 2021). The repetition of such an intervention over time will lead to better learning and adaptation (Dusane & Bhatt, 2021).

2-6-3 Responses to the unpredictable gait perturbations in individuals at the chronic phase post-stroke

Comparison of the responses of healthy individuals to unpredictable perturbations during gait with the responses of individuals at the chronic phase post-stroke provides an opportunity to understand the impairments of the person with stroke. Studies of healthy individuals revealed pure reactive postural responses happen only after the first unpredictable perturbations during gait (Marigold, Bethune, & Patla, 2003b). Patla et al. (2003) described three types of responses to an unpredictable perturbation during gait: 1) short-latency response (30-40 ms) resulting from a mono-synaptic loop, 2) longer latency response (70-90 ms) emerged due to activation of a poly-synaptic loop 3) functionally relevant behavioural response with the latency of 100-200 ms. The functionally relevant behavioural responses include phase-dependent patterns of activation of muscles (Eng, Winter, & Patla, 1994; Rietdyk, Patla, Winter, Ishac, & Little, 1999). The reactive postural responses of healthy individuals to subsequent unpredictable perturbations are highly affected by the experience of the first perturbation and feedforward control mechanisms (Marigold et al., 2003a). The applied unpredictable perturbation contributes to the improvement and adaptation of feedforward mechanisms. According to Oates (Oates, Patla, Frank, & Greig, 2005), prior unpredictable slip perturbation adaptively leads to shorter step length, increased MOS, the forward shift of COM along the AP axis and reduction of forward horizontal velocity through feedforward mechanisms (Oates, Frank, & Patla, 2010). Additionally, interlimb coordination is necessary (Krasovsky et al., 2012). The studies in healthy individuals showed that successful recovery of dynamic balance during gait is based on the coordinated reaction of all segments of

the body (Martelli, Monaco, Bassi Luciani, & Micera, 2013). Such a rapid adaptive coordinated reaction elicited and updated based on feedback and feedforward mechanisms can effectively keep COM within moving BOS during gait (Marigold & Patla, 2002). Appropriate foot placement plays a critical role in the controlling effect of the position of COP on the acceleration of COM in healthy individuals (Oates et al., 2005). Healthy individuals are capable of reaching the adaptive feedforward improvements only after one time of experiencing unpredictable perturbations (Oates et al., 2010). The following paragraphs describe the impaired reactions of individuals post-stroke to unpredictable perturbations during gait.

Studies that investigated the reactions of participants with stroke at the chronic phase to unpredictable perturbations during the specific task of gait are limited and include 10–44 participants with different levels of mobility (Buurke et al., 2020; Dusane & Bhatt, 2021; Haarman et al., 2017; Hak, Houdijk, Steenbrink, et al., 2013; Kajrolkar & Bhatt, 2016; Kajrolkar, Yang, Pai, & Bhatt, 2014; Krasovsky et al., 2013; Punt et al., 2017; Sharafi et al., 2016; Zadravec et al., 2020). The studies used different approaches for reproducing conditions that perturb the body during gait and the majority of them did not include a control group. We can use the results of these studies to find out the inabilities of individuals post-stroke in response to different types of unpredictable gait perturbations. Additionally, the findings probably could be used to improve the quality of the training interventions by applying appropriate parameters of unpredictable perturbations during gait.

2-6-3-1 Responses to the unpredictable gait perturbations in individuals at the chronic phase post-stroke in the anteroposterior direction

In a study among 10 individuals with stroke, Kajrolkar et al.(2014) applied two unpredictable slip perturbations during gait on the leading nonparetic side. Gait perturbations were applied by the unpredictable forward movement of a movable platform that slid anteriorly 24 centimeters at the heel contact phase of gait. The authors studied the reactive stepping reactions to the first perturbation. Additionally, they studied the adaptation resulting from the first perturbation on the reaction to the second perturbation. The authors used both the position and velocity of the COM (referred together as the COM state) relative to the BOS to calculate the backward loss of balance. It is necessary to explain that at the time of the perturbation, the COM is located posterior to the BOS of the leading foot (Yang, Anderson, & Pai, 2008). The forward velocity of the COM is critical for moving the COM into the moving BOS at the time of perturbation. The speed of COM should be more than the speed of the moving BOS. Thus, the forward velocity of the COM relative to the BOS was used as a threshold to predict the occurrence of backward loss of balance. The authors argued that the backward loss of balance happened if the forward velocity of the COM was lower than the mentioned threshold. The shortest distance between the threshold of the backward loss of balance and the COM state was calculated as the stability of the COM state at the time of execution of the perturbation. They described two compensatory paretic steps: 1) forward movement of the paretic side and landing it in front of the nonparetic perturbed side or 2) taking a long paretic recovery step landed posterior to the nonparetic side. The first slip perturbation of the leading nonparetic foot led to 100% backward loss of balance. The inability of participants to execute

one of the two mentioned types of compensatory steps was the reason for the backward loss of balance. The second slip led to a significant reduction of backward falls through the improvement of using feedback mechanisms to re-establish balance. However, the feedforward mechanisms did not improve the stability of the COM state at the instance of execution of the perturbation (Kajrolkar et al., 2014).

In another study, unpredictable slip perturbations were applied during gait to two groups of individuals at the chronic phase post-stroke: the nonparetic-slip group and the paretic-slip group (Kajrolkar & Bhatt, 2016). The nonparetic-slip group received the perturbations only on the nonparetic side and vice versa. Again, gait perturbations were applied by the unpredictable forward movement of a movable platform that slid anteriorly 24 centimeters at the heel contact (Kajrolkar et al., 2014). The authors wanted to know whether the paretic and nonparetic limbs were able to react appropriately to prevent falls after unpredictable slip perturbations during gait. They reported that participants with stroke at the chronic phase showed a reduced capacity for initiation and execution of a stepping response on the paretic side (Kajrolkar & Bhatt, 2016). However, the number of falls was equal in both groups which indicates the reduced ability of both paretic and nonparetic sides (regardless of the side of the application of perturbations) for maintaining dynamic balance. Dusane and Bhatt (2021) applied repeated low-intensity slip perturbations during gait which were reproduced like the two previous studies by Kajrolkar (Kajrolkar & Bhatt, 2016; Kajrolkar et al., 2014). Additionally, the high-intensity slip perturbations during gait were reproduced and applied by a sudden forward movement of the movable platform for 45 cm. The low-intensity and high-intensity perturbations were applied on both

paretic and nonparetic sides. The authors reported lower stability of the paretic side compared to the nonparetic side at both intensities of slip perturbations. These studies highlighted the importance of a task-specific intervention for improving dynamic balance in individuals at the chronic phase post-stroke.

Krasovsky et al. (2013) have examined the impact of unpredictable perturbations during gait in high-functioning participants with stroke at the chronic phase and a healthy control group. The perturbations were applied by a cuff attached to both ankles during walking on a treadmill. The healthy group was asked to reduce their speed and walk at matched speed with the stroke group. The authors found three different strategies in response to unpredictable perturbations during gait, namely lowering, elevating the perturbed leg or a combination of elevating and lowering of the leg. The lowering strategy was done by decreasing step length and step time after perturbation. The elevating strategy was accomplished by a prolonged swing phase of the perturbed leg. The combined strategy was composed of the elevating strategy followed by the lowering strategy in the perturbed leg. Most of the time, both groups used the combined strategy. While the stroke group used the elevation strategy in 5% of the cases, the healthy group used it in 49% of the cases. The finding indicates the reduced ability of individuals post-stroke to elevate the perturbed leg, in comparison to healthy individuals. Swing length and swing time were reduced at the perturbed step and the first step after the perturbation in both groups depending on the type of strategy used. The duration of the double support phase was calculated before and after applying the perturbations. Returning to the same duration of the double support phase after perturbations is similar to the double support time before the perturbations

used to quantify recovery from perturbations. The recovery from perturbations in the stroke group needed more time than in the healthy group. Individuals post-stroke with a faster comfortable speed than other individuals with stroke had more coordinated movements of the arm and the leg in reaction to the perturbations applied only on the nonparetic side. The healthy participants with faster comfortable gait speed also had more coordinated reactions, compared to the healthy slow walkers. However, participants with a faster comfortable gait speed did not recover faster from perturbations than the participants with a slower comfortable speed. The authors mentioned that re-establishment of dynamic balance after perturbations is not functionally relevant to the coordinated movements of arms and legs after perturbations (Krasovsky et al., 2013). The finding of Krasovsky indicates the requirement of understanding the priority of mechanisms of dynamic balance improvements to address them using a task-specific intervention.

To understand the neuromuscular mechanisms underlying reactive postural reactions, Sharafi et al. (2016) applied unpredictable trip perturbations at the single support phase of gait. The perturbations were applied on both paretic and nonparetic sides. The activation pattern of muscles on the paretic and nonparetic sides in reaction to the trip perturbations during gait was largely similar to healthy participants (Sharafi et al., 2016). The mentioned similarity indicates the preservation of the programmed postural reactions after stroke. According to the authors, the only difference between individuals post-stroke and the healthy participants was delayed activation of the muscles after perturbation. The difference indicates longer transmission times due to

the involvement of supraspinal pathways responsible for interlimb reflexes (Sharifi et al., 2016).

The margin of stability (MOS), the distance between the XCOM and the border of the BOS, is one of the determinants of fall prediction. Generally, individuals with hemiparesis post-stroke walk at their comfortable speed with smaller MOS in the AP direction compared to healthy individuals and wider MOS in the ML direction on the paretic side compared to the nonparetic side (Buurke et al., 2020). Buurke et al. (2020) applied repeated slip perturbations on both paretic and nonparetic sides. During the recovery step, on the paretic side, the increase of MOS in the AP direction was associated with the decrease of MOS in the ML direction and vice versa. The authors used the term “maladaptive coupling of sagittal and frontal plane stability”. The term indicates the simultaneous increase of the possibility of fall in the AP direction was accompanied by the decrease of the possibility of fall in the ML direction and vice versa (Buurke et al., 2020). The finding emphasizes the importance of interventions to improve dynamic balance in this population.

2-6-3-2 Responses to the unpredictable gait perturbations in individuals at the chronic phase post-stroke in the ML direction

Maintaining dynamic balance in ML direction is more impaired in individuals post-stroke, compared to the dynamic balance in AP direction. Increased incidence of falls in ML direction reflects the reduced ability of this population in maintaining the dynamic balance in ML direction. Thus, some of the studies aimed to specifically assess the inability by applying unpredictable perturbations during gait in ML direction in this population.

Hak et al. (2013) reported that individuals post-stroke showed similar MOS as a group of healthy participants in the ML direction in reaction to the perturbations. A similar MOS in individuals post-stroke was achieved by an increase in the step width and the step frequency, compared to the healthy group. Establishing a MOS similar to the MOS of the healthy group was a strategy to maintain the dynamic balance. However, the step length and speed were reduced in the stroke group in reaction to the perturbations which led to a tendency toward reducing the backward MOS in the AP direction. According to the authors, this reduced MOS that resulted from the perturbations in the ML direction led to an increase in the possibility of backward fall of individuals post-stroke in the AP direction (Hak et al., 2013). The findings are in line with the findings of Buurke et al. (2020) who reported “maladaptive coupling of sagittal and frontal plane stability” in reaction to perturbations in the AP direction.

Haarman et al. (2017) reported the ability of mildly impaired individuals at the chronic phase post-stroke in the modulation of the first compensatory step after unpredictable perturbation at the pelvic level in the ML direction. The ability was regardless of the side of the application of the perturbation. Perturbations were applied for 150 milliseconds through forces equal to 4, 7 and 10% of the weight of the body toward and away from the stance foot. At each intensity and each direction, 5 perturbations were applied yielding a total of 60 perturbations per participant. The results showed the reduced ability to control the acceleration of the COM by the paretic side. The authors reported a larger distance between the paretic foot and the COM compared to the same distance on the nonparetic side. Additionally, larger variability of the velocity of the COM in the ML direction on the paretic single support

phase after perturbation was found. The authors suggested that reduced strength of the paretic side contributes to the findings. However, the participants were able to modulate the reactions on both sides by increasing the activity of the gluteus medius proportional to the intensity of the perturbation to maintain balance.

2-6-3-3 Responses to the unpredictable gait perturbations in individuals at the chronic phase post-stroke in both the AP and ML directions

As external perturbations in ordinary life happen in both the AP and ML directions, the following studies addressed the mechanisms of regaining dynamic balance and fall prevention in both AP and ML directions. Zadravec et al. (2020) applied forward and backward perturbations in addition to the inward and outward perturbations relative to the side of the leading foot at the double support phase. The participants walked at the constant speed of .4 m/s on a split-belt treadmill while the intensity of the perturbations was set as 10% of the weight of the participants. Thus, participants did not walk at their comfortable speed. The authors recruited high-functioning individuals at the chronic phase post-stroke and a group of healthy participants. The healthy group was younger than the stroke groups (35.7 ± 8.4 vs 53.6 ± 8.7). Compared to the reactions of the healthy group to the gait perturbations, the authors assigned the individuals with stroke into two groups; the inside group and the outside group. The inside group of individuals with stroke showed similar reactions as the healthy participants. The outside group of individuals post-stroke reacted differently than the healthy participants in responses to the forward and backward perturbations as well as the perturbations directed toward the side of the leading foot. The outside group had limited ability on the paretic side to show

appropriate ankle strategy in response to the mentioned perturbations similar to the healthy participants. Instead, the outside group took a long nonparetic step in reaction to the forward perturbation, a short step in reaction to the backward perturbation and a cross-step in reaction to the perturbations directed toward the side of the leading foot. The findings indicate the inability of the paretic side to the execution of a proper strategy with a lower energy requirement and the substitution of the nonparetic side to have an alternative strategy with a higher energy requirement.

Punt et al. (2017) asked participants with stroke at the chronic phase to walk on a split-belt treadmill at a constant speed of .41 m/s and applied perturbations in AP and ML directions. They calculated characteristics of BOS and MOS in AP and the ML directions at both sides in response to trips in the AP direction in addition to perturbations to right and left sides in the ML direction. Then, based on the fall incidence in ordinary life during six months after the assessment session, the authors categorized the participants into fallers and non-fallers groups. The authors reported that there were limited differences between the groups in the case of characteristics of BOS and MOS after perturbations. They mentioned that trying to keep the constant speed of .41 m/s contributed to the differences between the groups during the second step after the perturbation of the body toward the stance foot. So, the responses of the participants in this study were elicited by the two factors of constant gait speed and perturbations. Thus, the calculated characteristics of BOS and MOS are not attributable to the applied perturbations. However, their findings reflected the presence of impairments that should be addressed during the rehabilitation process.

These two studies (Punt et al., 2017; Zadravec et al., 2020) revealed different aspects of the inability of individuals at the chronic phase post-stroke for maintaining balance in reaction to the unpredictable perturbations during gait. Totally, the findings support the importance of applying a task-specific intervention to improve dynamic balance during gait.

2-6-4 Studies applied unpredictable perturbations during gait as a training intervention in individuals at the chronic phase post-stroke

In this section, I propose a summary of studies that applied unpredictable perturbations as an intervention for different purposes like improvement of dynamic balance or assessment of feasibility for fall prediction (Tables 1-3).

Previously, four studies trained persons with stroke at the chronic phase using unpredictable perturbation during gait training for reproducing conditions like slip or trip (Dusane & Bhatt, 2021; Mansfield et al., 2018; Matjačić et al., 2018; Punt et al., 2019). Perturbations were applied 1) manually by a physiotherapist (Mansfield et al., 2018), 2) by random pushes at the pelvis level (Matjačić et al., 2018), 3) by increasing and decreasing the speed of one of the belts of a split-belt treadmill to reproduce conditions like slip and trip (Punt et al., 2019) or 4) at both feet simultaneously by increasing the speed of a one-belt treadmill to reproduce conditions like slip (Dusane & Bhatt, 2021).

Table 1 Different types of unpredictable perturbations during gait applied in individuals at the chronic phase post-stroke

Dusane & Bhatt (2021)	Punt et al. (2019)	Matjačić et al. (2018)	Mansfield et al. (2018)
Purpose	To study the effects of slips on fall-resisting skills of participants with stroke at the chronic phase	To study the effect of gait perturbation training on characteristics of steady-state gait and daily-life gait, assessment of the effect of the intervention on the fall prediction model, assessment of the ability of participants to tolerate a progressively increasing training workload	To assess the feasibility of applying gait perturbation training in the ML direction using a balance-assessment robot and an instrumented treadmill (BAR-TM robot)
Type of perturbation	Unpredictable slips applied by one-belt treadmill	Predictable perturbations (virtual obstacles on one side of the treadmill or on the entire width of the treadmill), unpredictable perturbations (slips, trips, perturbations along ML axis) at heel contact, midstance and toe-off, different speeds of gait during training sessions	Random pelvis pushes in AP and ML directions at different speeds

Increasing the intensity and number of perturbations may contribute to the improvement of the training effects (Lee, Bhatt, Liu, Wang, & Pai, 2018). According to Savin et al. (2013), compared to healthy participants, the rate of adaptation to perturbations in individuals post-stroke is reduced. Applying higher repetitions of gait perturbations is suggested to be more advantageous due to increasing motor learning in this population (Dusane & Bhatt, 2021). The studies did not use the same units for reporting the intensities. Also, two of the studies did not report the number of

perturbations. Table 2 presented the intensities and number of repetitions applied in the studies.

Table 2 Intensities of unpredictable perturbations during gait used in the studies in individuals at the chronic phase post-stroke

	Dusane & Bhatt (2021)	Punt et al. (2019)	Matjačić et al. (2018)	Mansfield et al. (2018)
Intensity	Six progressively increasing intensity levels at self-selected gait speed (determined from 10-MWT) by increasing the acceleration of the belt at the level of 3 m/s^2 for producing slip distances of 1.5, 3.37, 6, 9.37, 13.5, 18.37 cm for the six levels	Five levels: for slips and trips, each level corresponded with .1 m/s increase or decrease of belt speed, an increase of 1 cm at each level for ML direction perturbations, 4 to 2 strides between each perturbation (4 strides for full recovery from perturbation and 2 strides for prevention of full recovery before receiving new perturbation)	Low and high amplitudes (50-100 Newton) for 150 ms	Increasing the difficulty level until participants need an upper extremity response or use an overhead harness or multi-step response for about 50% of the cases
Number of participants, training sessions and repetitions	Stroke (n=11), No control group, 4 sessions over 4 weeks, 200 repetitions at different levels in 1 st session, 120 repetitions in 2 nd and 3 rd sessions, 80 repetitions in 4 th session	Stroke (n=10), No control group, 10 sessions over 6 weeks, number of perturbations not reported	Stroke (n=1), healthy control (n=1), 30 sessions over 10 weeks, number of perturbations not reported	Gait perturbation (n=41), traditional balance training (n=42), 10 sessions + 1 booster, at least 60 postural perturbations per session

10-MWT: ten-meter walking test, m/s^2 : meter per second square, ms: milliseconds

The importance of applying higher intensity of perturbations is highlighted by some of these studies. Dusane and Bhatt (2021) reported a reduced number of falls and improvement of compensatory steps only at higher intensities of applied perturbations (levels 5 and 6). Also, Matjačić et al. (2018) stated only high amplitude perturbations contributed to more lateral placement of the paretic leg.

Table 3 Results of the studies

	Dusane & Bhatt (2021)	Punt et al. (2019)	Matjačić et al. (2018)	Mansfield et al. (2018)
Laboratory evaluation	Reduced number of falls ($p=.001$), reduced number of compensatory steps after perturbations ($p=.001$), increased fall threshold ($p=.01$), improved treadmill gait speed ($p=.003$)	Reduced predicted fall risk ($p=.01$), no change of local dynamic stability (which is a variable to evaluate the sensitivity of the postural control system in reaction to the perturbations), improved steady-state gait: treadmill gait speed ($p=.01$), increased paretic and nonparetic step length ($p\le.03$), reduced variabilities of stride and step time at both sides, paretic swing time ($p\le.05$)	The ability of the paretic side to make a cross-step after perturbations of the nonparetic side, activation of in-stance strategy on the paretic side (no p-value is reported)	
Clinical/overground measures	Unchanged scores of ABC scale, MiniBESTest, BBS ($p>.05$)	Unchanged overground predictors of fall risk ($p=.3$), increased number of walking bouts per day ($p=.02$), increased stride time ($p=.02$), decreased smoothness of walking ($p=.04$)	Modest improvement of FAC, 6-MWT, 10-MWT, TUG and FSST	No difference for the number of falls ($p=.44$), better improvement of reactive postural control subsystem of MiniBESTest in Perturb group ($p=.0084$) with retention for 6 (p=.0055) and 12 months ($p=.0013$), improvement of sensory orientation subsystem of MiniBESTest in the control group ($p=.044$)

FAC: Functional Ambulatory Category, 6-MWT: six-minute walking test, 10-MWT: ten-meter walking test, TUG: timed Up and Go, FSST: four-step square test, ABC scale: Activity-specific Balance Confidence scale, BBS: Berg Balance Scale

In the studies of Mansfield et al. (2018), Matjačić et al. (2018) and Punt et al. (2019), perturbations were applied in both the AP and ML directions. However, Dusane and Bhatt (2021) applied perturbations only in the AP direction. In addition to applied perturbations, speed increased progressively during training sessions in these studies except for the study of Dusane and Bhatt (2021). In the latter, the authors

did not report whether the participants walked on the treadmill at a constant comfortable speed during all training sessions or they increased the speed of the treadmill during the training sessions (Dusane & Bhatt, 2021).

Table 4 Conclusions of the studies

	Dusane & Bhatt (2021)	Punt et al. (2019)	Matjačić et al. (2018)	Mansfield et al. (2018)
Conclusion	Progressively increased intensity of slip-perturbations induced adaptive improvement in fall threshold and compensatory stepping	Improved quality of treadmill gait which contributed to reduced predicted fall risks without generalization to overground gait	The intervention may be a feasible approach for improvement of balancing skills	Inconclusive results, perturbation training may prevent falls in ordinary life, and booster sessions may be necessary for more retention

As studies did not control the confounding factor of speed during training sessions, the reported speed improvement in these studies (Table 3) could not be attributed to perturbation training. Likewise, it is possible to attribute other advantages of the interventions to either perturbation, speed increase or both of them (Punt et al., 2019). Mansfield et al. (2018) and Punt et al. (2019) also included predictable perturbation during training sessions which targeted anticipatory postural adjustments, not reactive postural responses. As explained in section 2-3, unpredictable perturbation training contributes to the improvement of both reactive and anticipatory postural responses. However, based on the type of exercises included in the studies of Mansfield et al. (2018) and Punt et al. (2019), the findings of these studies resulted from the combined effects of predictable and unpredictable perturbations in addition to speed increase in the two studies. In addition to increasing the speed of the treadmill during sessions, Punt added a cognitive dual-task (visual

Stroop task) to unpredictable perturbations during the last training sessions (Punt et al., 2019). The studies of Dusane and Bhatt (2021) and Punt et al. (2019) did not include a control group to compare the results of the stroke groups with the results of a reference group.

The balance abilities are addressed by the studies presented above. Punt et al. (2019) reported no change in local dynamic stability (which is a variable to evaluate the sensitivity of the postural control system in reaction to the perturbations) evaluated on the treadmill after the intervention. Mansfield et al. (2018) reported significant improvement of the reactive subscale of MiniBESTest in the perturbation training group after intervention and improvement of the total score of MiniBESTest after 12 months in this group. Matjačić et al. (2018) reported modest balance improvement after intervention measured by Timed up and Go (TUG) and the Four Square Step Test (FSST). Additionally, balance confidence was measured in the studies of Mansfield and Dusane and Bhatt (2021) and Mansfield et al. (2018). They reported no improvement in balance confidence after the intervention.

In a recent study, Dusane and Bhatt (2021) reported increased gait speed on the treadmill, reduced number of falls and compensatory steps during gait on the treadmill after the intervention. The authors calculated the stability of the COM state similar to the study of Kajrolkar (explained in section 2-6-6) (Kajrolkar et al., 2014). As presented in Table 2, Dusane and colleagues applied the slip perturbations with six levels of intensity. After training, the stability of the COM state at the time of the execution of the perturbation (pre-slip stability) was only improved at level 6 of the intensity. The stability of the COM state at post-slip after training was improved at

levels 2,3 and 5 of the intensity. The treadmill speed also improved significantly after intervention. The variables related to gait on the treadmill in the lab were improved. However, their intervention did not improve functional balance (evaluated by BBS) and dynamic balance (evaluated by MiniBESTest) and balance confidence, overground gait speed (evaluated by 10-Meter Walk Test) and cardiovascular endurance (evaluated by 6-minute walk test) (Dusane & Bhatt, 2021). Based on the analysis of the previous studies in individuals at the chronic phase post-stroke, no study applied intense and unpredictable slip and trip perturbations during gait training without any additional interventions/tasks. The following section will explain the aims of this thesis in detail.

Chapter 3 Objectives and hypotheses

3-1 Main hypotheses and objectives

Reduced balance and gait abilities are the main problems of individuals at the chronic phase post-stroke. Different types of interventions are aimed to improve these impairments. Limited studies have examined unpredictable perturbations during gait training. These studies included additional interventions/tasks or did not include a control group. Consequently, the findings of these studies could not be specifically attributed to the effect of unpredictable gait perturbations. Thus, it is necessary to study the effects of unpredictable perturbations during gait training without any additional interventions/tasks and to compare these effects with those obtained by individuals receiving another intervention (comparison group). The comparison between the two groups was one of the two general objectives of this thesis. In line with this objective, we conducted a randomized controlled pilot trial comparing the effects of intense and unpredictable slips and trips perturbation training with training that included walking-only on the treadmill in individuals at the chronic phase post-stroke. The intervention group received only perturbation training without any additional interventions like progressive increase of speed or cognitive tasks. The control group walked at their pre-training comfortable treadmill speed during all the training sessions. The duration of the training in both the intervention and the control groups was the same: nine training sessions over three weeks. The duration of each training session was according to the tolerance of the participants and was matched between the experimental and comparison groups. Our first hypothesis was that the

intense and unpredictable perturbations during gait training with progressive increase of intensity and repetition would improve balance and gait abilities. We hypothesized that applying unpredictable perturbation during gait training would improve both anticipatory and reactive responses.

On the other hand, community integration is one of the main objectives of rehabilitation interventions in individuals at the chronic phase post-stroke. The ability to walk at the speed of 1 m/s is known as the limit of independent walking in the community. The second main objective of this thesis was to study the differences of altered biomechanical determinants of dynamic balance during gait based on the cut-off over the ground speed of 1 m/s. We compared the biomechanical determinants of dynamic balance between a group of healthy and two groups of individuals post-stroke with overground comfortable self-selected gait speeds of more than 1 m/s (stroke-fast group) and less than 1 m/s (stroke-slow group). The biomechanical determinants of the dynamic balance were dimensions of the BOS in addition to the relative positions of the center of pressure (COP), the center of mass (COM) and the extrapolated COM (XCOM) in the BOS in the AP and ML directions. Additionally, we studied the association between the biomechanical variables and the Timed Up and Go (TUG) test as well as Chedoke-McMaster Stroke Assessment (CMSA). As the second hypothesis, we hypothesized to find similarities between the values of some of the biomechanical determinants of dynamic balance, particularly the values of XCOM which take into account the velocity of COM, in the stroke-fast group and the healthy group.

3-2 Specific objectives

The specific objectives of the two studies in this thesis are:

Study 1 (The randomized controlled trial):

- 1) To compare the effects of intense and unpredictable perturbations during gait training with walking-only on the treadmill training on balance and gait abilities in individuals at the chronic phase post-stroke.
- 2) To measure possible retention of the improvements in balance confidence and reintegration into the community 6 weeks after the end of both experimental and comparison groups.

Study 2 (The biomechanical study):

- 1) To compare the biomechanical determinants of dynamic balance in a group of healthy and two groups of participants with stroke at the chronic phase (with gait speed of faster than 1 m/s and slower than 1 m/s) at comfortable treadmill gait speed.
- 2) To compare the same biomechanical determinants of dynamic balance between the stroke groups at comfortable treadmill gait speed.
- 3) To determine how clinical balance abilities and motor impairments of the foot and the leg are related to alterations of the biomechanical determinants of dynamic balance in the two stroke groups.

Chapter 4 Methods

This chapter offers information regarding the recruitment of the participants and assessment, as well as the general course of the research. The specific methods used for each of the two studies are described in detail in chapter 5.

4-1 Design

The doctoral research project included two studies. The first one is a randomized controlled pilot trial to compare the effects of two interventions (with and without intense and unpredictable gait perturbation training) in individuals at the chronic phase post-stroke. The second one is a descriptive and correlational study involving the comparison of biomechanical determinants of dynamic balance during gait between a healthy group and two groups of individuals post-stroke. The stroke-fast group walked faster than 1 m/s and the stroke-slow group walked slower than 1 m/s.

4-2 Participants

For the randomized controlled pilot trial, participants were recruited using a list of individuals at the chronic phase post-stroke and healthy participants who participated in previous studies or were previously discharged from the Institut de réadaptation Gingras-Lindsay-de-Montréal (IRGLM). Also, advertisements were distributed in different stroke rehabilitation hospitals and centers like Lucie-Bruneau or among members of AXONE “Group de loisirs après-AVC du grand Montréal”, a community-based group of individuals post-stroke which was developed via the

internet for spending leisure time together. A person blinded to the process of assignment contacted the individuals with stroke and healthy by phone to provide a description of the study and invite them to participate in the study.

For the biomechanical study, the data of trials of gait of participants collected at comfortable self-selected speed during the randomized controlled pilot trial and data collected from a previous study conducted at IRGLM was used.

4-3 Clinical and laboratory evaluation of gait and balance

4-3-1 Pretraining evaluation

4-3-1-1 Clinical assessment

For detailed information regarding the clinical assessment, the reader is referred to the results section of the randomized controlled trial and the biomechanical study presented in chapter 5.

4-3-1-2 Laboratory evaluation

This section offers some details which are not specifically presented in the two studies. Laboratory assessment of gait and dynamic balance was done by marker-based motion capture. Using tapes and Velcro straps, three to six mounting active infrared markers were installed on major segments of the body including the head, upper trunk, lower trunk, pelvis, arms, forearms, hands, thighs, shanks, and feet (Figure 4.1). The three-dimensional position of the markers was tracked via an optoelectronic 3D-motion analysis system (NDI Optotrak Certus) (Surer & Kose, 2011). To reduce the fatigue of the participants, the majority of markers were installed

in a sitting position. Markers of the lower trunk and thighs were installed in a standing position. The infrared cameras used in this method only captured markers' positions. In this method, the body was defined as sixteen rigid segments that are attached through joints (Surer & Kose, 2011). Using a series of software developed at the IRGLM, kinematics characteristics of body segments were calculated based on the movements of the infrared markers in the 3D space. The anthropometric data were used for the calculation of the mass of each segment of the rigid body (Gard, Miff, & Kuo, 2004). Then, the COMs of different segments are used to calculate the position of the global COM (Gard et al., 2004). The calculations were done using the Zatsiorky-Seluyanov anthropometric model (de Leva, 1996). Using a split-belt treadmill with integrated force plates for each belt (Bertec Fit®), it was possible to measure the GRFs under each foot and moments at a sampling rate of 600 Hz during gait (Mawase, Haizler, Bar-Haim, & Karniel, 2013). The onset of vertical GRF was used to determine the heel contact time point and the offset of the vertical GRFs was used to detect the toe-off time point in each gait cycle using the Teager-Kaiser Energy Operator (TKEO) method (Solnik, Rider, Steinweg, DeVita, & Hortobagyi, 2010). The TKEO method uses the averaged standard deviation of recorded signals in standing position as the baseline signal and uses the baseline signal as a threshold. Exceeding this threshold is defined as the onset. The opposite condition is defined as the offset (Betschart, 2016).

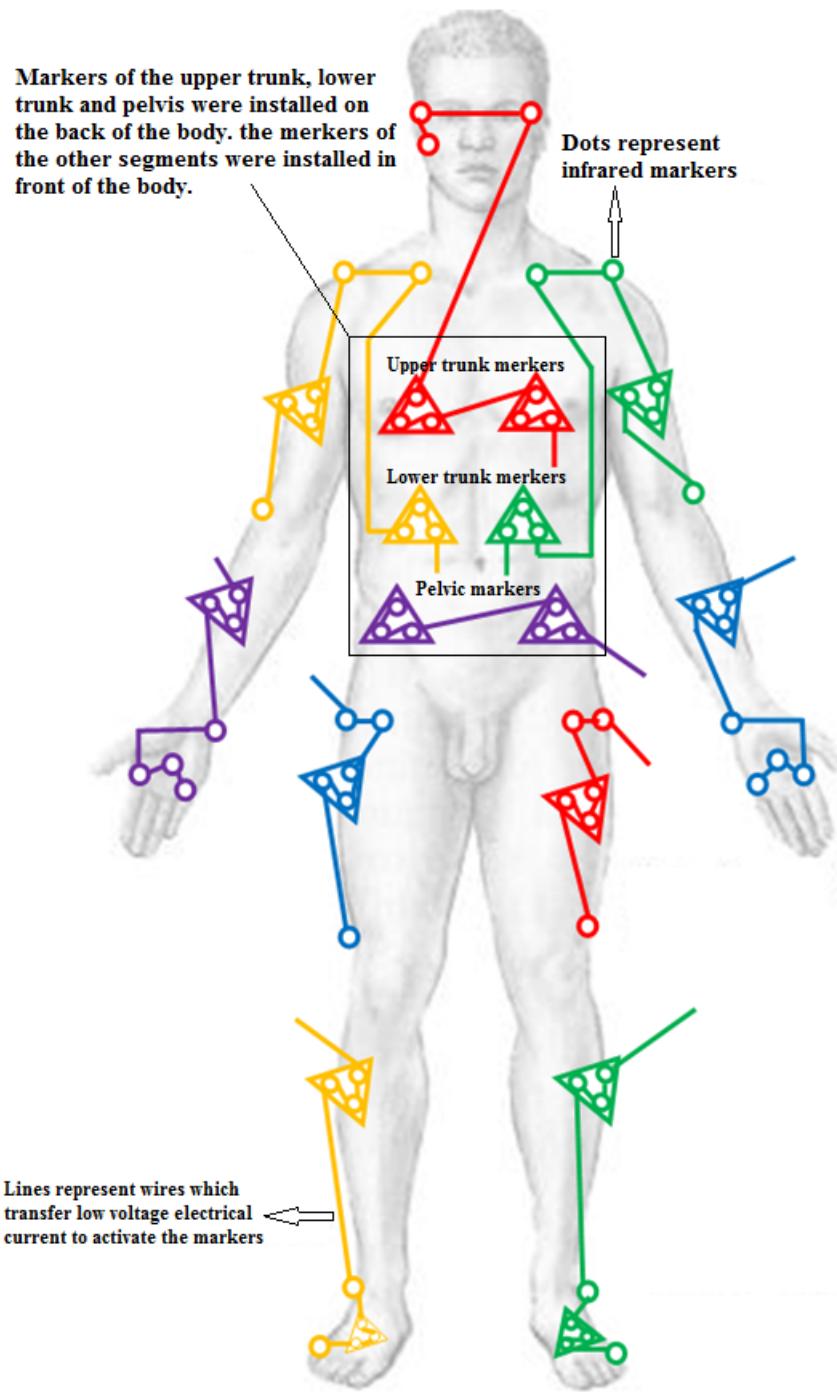


Figure 4.1. The position of the infrared markers installed on the different segments of the body.

After the installation of the markers, because the treadmill was higher than the ground level, a hydraulic scissor lift was used to bring the participant to the split-belt treadmill. Using a digitizing probe (Figure 4.2), the contours of the shoes were introduced to the infrared cameras while participants were seated on a chair. The counter of the shoes then was used to calculate the BOS in AP and ML directions.

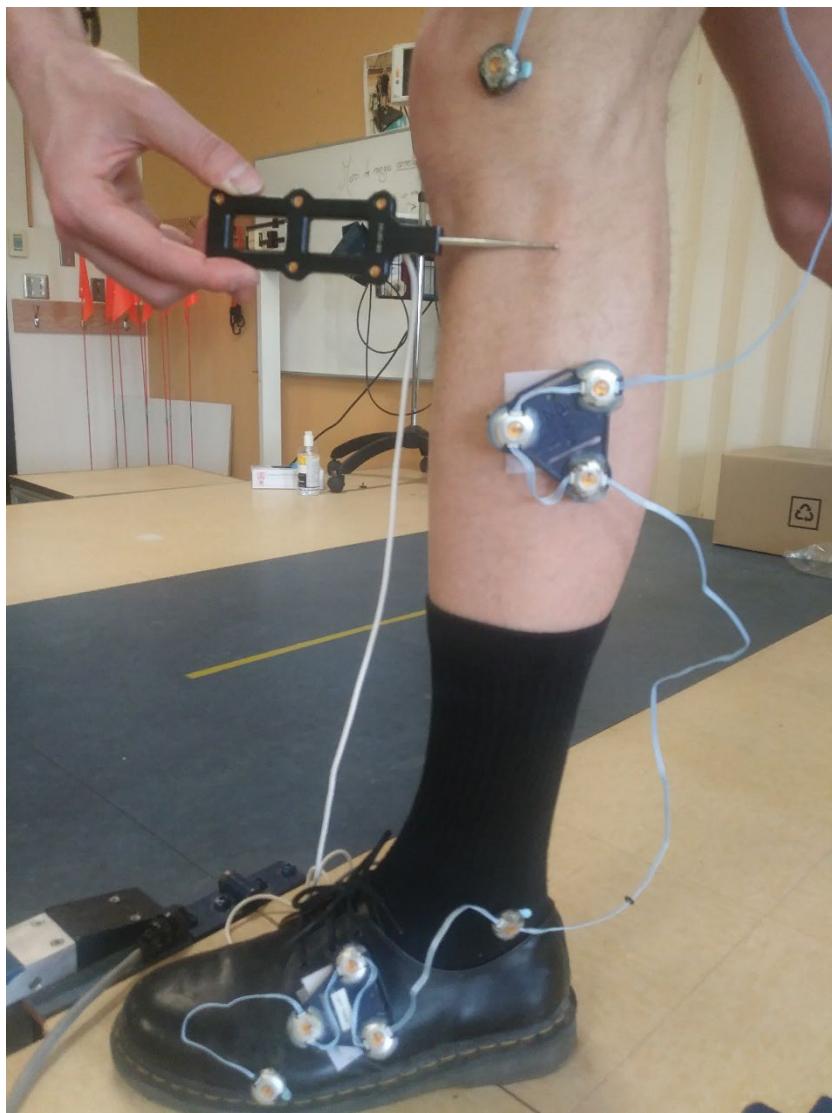


Figure 4.2. The digitized probe for introducing anatomical points to the infrared camera.

Then, in standing position and using the same digitizing probe, the location of a series of anatomical points was recorded by the infrared cameras (Figure 4.3.). These anatomical points were used later for the accurate calculation of the dimensions of the whole body in the 3D space.

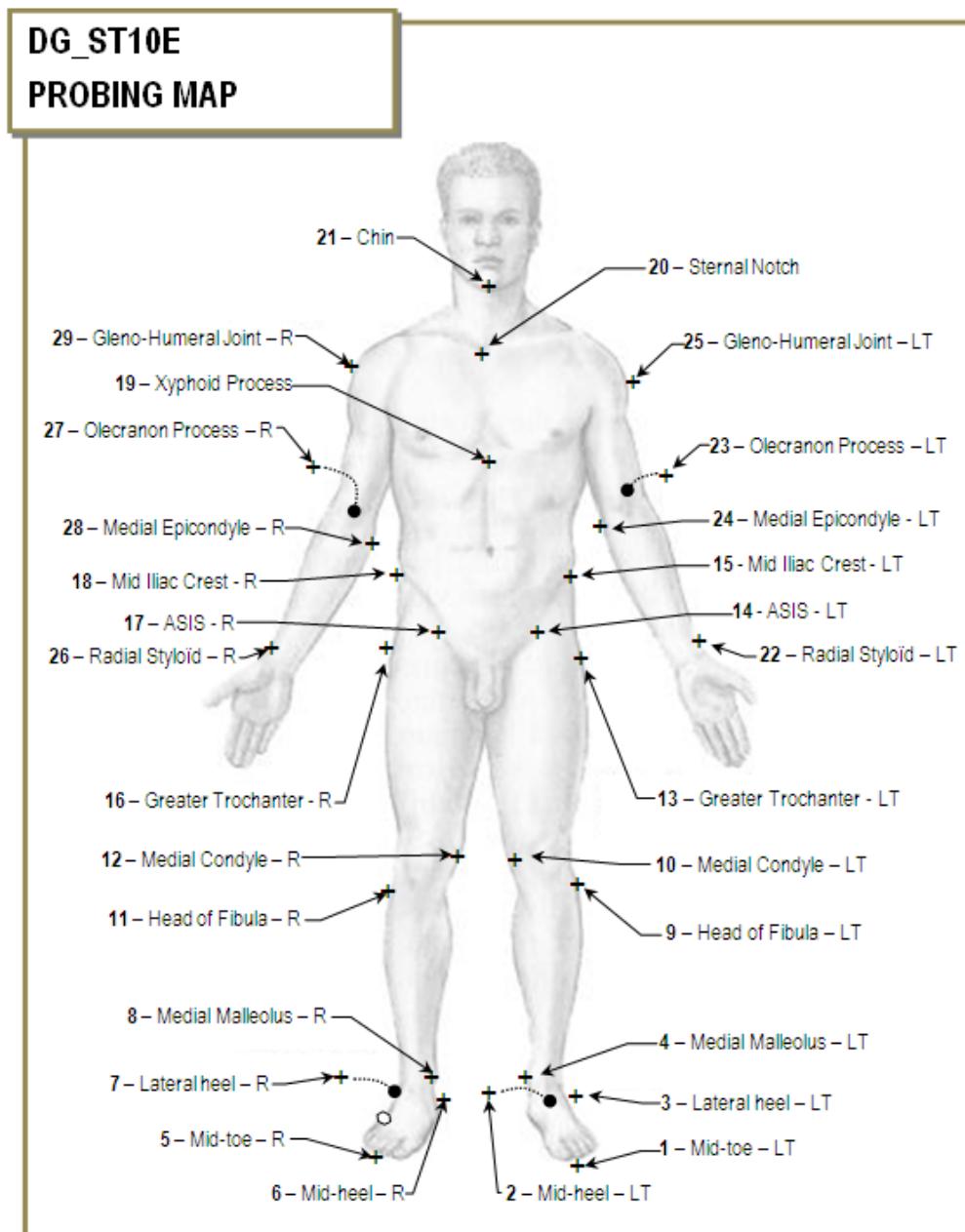


Figure 4.3. The anatomical points were used for the calculation of the dimensions of the body using a series of software developed at IRGLM.

Each gait analysis session began with 30 seconds of standing to record kinematic data and GRFs in the static situation and was followed by a trial to determine comfortable gait speed according to individual perception. This perception was tested both by progressively increasing and decreasing .1 m/s of the speed of the belts. Whenever reached the comfortable gait speed, the speed of the treadmill increased by .05 m/s. If participants mentioned that the new speed was not comfortable, the previously determined comfortable speed (before increasing .05 m/s) was selected as the comfortable gait speed. Then recordings were done at a comfortable treadmill speed (Figure 4.4.). Although we also recorded the activity of some of the muscles of the lower extremity using surface electromyography (EMG) (Noraxon Ins., USA) (Figure 4.4.), the analysis of EMG data was not included in this thesis.



Figure 4.4. After the installation of infrared markers, participants walked on an instrumented split-belt treadmill. The treadmill was used to apply unpredictable gait perturbations by increasing or decreasing the speed of one of its belts.

Chapter 5 Results

5-1 Intense and unpredictable perturbations during gait training improve dynamic balance abilities in hemiparetic individuals with stroke at the chronic phase: a randomized controlled pilot trial

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Each author made substantial contributions to the conception and design of the work. Esmaeili V and Duclos C. made substantial contributions to data acquisition, analysis, and interpretation of data, and drafted the work. Esmaeili V., Duclos C. and Bouyer L. substantively revised the manuscript. Each author has revised and approved the submitted version of the manuscript.

5-1-1 Abstract

Background: Previous studies have assessed the effects of perturbation training on balance after stroke. However, the perturbations were either applied while standing or were small in amplitude during gait, which is not representative of the most common fall conditions. The perturbations were also combined with other challenges such as progressive increases in treadmill speed.

Objective: To determine the benefit of treadmill training with intense and unpredictable perturbations compared to treadmill walking-only training for dynamic balance and gait post-stroke.

Methods: Twenty-one individuals post-stroke with reduced dynamic balance abilities, with or without a history of falls and the ability to walk on a treadmill without external support for at least 1min were allocated to either an unpredictable gait perturbation (experimental) group or a walking-only (comparison) group through covariate adaptive randomization. Nine training sessions were conducted over three weeks. Participants of the comparison group only walked on the treadmill during this period but were crossed over to the perturbation training at the end of the comparison intervention. Pre- and post-training evaluations included balance and gait abilities, maximal knee strength, balance confidence and community integration. Six-week phone follow-ups were conducted to question the balance confidence and community integration. Satisfaction with perturbation training was also assessed.

Results: With no baseline differences between groups (all $p > .075$), perturbation training yielded large improvements in most variables in the Experimental group

(n=10, $p < .05$, Effect Size: ES > .46) and the post-crossing in comparison group (n=7, $p \leq .089$, ES > .45), except for maximal strength ($p > .23$). Walking-only training in the pre-crossing comparison group (n = 8) mostly had no effect ($p > .292$, ES < .26), except on balance confidence ($p = .063$, ES = .46). The effects of the gait training were still present on balance confidence and community integration at follow-up. Based on scores of Short Feedback Questionnaire modified for perturbations, the satisfaction with the training program was high.

Conclusion: Intense and unpredictable gait perturbations have the potential to be an efficient component of training to improve balance abilities and community integration in individuals with stroke at the chronic phase.

Retrospective registration: ClinicalTrials.gov. March 18th, 2020. Identifier: NCT04314830.

Keywords: Stroke, Perturbation training, Balance, Gait, Strength, Community mobility

5-1-2 Background

Post-stroke impairments, particularly those affecting dynamic balance, are responsible for a fall incidence rate as high as 37 to 73% during the first year after stroke (Batchelor, Mackintosh, Said, & Hill, 2012; Garland et al., 2009; Pollock et al., 2011). Dynamic balance can be defined as the ability to achieve, maintain, or restore the line of gravity within the continuously changing base of support (Leroux et al., 2006; Pollock et al., 2000). Dynamic balance impairments in individuals post-stroke are due to decreased sensory information and muscular strength on the paretic side (Leroux et al., 2006), slow gait speed, (von Schroeder, Coutts, Lyden, Billings, & Nickel, 1995) reduced adaptability to constraints, (Said, Goldie, Patla, & Sparrow, 2001) impaired timing of muscle activation (Garland et al., 2009) and delayed or disrupted postural responses (Mansfield et al., 2015a; Sawacha et al., 2013). Impaired dynamic balance and related falls result in psychological and physical consequences such as reduced social participation and activity restriction, fear of falling and fractures (Weerdesteyn et al., 2008). Effective dynamic balance training post-stroke should include balance perturbations during gait (Granacher et al., 2011; Lubetzky-Vilnai & Kartin, 2010). Nonspecific training approaches with mobility exercises improve functional balance and mobility in persons with stroke, (Marigold et al., 2005; Vearrier, Langan, Shumway-Cook, & Woollacott, 2005) but the effects are small (Veerbeek et al., 2014). In addition, individuals post-stroke predominantly fall during gait (Weerdesteyn et al., 2008) where compensatory strategies that are essential for balance recovery require activation of neural pathways specific to involuntary postural responses (Maki & McIlroy, 1997). On the other hand, the

stepping strategy, i.e., taking a step, or changing its characteristics, to maintain balance, is essential for counteracting unpredictable situations leading to falls while walking in ordinary life (Maki & McIlroy, 1997). To trigger this strategy, perturbations should be unpredictable and intense enough to be challenging (Gerards et al., 2017).

While gait perturbation training has already been reported as an effective method for reducing fall rates in older adults, (Gerards et al., 2017; Pai & Bhatt, 2007) there is limited evidence on the effectiveness of perturbation training in individuals post-stroke (Handelzalts et al., 2019; Mansfield et al., 2018; Punt et al., 2019). Two recent studies used perturbations in a standing position, which had a limited effect on balance abilities, similar to control, traditional balance training (Kumar & Pathan, 2016; Mansfield et al., 2018). Another study that used low-amplitude perturbations did not trigger large stepping responses (Punt et al., 2019). Lastly, gradual increases in treadmill speed of walking during the training sessions may be a confounder in these studies, (Handelzalts et al., 2019; Punt et al., 2019) given that treadmill gait training is known to improve gait abilities (Mehrholz, Thomas, & Elsner, 2017) and possibly balance (Tally et al., 2017; van Duijnhoven et al., 2016). To determine whether gait perturbations are effective in clinically improving dynamic balance, it is necessary to control for the effect of gait training on balance and gait abilities. In addition, perturbations that occur in daily life vary in intensity and require specific adaptations in stepping reactions or gait pattern. Therefore it seems necessary to include medium-to-large perturbations in training programs to challenge gait adaptability in individuals with stroke. The purpose of this pilot study was thus to compare the effects of gait training with and without unpredictable perturbations that

trigger stepping reactions on dynamic balance and gait abilities in individuals at the chronic phase post-stroke. In both groups, we also measured possible sustained improvements in balance confidence and reintegration into the community six weeks after the end. We hypothesized that the experimental perturbation training (Experimental) group would improve in dynamic balance, walking speed, balance confidence and muscle strength. These effects would facilitate the transfer of improved balance abilities towards better community integration (Punt et al., 2019). The control group (comparison), which would walk on the treadmill without perturbation, would only improve in walking speed, and possibly dynamic balance, but to a lower extent due to the lower-level challenge of the steady treadmill speed throughout the training program (Handelzalts et al., 2019; Tally et al., 2017). The participants in this group who would cross over to perturbation training once the no-perturbation training was finished, would demonstrate further improvements in balance and gait abilities during this second training period.

5-1-3 Participants and methods

A convenience sample of 21 individuals with a unilateral stroke at the chronic phase (> 6 months) was recruited and allocated to one of two groups (2 females in each group): Experimental and comparison. In the absence of preliminary data, sample size was not determined a priori. Inclusion criteria included: 1) reduced dynamic balance abilities (MiniBESTest score below the lower limit of the 95% confidence interval of normative data according to age group (O'Hoski et al., 2014)) 2) with or without a history of falls and 3) the ability to walk on a treadmill without external support such as handrails or a walking aid for at least 1 min. Exclusion criteria

included 1) hemineglect (more than 6 omissions on the Bells Cancellation Test) (Lezak, 1995), 2) major cognitive impairment (Mini-Mental State Examination score below 24/30), (Folstein, Folstein, & McHugh, 1975) 3) uncorrected visual deficit or pathologies other than stroke affecting gait or balance. The medical files of the participants were reviewed to confirm the absence of such pathologies. Clinical characteristics, such as socio-demographic data (age, sex, time since stroke) were obtained from the participants' medical charts and interviews. The Chedoke-McMaster Stroke Assessment (CMSA) was used to determine motor impairments at the foot and leg (Gowland et al., 1993). Spasticity was evaluated using the Composite Spasticity Index at the hip, knee and ankle (total scores of Levin & Hui Chan for hip, knee and ankle) (Levin & Hui-Chan, 1993). The Consolidated Standards of Reporting Trials (CONSORT (Schulz, Altman, & Moher, 2010)) and Template for Intervention Description and Replication (TIDieR (Hoffmann et al., 2014)) checklists were used to prepare this manuscript.

The participants attended nine training sessions (Figure 5.1.) over 3 weeks. A split-belt treadmill (Bertec Fit®) was used to induce perturbations by changing the speed of each belt independently. Each perturbation training session began with a 60-s walking period at a comfortable treadmill speed. First, one type of perturbation was applied repeatedly (i.e., the same type of perturbation, repeated with the same intensity, but unpredictable in time). Then, unpredictable perturbations were applied (i.e., type, intensity and time of the perturbation were unpredictable). When the perturbations were repeated, 10 perturbations were applied during one trial at the same intensity level, set as a percentage of the comfortable gait speed. By increasing or decreasing the speed of one of the belts by a percentage of the comfortable gait

speed (140, 160, 180%... or 60, 40, 20 and 0%), different intensities and types of perturbations could be produced (i.e., faster-belt or slower-belt perturbations). Faster-belt perturbations simulated trips and slower-belt perturbations simulated slips (Ilmane, Croteau, & Duclos, 2015). The maximal intensity of the perturbations was chosen when the gait pattern became altered due to large stepping reactions and/or the participant's tolerance, i.e., whether he/she accepted or not to increase the intensity of perturbation. Each participant had three faster-belt, repeated perturbation trials followed by three slower-belt, repeated perturbation trials that increased in difficulty. These trials were first conducted on the non-paretic side and then on the paretic side, with perturbations being applied every 6 to 10 strides. Unpredictable perturbation trials included perturbations on either side, at the highest intensity level and 50% of the highest intensity of faster-belt and slower-belt perturbations reached during the repeated perturbation trials. Each of these perturbations was repeated twice, for a total of 16 perturbations per unpredictable perturbation trial (two sides, two levels of difficulty for fast- and slower-belt perturbations, each repeated twice). The number of unpredictable perturbation trials depended on each participant's tolerance, i.e., he/she agreed to have another trial. The intensity of the perturbations also gradually increased with each session based on the participants' tolerance. A harness was used to prevent a fall during training without providing any body weight support during gait or the perturbations.

Participants in the comparison group only walked on the treadmill at their comfortable treadmill speed. The duration of the training sessions (walking time) for each participant in the comparison group was matched against that of a participant in the experimental group with a similar overground speed. Comparison participants

were offered to cross over to the experimental treatment at the end of the control intervention. To limit the effect of the gait training itself, treadmill speed between perturbations was not increased across the nine sessions of each training program.

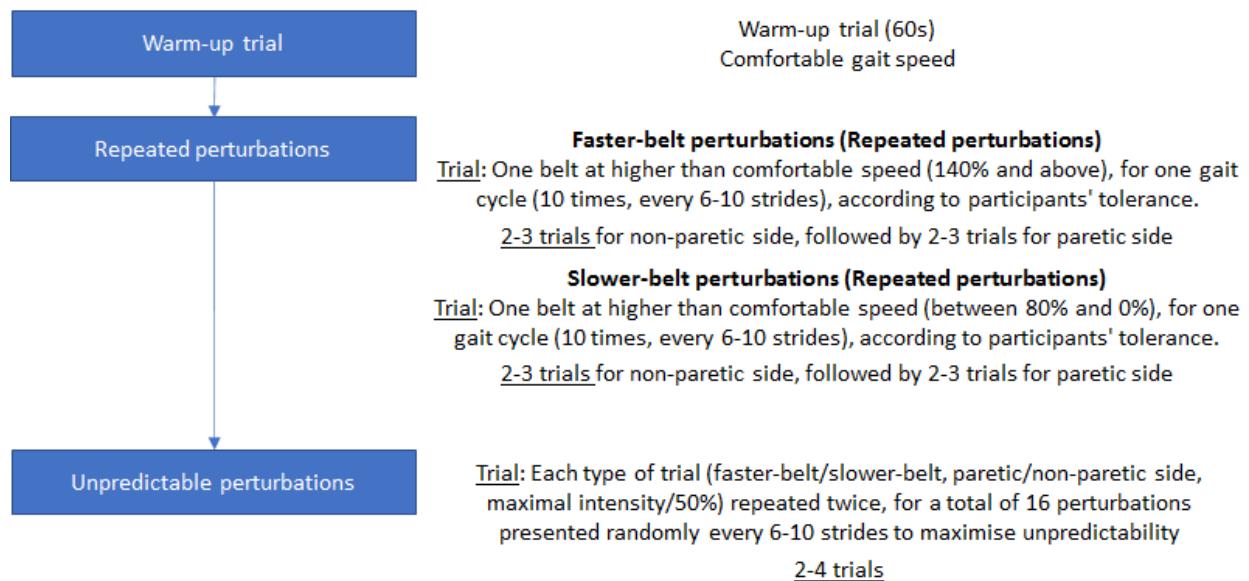


Figure 5.1. Description of the content of one trial session

The following two primary outcome measures were used to evaluate dynamic balance and gait speed. The Mini-BESTest was used to assess balance abilities in dynamic conditions while performing 14 dynamic tasks, categorized into four subsystems (anticipatory activity, reactive postural control, sensory orientation and dynamic gait) (Tsang et al., 2013). The Minimal Clinically Important Difference (MCID) of the Mini-BESTest in individuals at the chronic phase post-stroke is 4/28 points (Godi et al., 2013). The 10-Meter Walk Test was used to evaluate gait speed at comfortable and fast overground speeds, which, on its own, is a good indicator of the level of independence (Bowden, Balasubramanian, Behrman, & Kautz, 2008). The MCID of the 10-Meter Walk Test is .14 m/s in the stroke population (Perera, Mody, Woodman, & Studenski, 2006). Ten MW showed excellent reliability (ICC=.94 for

self-selected speed and ICC=.97 for faster speed) (Flansbjer, Holmback, Downham, Patten, & Lexell, 2005), excellent intrarater reliability (ICC=.99) (Wolf et al., 1999) and, excellent correlation with Barthel Index ($r=.78$) as predictive validity (Tyson & Connell, 2009).

In order to better understand how the training programs could potentially improve balance and gait abilities, we also evaluated the following secondary outcome measures. Maximal muscle strength was evaluated on the paretic and non-paretic knee extensors using a Biodex dynamometer in isometric conditions at 90° knee flexion. Balance confidence was evaluated using the Activity-specific Balance Confidence (ABC) scale. This questionnaire assesses how confident individuals are in maintaining balance during 16 tasks using a 0–100% scale, with 100% being completely confident (Botner et al., 2005). Beyond the concept and features of balance ability, the questionnaire is associated with functional mobility (Dean & Kautz, 2015). ABC has excellent test-retest reliability (ICC=.85 with 95% confidence interval =.68-.93) (Botner et al., 2005), excellent internal consistency (Cronbach alpha =.94) (Salbach et al., 2006) and, adequate correlation with gait speed ($r=.48$) as construct validity (Botner et al., 2005). Improvement of mobility may improve reintegration into normal social activities (e.g. recreational activities, community trips, and interactions with family). The Reintegration to Normal Living Index (RNLI) is a questionnaire that was used to determine whether the training programs had an effect on the activities of daily living of the participants. A lower score represents better integration. The MCID of the RNLI is 7% (Mayo et al., 2015). RNLI had good internal consistency and test-retest reliability (Daneski, Coshall, Tilling, & Wolfe, 2003; Pang, Lau, Yeung, Liao, & Chung, 2011), strong correlation with Barthel Index as construct validity (Daneski

et al., 2003), excellent internal consistency (Cronbach alpha=.92) (Bluvol & Ford-Gilboe, 2004). Clinical and strength assessments were performed in the week before and the week after the end of the training programs by different evaluators trained in the use of these evaluation tools and blinded to group assignment and time of assessment. Balance confidence and reintegration into social activities were re-evaluated 6 weeks after the end of the training program via a phone interview (Figure 5.2.) to evaluate the sustained effect of the intervention. In addition, the level of satisfaction with the perturbation training program was evaluated using the Short Feedback Questionnaire (SFQ) (Archambault, Blackburn, Reid, Routhier, & Miller, 2017) modified for perturbations (SFQ-Mp) in the week following the end of the perturbation training. The questionnaire items with a five-point rating scale are presented in Figure 5.5. Comparison participants who crossed over to the non-perturbation training program after the 6-week follow-up phone interview were also evaluated clinically before, immediately after and 6 weeks after the second training program as were the participants in the experimental group (Figure 5.2.). Data collection and training sessions were performed at the Gingras-Lindsay Rehabilitation Institute in Montreal, Canada. The study received ethical approval from the Research Ethics Committee of the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR-998-0914). All participants signed a consent form prior to study enrollment.

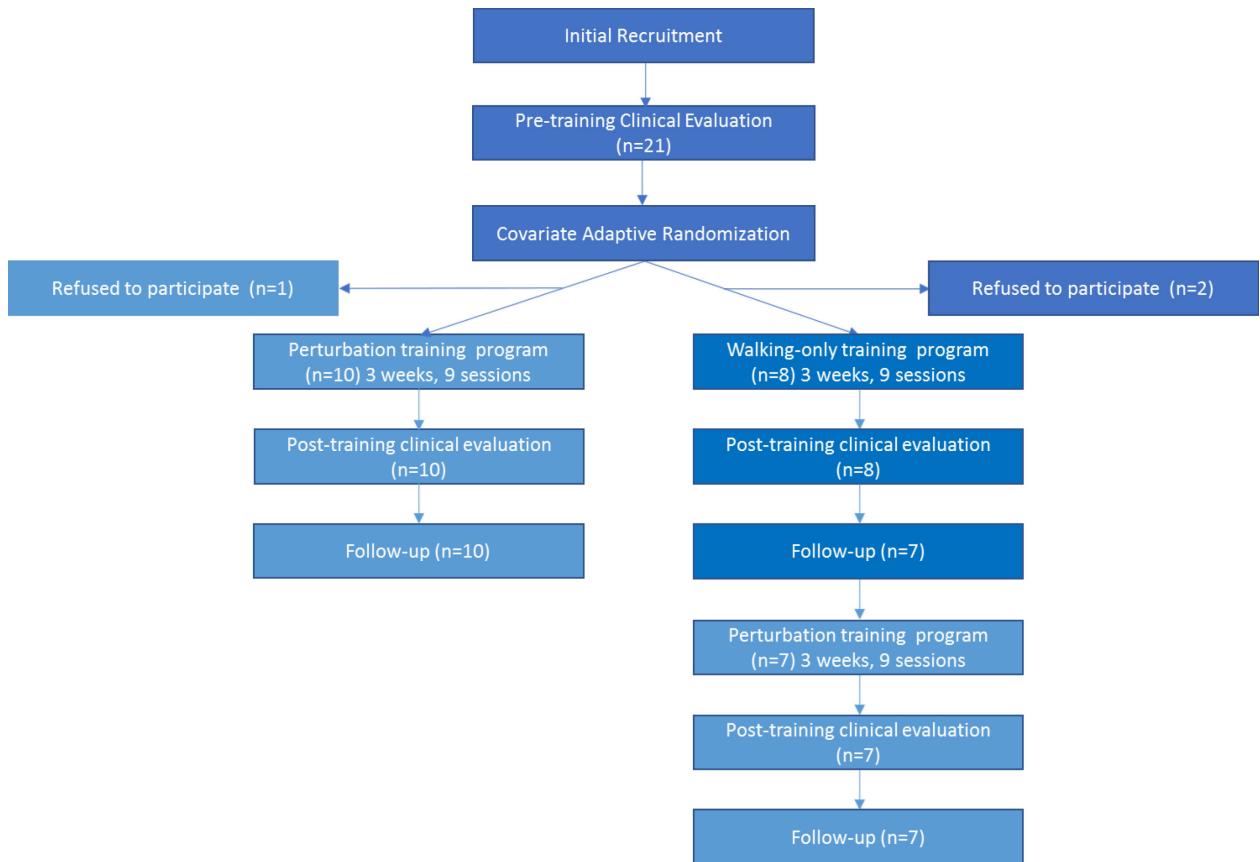


Figure 5.2. Flow diagram of the study; text boxes with a light blue background highlight the perturbation training periods

To reduce the risk of potential bias due to small-sized groups, we used a covariate adaptive randomization process, (Suresh, 2011) with the following baseline characteristics tentatively matched between groups: dynamic balance abilities, comfortable and fast overground gait speed, age, motor impairments of the leg and foot, height, and weight. An initial experimental subgroup was recruited for perturbation training. Then new participants were placed in either the comparison or the experimental group depending on matching characteristics. Blinding of the participants and the person allocating the individuals post-stroke to groups was not possible due to the nature of the intervention and the design of the study (partial cross-

over). The two experimenters, who were trained physical therapists and were supervising the training sessions were also not blinded regarding the intervention.

Baseline and post-training data were compared within the experimental and comparison (walking-only and perturbations post-cross over) groups to show the effects of each training using Wilcoxon tests. In addition, balance confidence and RNLI scores measured at the 6-week follow-up were compared to pre-training and immediate post-training values using Wilcoxon tests to estimate the immediate and six-week effects of each training program. Associated effect sizes (r) were calculated using the Z value of the Wilcoxon signed-rank test ($r = Z/\sqrt{N}$) (Rosenthal, 1994). We compared primary and secondary outcomes at baseline, immediately following the training program (and at the 6-week follow-up for ABC scale and RNLI only) using Mann-Whitney U tests to show 1) whether the clinical characteristics of the groups differed before training, and 2) whether the perturbation programs (experimental and comparison groups) resulted in better performance post-training and at follow-up than the walking-only program (comparison group only). In addition, we compared the scores obtained for each subsystem of the Mini-BESTest at baseline and immediately after the training programs, using Wilcoxon tests, to determine whether subsystems of balance were specifically improved by the perturbation or walking-only training programs.

5-1-4 Results

No significant differences were found before training between the experimental group and the comparison group (Mann-Whitney U test; walking-only: $p > .075$ (Table 5.1), and secondary perturbation training program after cross over: $p \geq .135$). All

participants attended the nine sessions in each of their training programs. It was supposed that the participants in each group complete nine training sessions over three weeks. The average duration of participation in the training periods was 21.6 (8.2) (Mean (SD), experimental), 18.3 (5.0) (comparison walking-only), and 20.1 (3.3) (comparison, perturbations) days. The follow-up periods were 60.1 (23.2) (experimental), 55.5 (12.9) (comparison walking-only), and 91.4 (38.9) (comparison, perturbations) days. The duration between the follow-up of the first training period and the first day of the second period of training for the comparison group was 45.4 (27.4) days. Various delays due to medical or personal reasons increased training duration or time between training in four participants. One participant allocated to the experimental group and two participants in the comparison group refused to participate in the study after allocation (Figure 5.2.). Given that the recruitment and training stopped in the winter due to inclement weather, the perturbation training post-cross over for the comparison group was often delayed and done mostly during the following summer.

On average, the total number of repeated and unpredictable perturbations applied over the nine sessions scheduled in the training program for each participant reached 618 (183) and 768 (237), respectively, with a progressive increase in the number of unpredictable perturbations and a decrease in the repeated perturbations throughout the training program (Figure 5.3.). The highest intensity of faster-belt and slower-belt perturbations was 280% and 0% respectively, except for three participants who did not reach such a level of difficulty. The first time when the participants were able to handle the highest intensity of slowest-belt perturbation (0%) was between the 2nd and the 6th training session (mean (SD): 3.8 (1.6)). The corresponding values for

the fastest-belt perturbation (280%) were observed between the 4th and 9th training sessions (mean (SD): 6.7 (1.4)). Neither perturbation training nor walking-only training worsened spasticity (Wilcoxon $p \geq .257$ for Composite Spasticity Index scores at the hip, knee and ankle). The duration of each session ranged from 35 to 70 min depending on gait cadence and the amount of rest the participants required.

5-1-4-1 Effects of perturbation training vs. walking-only training

Perturbation training led to large improvements in dynamic balance and comfortable and fast overground speeds in the experimental group (Table 5.2, Figure 5.4.). This increase was equal or above the MCID level for dynamic balance in 5/10 participants (+ 6 (2)/28) vs. only 1/8 in the walking-only group, and equal or above the MCID level for comfortable speed in 6/10 participants, vs. 0/8 in the walking-only group. Concerning the subsystems of balance control, only anticipatory activity score increased significantly with both training programs (Perturbation (n = 17) (Median (interquartile range)): 3.0 (2.0) to 4.5 (2.5)/6 ($p = .006$) vs. Walking-only: (n = 8): 3.0 (2.0) to 4.5 (2.3)/6 ($p = .011$)). Reactive postural control (3.0 (2.5) to 3.9 (2.5) ($p = .039$) vs 2.4 (4.0) to 1.5 (4.5) ($p = 1$)), gait scores (6.0 (3.0) to 8.0 (2.5)/10 ($p = .002$) vs 7.0 (1.8) to 6.5 (2.8)/10 ($p = .262$)) increased significantly only with perturbation training. Scores for sensory orientation, that were high at baseline, did not change significantly with any training (6.0 (1.0) to 6.0 (0)/6 ($p = .059$) vs 4.5 (2.0) to 5.4 (1.8)/6 ($p = .336$)).

Table 5.1 General characteristics and clinical scores at baseline for the experimental and comparison groups

Baseline characteristics	Experimental group (median (IQR))	Comparison group (median (IQR))	p values
Height (cm)	173.0 (20.0)	170.5 (16.0)	.656
Mass (kg)	83.2 (25.0)	77.9 (9.4)	.477
Age (years)	58.0 (6.7)	57.5 (18.0)	.964
Months post stroke (months)	67.5 (19.0)	104.5 (137.0)	.075
Chedoke leg (/7)	5.0 (1.5)	5.0 (2.75)	.829
Chedoke foot (/7)	3.0 (2.0)	2.0 (2.0)	.573
Hip Spasticity	2.0 (0)	2.0 (2.5)	.882
Knee Spasticity	4.5 (2.8)	4.5 (5.3)	.964
Ankle Spasticity	4.0 (1.5)	5.0 (3.3)	.360
Dynamic balance (/28)	20.0 (2.75)	16.5 (6.25)	.447
Comfortable over ground speed (m/s)	.9 (.31)	.96 (.50)	.689
Fast over ground speed (m/s)	1.35 (.57)	1.24 (.46)	1.000
Paretic knee extensors maximal strength (Nm)	94.5 (46.6)	113.9 (45.9)	.165
Non-paretic knee extensors maximal strength (Nm)	139.1 (51.4)	123.2 (49.2)	.643
Balance confidence (ABC scale)(/100)	75.9 (31.3)	65.9 (17.5)	.398
Community integration (RNLI) (/22)	3.0 (4.5)	2.0 (1.75)	.591

Note: IQR Interquartile range

Perturbation training resulted in a significant improvement in balance confidence scores in the experimental group (from 75.9 to 76.6%) (Table 5.2). Maximal strength increased significantly on the paretic (+ 47.0%) and non-paretic (+ 16.0%) knee extensors in experimental group, but not in the comparison group (less than 8.1% increase) (Table 5.2). RNLI results improved significantly with a median score reduction in the experimental group only (Table 5.2). Post-training comparisons between the experimental group and the comparison walking-only group showed only a difference in dynamic balance (Mann-Whitney U $p = .006$). Perturbation training in the experimental group had a large effect size with respect to most variables ($ES > .46$). However, walking-only training in the comparison group had little ($ES < .26$) to

no effect size for most variables, except for balance confidence (ES = .46) (Table 2, Figure 5.4.).

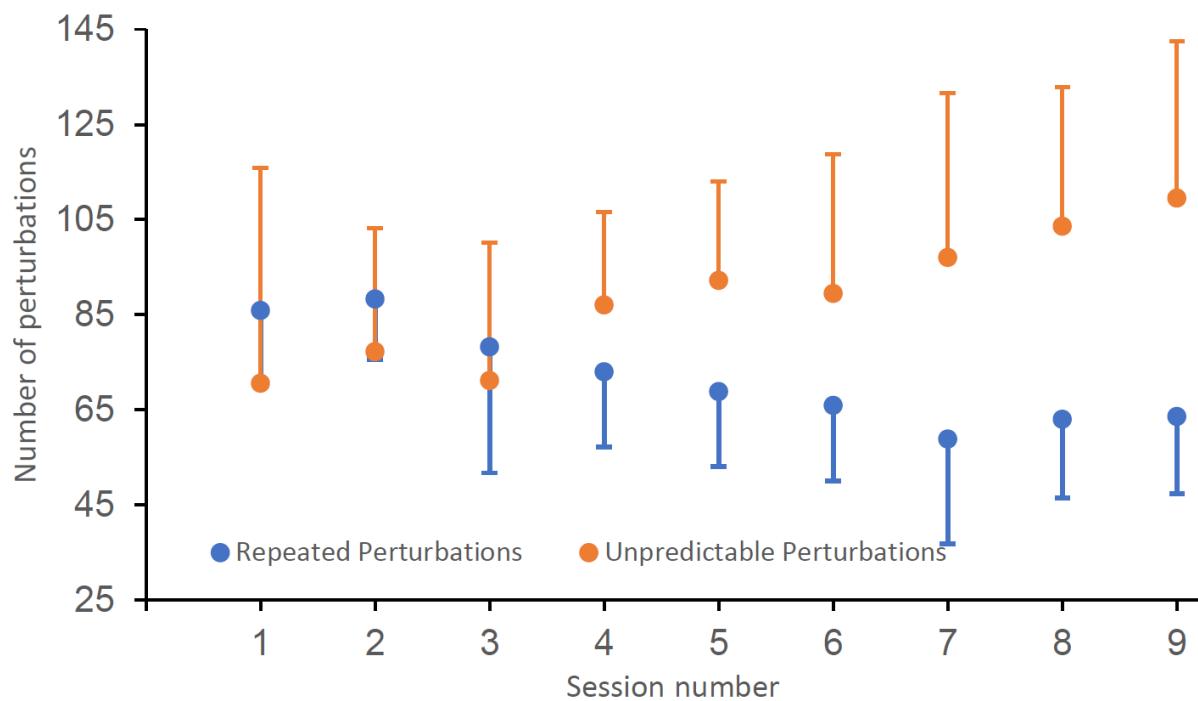


Figure 5.3. Mean and standard deviations (error bars) of the number of repeated (blue) and unpredictable (orange) perturbations applied to the 17 participants (experimental group: n=10, comparison group after crossover: n=7) who received perturbation training

Table 5.2 Within and between group comparisons of primary outcome measures

		Experimental Group (mean (SD), n=10)	Comparison Group (walking-only training) (mean (SD), n=8)	Comparison Group (perturbation training) (mean (SD), n=7)
Dynamic balance (Mini-BESTest)	Pre	18.9 (4.3)	17.2 (3.7)	16.8 (3.2)
	Post	22.9 (2.2)	17.2 (3.8)	20.3 (3.3)
Within group comparison pre-post training	Effect Size	.63	.21	.45
	P value	.005	.932	.089
Between group comparison vs Exp group post training	P value		.007	.069
Within Cmp. group post training	P value			.042
Comfortable over ground speed (10 m walking test)	Pre	.9 (.3)	1.0 (.2)	.97 (.3)
	Post	1.05 (.4)	1.0 (.2)	1.1 (.3)
Within group comparison pre-post training	Effect Size	.46	.26	.47
	P value	.038	.292	.075
Between group comparison vs Exp group post training	P value		.594	.807
Within Cmp. group post training	P value			.018
Fast over ground speed (10 m walking test)	Pre	1.3 (.5)	1.3 (.3)	1.3 (.3)
	Post	1.4 (.6)	1.3 (.3)	1.4 (.3)
Within group comparison pre-post training	Effect Size	.60	.13	.47
	P value	.007	.612	.080
Between group comparison vs Exp group post training	P value		.424	.626
Within Cmp. group post training	P value			.141
Paretic knee extensors maximal strength (Dynamometry)	Pre	87.5 (27.4)	113.8 (32.1)	106.6 (38.8)
	Post	120.2 (46.6) (n=7)	114.8 (43.1)	113.3 (31.7)
Within group comparison pre-post training	Effect Size	.59	.07	.32
	P value	.028	.779	.237
Between group comparison vs Exp group post training	P value		.643	.482
Within Cmp. group post training	P value			.612
Non-paretic knee extensors maximal strength (Dynamometry)	Pre	140.0 (52.8)	155.7 (41.8)	152.5 (16.5)
	Post	177.2(45.2) (n=7)	157.0 (41.9)	162.4 (28.9)
Within group comparison pre-post training	Effect Size	.58	.17	.27
	P value	.028	.484	.310
Between group comparison vs Exp group post training	P value		.247	.848
Within Cmp. group post training	P value			.735
Balance confidence (ABC)	Pre	68.8 (24.1)	66.4 (13.6)	71.8 (13.7)
	Post	73.2 (24.9)	72.7 (13.9)	80.2 (8.4)
Within group comparison pre-post training	Effect Size	.52	.46	.54
	P value	.021	.063	.042
Between group comparison vs Exp group post training	P value		.657	.922
Within Cmp. group post training	P value			.043
Reintegration to normal living (RNLI)	Pre	3.7 (4.7)	2.4 (2.4)	1.9 (2.5)
	Post	1.4 (1.2) (n=9)	2.5 (2.7)	1.4 (2.6)
Within group comparison pre-post training	Effect Size	.46	.00	.46
	P value	.040	.100	.083
Between group comparison vs Exp group post training	P value		.588	.403
Within Cmp. group post training	P value			.066

Exp: experimental group, Cmp.: comparison group, IQR: Interquartile range

5-1-4-2 Effects of secondary perturbation training in the comparison group

All but one of the comparison participants ($n=7$) crossed over to participate in the secondary training with perturbations. There was no difference between post-walking-only training and before perturbation training in the comparison group (Wilcoxon $p \geq .236$; Table 5.2). Unpredictable gait perturbation training in the comparison group significantly improved balance confidence, with a trend toward a significant difference in dynamic balance, comfortable and faster overground speeds and RNLI results (Table 5.2). Unpredictable gait perturbation training did not improve maximal knee extensor strength on the paretic and non-paretic sides. Medium to large effect sizes were found for all variables ($ES > .45$) except for maximal paretic and non-paretic knee extensor strength ($ES \leq .31$). There was no significant difference between the experimental and comparison groups after perturbation training (Mann-Whitney U $p \geq .069$); however, dynamic balance, walking at a comfortable speed, and ABC (Table 5.2) improved (Wilcoxon $p \leq .043$) after the perturbation program compared to after the walking-only program in the comparison group. Maximal knee extensor strength never changed in this group (Wilcoxon $p \geq .612$). Reintegration to Normal Living index results showed a tendency toward a larger improvement after the perturbation training program than after the walking-only training program in the comparison group (Wilcoxon $p = .066$) (Figure 5.4.).

5-1-4-3 Effects after six weeks

At the 6-week follow-up, there was no difference in balance confidence (ABC score) or community reintegration (RNLI) compared to post-training for any type of training in either group (Wilcoxon $p \geq .223$). However, community reintegration did not differ from pretraining values (Wilcoxon $p < .271$). Balance confidence was still different from pre-training in the experimental group and after walking-only in the comparison group (Wilcoxon $p < .047$, but $p = .345$ for perturbation training in the comparison group).

5-1-4-4 Participant satisfaction

Participants were generally satisfied with the perturbation training program as more than 62.5% (10/16) of them answered “very” or “extremely” when answering items 1–6 and 8 on the SFQ-Mp questionnaire (Figure 5.5.). When answering the question about “feeling discomfort”, 75% of participants selected “not at all” and “slightly”. About the difficulty level used in the perturbation training program, 37.5% (6/16) were neutral while the rest of the participants were split between “very” or “extremely difficult” (31.25% (5/16)) and “not at all” or “slightly difficult” (31.25%).

5-1-5 Discussion

The results of this pilot study support the clinical efficacy of unpredictable gait perturbations compared to walking-only treadmill training in improving dynamic balance and gait abilities in individuals with stroke at the chronic phase. Perturbation

training had a significant and large effect on most variables in the Perturb group. In addition, large balance and gait improvements were also observed after perturbation training in the comparison group after the walking-only training program failed to produce improvements in balance and gait. The comparison group results also underscore the superiority of the perturbation program, as the lack of improvement during the walking-only training program was not due to the inability of the control participants to improve (i.e., they were not at their maximum in their balance and gait abilities prior to the walking-only program).

Allocation details

To match variables across groups before training, we had to allocate the first nine participants to the experimental group, which could have potentially increased the selection bias (Rosenberger, Sverdlov, & Hu, 2012). However, this did not deviate from the randomization method. This occurred because new potential participants did not match the characteristics of the participants previously included in the experimental group and could thus not be allocated to the comparison group. Also, two participants allocated to the comparison group could not participate in the control, walking-only, training program after randomization (the one participant had new medical issues, not related with the project and the other was concomitantly diagnosed with cancer). Therefore, despite no pre-training statistical difference between the groups, comfortable speed (.1 m/s) and RNLI (4%) were initially higher in the comparison group, and dynamic balance was better (1.7/28) in the experimental group. This likely affected between-group comparisons, mostly in favor of the walking-only training in the comparison group. As a result, the positive results presented here had to be strong to reach statistical significance.

Effect of perturbation training on dynamic balance

Improvement in dynamic balance was the sole statistically significant difference, with a large effect size, between perturbation training in the experimental group and walking-only training in the comparison group. In comparison to the experimental group, walking-only training did not improve dynamic balance at group or individual levels. More specifically, perturbation training had a specific effect on reactive postural control and dynamic gait subsystems, contrary to walking-only. Since reduced balance abilities are major risk factor for falls, (Weerdesteyn et al., 2008) these results may have an impact on the risk of falls; however, the number of falls post-training was not evaluated in the present study. Note that one of our participants initially presented with low gait speed (.39 m/s) and balance (11/28 on the MiniBESTest) abilities. This participant attended all the training sessions with perturbations, improved his balance abilities (20/28 on the MiniBESTest) and enjoyed the perturbation training for its level of challenge. This highlights the feasibility of using perturbations that can be easily adapted to participants' abilities. Previous perturbation training programs among individuals with stroke at the chronic and subacute phases, consisted of 10– 12 sessions during which perturbations were applied manually or by the anteroposterior or mediolateral translation of the support platform or treadmill in a standing position or during gait (Handelzalts et al., 2019; Kumar & Pathan, 2016; Punt et al., 2019; Schinkel-Ivy et al., 2019; van Duijnhoven et al., 2018). Improvements in reactive and proactive balance control after perturbation training (Handelzalts et al., 2019; Schinkel-Ivy et al., 2019; van Duijnhoven et al., 2018), also observed in our results, and specifically for reactive activity and dynamic gait (Kumar & Pathan, 2016). BBS was not used in this study because we targeted

dynamic balance with the perturbation training and because of the ceiling effect of the BBS in individuals post-stroke (Pollock et al., 2011).

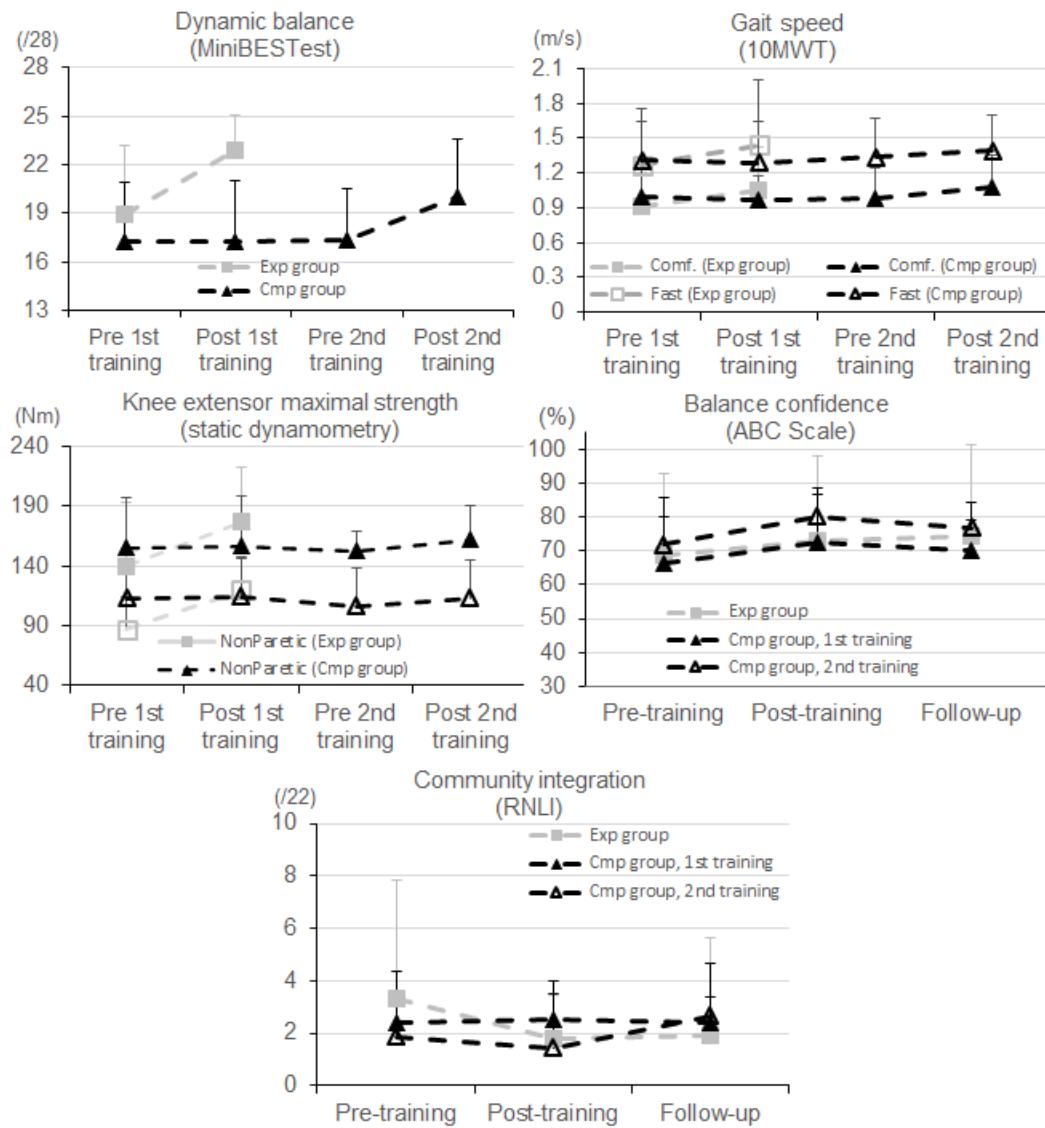


Figure 5.4. Effects of perturbation (experimental group (grey) and comparison group 2nd training (solid black) and walking-only training (comparison group 1st training (black outline))) on dynamic balance (MiniBESTest top left), walking speed (10 MWT, top right), maximal knee extension strength (dynamometry, middle left), balance confidence (ABC, middle right) and level of community reintegration (RNLI, bottom) pre; and immediate post-training as well at the 6-weeks follow-up for balance confidence and community reintegration. Exp: experimental group, Cmp: comparison group, NParetic: Nonparetic side.* indicates statistically significant change compared to the previous assessment time

Effect of perturbation training on gait speed

In addition to dynamic balance, gait speed also improved in the experimental group. This improvement could be attributed to perturbation training since the speed on the treadmill was not increased in any group during training. Improvements after perturbation training post-crossover, compared to the absence of improvement post walking-only training in the comparison group, emphasize the beneficial effect of perturbation training on abilities in individuals at the chronic phase post-stroke. Punt et al. also reported comfortable speed improvements, similar to our study (+ .16 m/s) (Punt et al., 2019). However, their training program included periods of gait at a higher than comfortable gait speed, (Handelzalts et al., 2019; Kumar & Pathan, 2016; Mansfield et al., 2018; Punt et al., 2019) which could have equally led to improved gait speed as much as did perturbations. It is therefore possible that the challenge posed by gait perturbations in the present study is a strong enough stimulus to improve the abilities required for both balance and gait. Contrary to our hypothesis, walking-only training did not improve gait abilities in the control group. This is likely explained by the good walking abilities of the participants pre-training (mean speed of 1.0 m/s) and confirms the limited challenge that walking at a comfortable speed posed for this group.

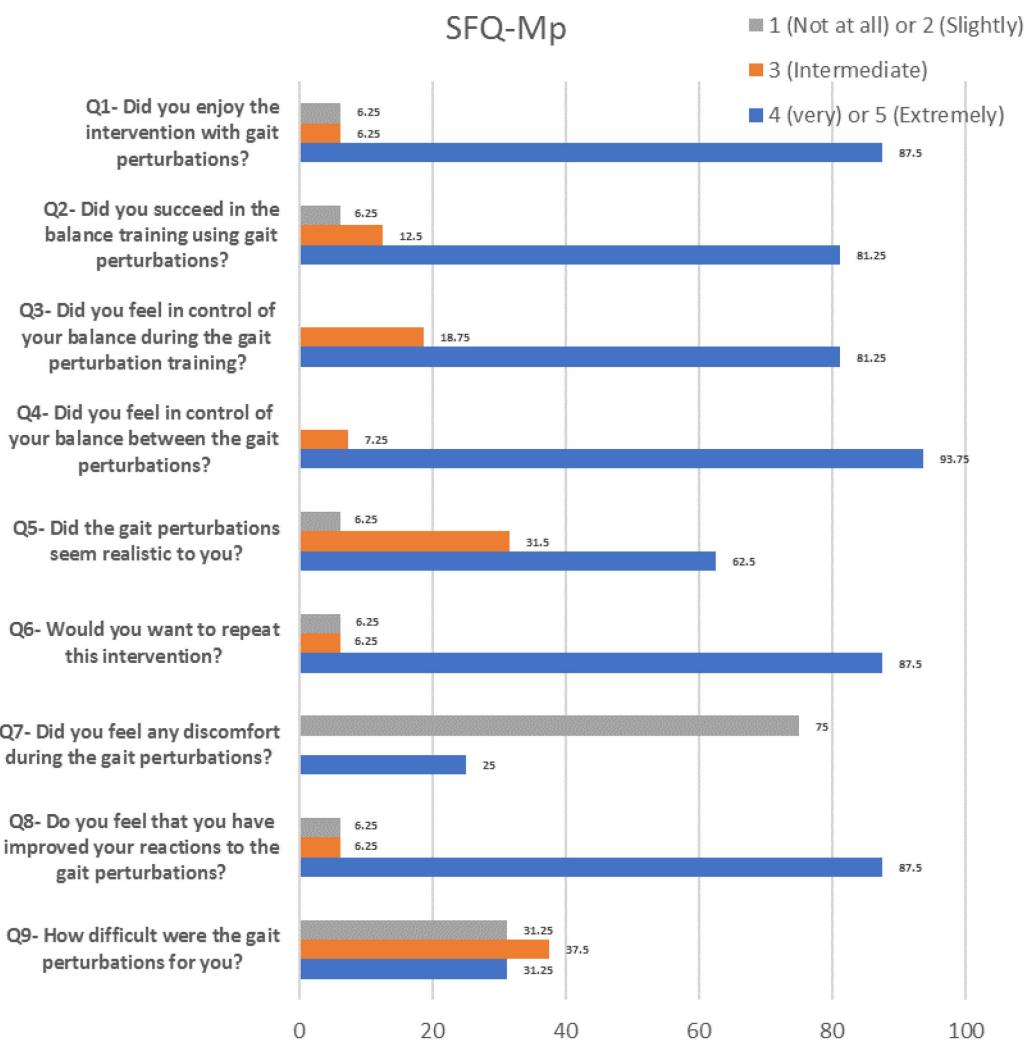


Figure 5.5. Responses to Short Form Questionnaire-Modified for Perturbations (SFQ-Mp) for participants who attended perturbation training (experimental group: n=10, comparison group: n=7), expressed as a percentage (%) of total responses.

Effect of perturbation training on secondary outcomes

Secondary outcomes also noticeably improved. Balance confidence increased with both types of training. Other studies found similar results between + 3.6 points and 10 points on the ABC scale, over 10 to 30 training sessions using moveable platform perturbations, (van Duijnhoven et al., 2018) manual perturbation in a

standing position, (Mansfield et al., 2018) and an agility exercise program designed to challenge dynamic balance (Marigold et al., 2005). However, this improvement may not be directly related to perturbation as balance confidence increased by similar amounts between perturbation- and walking-only training. The combination/duration of the two training periods that the comparison group received may also have potentialized the effect on balance confidence. Longer periods of intervention indeed tend to provide greater improvement in balance confidence in older adults (Bula, Monod, Hoskovec, & Rochat, 2011). Lastly, maximal knee extensor strength improved in the experimental group, but not during the secondary perturbation training in the comparison group. However, dynamic balance improved in both groups after perturbation training. Higher maximal strength may thus not be a prerequisite for balance improvement, as underscored by the conflicting evidence of the effect of strength training on balance in a previous meta-analysis (Morris, Dodd, & Morris, 2004).

Perturbation training in the experimental group led to an increased level of community reintegration as evaluated by the RNLI, with some sustained effect at 6 weeks. Improvement in RNLI scores after perturbation training supports the fact that improvements in balance abilities translated into better participation and mobility in the community. Previous studies that used progressive standing perturbations (Mansfield et al., 2018) or low-intensity gait perturbations (Punt et al., 2019) did not show transfer to daily-life mobility. It is possible that the more intense and higher number of gait perturbations used in our study may have had a better effect on mobility and thus on community reintegration. These effects might be explained by the fact that these perturbations were applied during gait, at various and sometimes

high intensities, in an unpredictable manner, and required adapted stepping reactions that could be used during the loss of balance in daily life (McCrum et al., 2017). Such an effect in daily life may also explain the sustained effect at 6 weeks (Bhatt, Yang, & Pai, 2012; McCrum et al., 2017; Pai, Yang, Bhatt, & Wang, 2014). It is to be noted that this result may also have been affected by the large variability of the pre-training median score in the experimental group. Also, both groups had an already good level of reintegration (i.e., low score) observed pre-training. Further studies are necessary to confirm increased community integration through objective measures and long-term follow-up.

Despite the loss of balance induced by the perturbations and the intense postural reactions they triggered, a large majority of the participants felt in control during and between the perturbations and enjoyed the perturbation program, with very little discomfort. This might have been facilitated by the design of the program, with repeated perturbations followed by unpredictable perturbations, and by the possibility of producing small intensity perturbations at first, which then increased according to the participant's comfort level. Such progression in the intensity of the perturbations was facilitated by the use of a treadmill. However, progression in level of difficulty might need to be more personalized as the perception of difficulty was reported by our participants as being between “Not difficult” and “Extremely difficult.” Despite this wide range of difficulty perception, most participants thought they were successful and improved their balance abilities during the training. The only other subjective evaluation found in the literature concerned the difficulty of the perturbation, which was rated as high as 7/10, with 10 representing a very difficult

challenge (Handelzalts et al., 2019). In that study, only mediolateral perturbations were used during gait, at the highest intensity possible without inducing a fall.

5-1-6 Limitations

Participants were allocated to groups by covariate adaptive randomization due to small-sized groups, resulting in no statistical differences pre-training. However, minor pre-training differences in clinical scores may have limited the demonstration of the superiority of the perturbation training over walking-only training across all primary outcome measures, rather than just for balance abilities, despite the absence of improvement of the mentioned outcomes due to walking-only training. Secondly, fall-related data were not collected after the study. However, though most of the participants were not prone to falling, their balance abilities were below normal, which is one of the main risk factors for falls (Weerdesteyn et al., 2008). In addition, because of their reduced balance confidence, the participants may have reduced their activities to reduce fall risks, thus affecting the pretraining risk of falls. Since being prone to falling was not an inclusion criterion, evaluating the number of falls pre- and post-training was not considered useful, particularly given the short follow-up period. To show the effectiveness of this promising method for reducing falls, as already observed in other populations, further studies with a large sample size are necessary to complete previous inconclusive findings (Mansfield, Wong, Bryce, Knorr, & Patterson, 2015; Punt et al., 2019). Furthermore, different intensities of perturbation and longer follow-up periods should be tested in individuals post-stroke with various levels of deficits. Since both repeated and unpredictable perturbations were applied in each training session, it was not possible to determine which kind or combination

of perturbations was more effective in improving balance and gait abilities. It is also possible that the number of perturbations was higher than necessary for maximizing balance abilities. However, unpredictable balance perturbations are closer to real-life conditions and are thus conceptually warranted. Finally, split-belt treadmills are designed to cause unpredictable perturbations for clinical and rehabilitation purposes using a complex control system, (Viteckova et al., 2019) but their availability in clinical settings is rare, which may hamper the generalization of this approach. The large number of perturbations produced also makes this intervention difficult to apply in clinical practice due to the length of the training session.

5-1-7 Conclusion

The improvement of dynamic balance emphasizes the specific effect of intense and unpredictable perturbations on balance abilities over the effect of gait-only training on a treadmill. Large effect sizes obtained in the present study support the clinical effectiveness of this task-specific program in individuals with stroke at the chronic phase. Evaluation of this program, including variation in the type and number of perturbations generated, with larger sample size, long-term follow-up and fall monitoring, is now warranted.

5-1-8 Abbreviations

ABC Scale: Activity-specific Balance Confidence Scale; BBS: Berg Balance Scale;
CIUSSS: Centre Intégré Universitaire de Santé et de Services Sociaux;
CMSA: Chedoke-McMaster Stroke Assessment; CONSORT: Consolidated
Standards of Reporting Trials; ES: Effect size; MCID: Minimal
Clinically Important Difference; Mini-BESTest: Mini-Balance Evaluation Systems

Test; N Paretic: Non-paretic; Comparison group: Name of the control group where participants received the gait training program without perturbation in the first part, and were then offered to participate to the training program with gait perturbation once they finished gait training program without perturbations.; Experimental group: Name of the group where participants received the gait perturbation training program.; RNLI: Reintegration to Normal Living Index; SFQ-Mp: Short Feedback Questionnaire, modified for perturbations; TIDieR: Template for Intervention Description and Replication; TUG: Timed Up and Go

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5-1-11 Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author.

5-1-12 Ethics approval and consent to participate

Ethics approval was obtained from the Research Ethics Committee of the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal. All participants signed a consent form prior to study enrollment.

5-1-13 Competing interests

The authors declared no competing interests.

5-2 Characterization of biomechanical determinants of dynamic balance during gait at comfortable speed on split-belt treadmill and their relationships with clinical measures in individuals at the chronic phase post-stroke

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Each author made substantial contributions to the conception and design of the work.

Esmaeili V. and Miéville C. made substantial contributions to data acquisition, analysis, and interpretation of data. Esmaeili V., Miéville C. and Bourbonnais D. substantively revised the manuscript. Each author has revised and approved the submitted version of the manuscript in the thesis.

5-2-1 Abstract

Background: Impairments following stroke lead to decreased dynamic balance. This study aimed to evaluate changes in biomechanical determinants of dynamic balance at heel contact, midstance and toe-off time points of the gait cycle and their correlations with clinical scores.

Methods: A convenience sample consisting of a group of healthy ($n=15$) and two groups of participants with stroke at the chronic phase (stroke-fast group ($n=20$) and stroke-slow group ($n=18$) based on a cut-off overground gait speed of 1 m/s) were recruited. The length and width of the base of support (BOS) and relative positions of the center of pressure (COP), the center of mass (COM), extrapolated COM (XCOM) in BOS in anteroposterior (AP) and mediolateral (ML) directions during 25 gait cycles were calculated at a comfortable treadmill gait speed. Overground speed, motor impairments of the leg (CMSA leg) and foot (CSMA foot) and mobility were evaluated using 10-Meter Walk Test (10 MW), Chedoke-McMaster Stroke Assessment (CMSA) and Timed up and Go (TUG) respectively. The biomechanical determinants were compared between groups using one-way ANOVAs. Correlations coefficients of the scores of clinical measures and treadmill speed with determinants of dynamic balance were also calculated.

Results: BOS was longer in the AP direction for both stroke groups during midstance time points and wider at nonparetic midstance compared to the healthy group. In stroke groups, the positions of the COP and COM were closer to the posterior border of BOS at midstance time points and closer to the lateral border of the BOS at nonparetic midstance and toe-off. The position of the XCOM was closer to the posterior border of BOS at almost all of time points and closer to the lateral border of the BOS at nonparetic midstance. The treadmill gait speed, TUG and CSMA foot showed significant correlations mostly with BOS and XCOM in the AP direction.

Conclusion: Individuals post-stroke showed altered biomechanical variables as compared to healthy participants that we interpreted as a strategy to maintain their dynamic balance. Correlations suggest that the BOS and XCOM are important biomechanical variables contributing to dynamic balance. Speed improvement is

suggested to ameliorate dynamic gait balance in individuals with stroke through normalization of the values of the factors impacting dynamic balance.

Keywords: Stroke, dynamic balance, comfortable gait speed, split-belt treadmill

5-2-2 Background

Reduced mobility is observed in a large proportion of individuals post-stroke (Virani et al., 2020). Approximately two-thirds of individuals post-stroke are still unable to walk independently in the community when discharged from rehabilitation (Kennedy et al., 2021) leading to considerable limitation of social participation (Mizrachi et al., 2020).

To maintain balance during gait, the main mechanism is the control of the acceleration of the center of mass (COM) by the position of the centre of pressure (COP) (Hof, 2007; Hof et al., 2010; Jian et al., 1993; Winter, 1995). On the other hand, if the magnitude of the horizontal velocity of COM is high enough and also is directed outward of the BOS, it can challenge dynamic balance even when the projection of the position of COM is still within the BOS (Kao et al., 2014). Thus, the concept of extrapolated COM (XCOM) which considers the position and velocity of COM together, is used as one of the concepts for studying dynamic balance (Hof, 2008). As the calculation of XCOM comprises the velocity of COM, the position of XCOM depends on gait speed.

Gait speed is positively correlated with dynamic balance in healthy individuals (Lencioni, Carpinella, Rabuffetti, Cattaneo, & Ferrarin, 2020). Gait speed impacts other biomechanical determinants of dynamic balance. Increasing speed (up to a certain limit) in healthy participants leads to increasing step length (i.e., length of the base of support (BOS) (Buurke et al., 2020)) and more anterior position of COP (Lu, Lu, Lin, Hsieh, & Chan, 2017). However, the position of the projection of COM in anteroposterior AP direction (along AP axes) and the position of COP in mediolateral (ML) direction (along lateral axes) do not change as speed increases in healthy

participants (Lu et al., 2017). Step width (i.e., the width of BOS (Buurke et al., 2020)) does not change when speed is increased (Lu et al., 2017) or is reduced (De Bujanda, Nadeau, & Bourbonnais, 2004; Orendurff et al., 2004). Moreover, healthy participants keep the projection of the position of COM nearer to the midline of BOS in the ML direction at a faster speed than at comfortable speed (Orendurff et al., 2004). The characteristics of normal gait could be used to determine the alterations of the gait of individuals post-stroke.

The biomechanical characteristics of gait differ between stroke and healthy individuals. Since altered displacements of COP in individuals post-stroke result from impaired kinetic and kinematic including altered foot placement, it has been suggested that the COP reflects the impairments of the neuromuscular system (Mizelle, Rodgers, & Forrester, 2006). The alterations of displacements of COP or COM after stroke during different phases of gait have been associated with changes in gait characteristics such as step length, step width, and temporal characteristics including gait speed (Chisholm et al., 2011; Clark, Williams, Fini, Moore, & Bryant, 2012; Mizelle et al., 2006; Weerdesteyn et al., 2008). Gait speed is slower after stroke (Rosen et al., 2005). Gait speed is positively correlated with dynamic balance in individuals at the chronic phase post-stroke (Madhavan & Bishnoi, 2017). Chisholm et al. (2011) and Choi & Kim, (2018) mentioned that the position of COP in the AP direction correlated positively with gait speed in individuals post-stroke. In this population, the position of COP and the projection of COM in the ML direction was closer to the midline of BOS at faster gait speed compared to comfortable speed (Chisholm et al., 2011; Lamontagne & Fung, 2004). The distance between XCOM and BOS is shorter in the AP direction among individuals post-stroke compared to healthy

participants and the distance is larger on the paretic side than on the nonparetic side in both AP and ML directions (Buurke et al., 2020; Hak, Houdijk et al., 2013). Altogether, the above-mentioned changes in determinants of dynamic balance impact dynamic balance during gait.

Health professionals are using clinical measures to evaluate mobility and balance in individuals with hemiparesis due to stroke. Gait speed (10-Meter Walk Test), Timed Up and Go (TUG) test and Chedoke-McMaster Stroke Assessment (CMSA) have been used frequently in clinical practice and in numerous studies to evaluate gait and balance abilities as well as motor impairments of individuals post-stroke (Bonnyaud, Pradon, Bensmail, & Roche, 2015; Chisholm et al., 2011; Horak et al., 2009). However, the relationships between scores of the clinical measures and changes in the above-mentioned biomechanical variables during gait following stroke are not established clearly. Almost all of the clinical measures quantify dynamic balance through some predetermined situations without addressing underlying biomechanical mechanisms (Van Meulen, Weenk, Buurke, van Beijnum, & Veltink, 2016). Several studies have shown links between clinical and biomechanical measures in tasks other than gait (Chou, Kaufman, Hahn, & Brey, 2003; Chou et al., 2003; Duclos, Nadeau, & Lecours, 2008; Mansfield, Mochizuki, Inness, & McIlroy, 2012; Marigold et al., 2004). For example, an association was found between reduced strength of the lower limb and sensorimotor capacities with alteration in the control of COP in a standing position after stroke (Mansfield et al., 2012; Marigold et al., 2004). Also, a higher level of balance, measured using the Berg Balance Scale (BBS), was associated with between-limb COP position synchronization in a static standing position (Mansfield et al., 2012). Reduced post-stroke sensorimotor capacities were

also linked to alteration in the control of COP during standing up from a chair (Duclos et al., 2008). A negative correlation between balance confidence and position of COP in AP and ML directions in standing position has also been reported (Schinkel-Ivy, Inness, & Mansfield, 2016).

However, previous studies did not address biomechanical variables during gait to help interpretation of contradicting findings between scores of clinical measures and biomechanical parameters. For example, a larger distance between XCOM and BOS in the ML direction is usually interpreted as better dynamic stability compared to a shorter distance between XCOM and BOS (Buurke et al., 2020; Van Meulen et al., 2016). A larger distance between XCOM and BOS was paradoxically found in individuals post-stroke with lower balance capacities as measured clinically (Vistamehr, Kautz, Bowden, & Neptune, 2016). Thus, it is necessary to better understand the link between clinical measures and the main parameters of post-stroke dynamic balance (COP, COM and XCOM) during gait.

The purpose of this study was thus to compare dimensions of BOS and the relative positions of COP, the projection of COM and XCOM in BOS in healthy and two groups of individuals at the chronic phase post-stroke (with comfortable self-selected gait speed faster than 1 m/s and slower than 1 m/s) as well as between stroke groups at heel contact, midstance and toe-off time points of gait cycle at a comfortable speed in AP and ML directions. The speed of 1 m/s was used as a criterion since it is considered the limit for walking safely and independently in the community on the level ground (Bijleveld-Uitman et al., 2013). We also aimed to determine how gait

speed, scores of TUG and motor impairments of the foot and leg are related to alteration of the mentioned biomechanical determinants of dynamic balance.

5-2-3 Methods

5-2-3-1 Participants

This study involved a part of data collected in two previous studies among a total of 53 participants (15 healthy and 38 participants with hemiparesis resulting from a first stroke that occurred more than 6 months ago) who participated in two studies (CRIR_616_0411 and CRIR-998-0914) via convenience sampling was used in this study. Participants, aged between 18 to 65 years old, were included if they were able to walk on a split-belt treadmill without external support (like Ankle Foot Orthosis) or walking aid. Exclusion criteria were hemineglect (more than 6 omissions on Bells cancellation test (Lezak, 1995)), cognitive impairment (Mini-Mental State Examination score under 24/30 (Folstein et al., 1975)), uncorrected visual deficit reported in their medical records or pathologies other than stroke which could affect their gait or balance. Research Ethics Committee of Center of Interdisciplinary Research in Rehabilitation of Great Montreal (CRIR) approved the study. All participants signed an informed consent form.

5-2-3-2 Clinical evaluation

Sociodemographic and anthropometric information (age, sex, weight, height) of all participants in addition to the time since the occurrence of stroke were obtained during clinical evaluation. The CMSA was used to determine motor impairments through 18 tasks performed with the foot or lower limb and scored from 1 (severe motor impairment) to 7 (no impairment) (Dang et al., 2011; Gowland et al., 1993). It

has excellent inter-rater reliability (intraclass correlation coefficient (ICC) =.98 for leg, ICC=.94 for foot) (Gowland et al., 1993). The concurrent validity which was evaluated by comparing scores of CMSA with Fugl-Meyer Assessment and Functional Independent Measure was excellent as the correlations with mentioned measures were .95 and .97 respectively (Gowland et al., 1993). Functional mobility was evaluated using TUG during which participants were asked to stand up from a sitting position on a chair with armrests, walk 3 meters, turn around, return to the chair and sit down at comfortable speed (Bonnyaud et al., 2015; Leroux et al., 2006). Overground comfortable speed was evaluated using the 10-Meter Walk Test (10 MWT) (Bowden et al., 2008). The CMSA, the TUG and the 10 MWT showed excellent test-retest reliability at a comfortable speed (ICC=.97, .99 and .94 respectively) (Flansbjer et al., 2005; Herman, Giladi, & Hausdorff, 2011; Tsang et al., 2013). Based on the results of the 10 MWT and the relation between gait speed and dynamic balance, individuals at the chronic phase post-stroke were either assigned to the stroke-fast group (overground comfortable speed more than 1 m/s) or the stroke-slow group (overground speed less than 1 m/s).

5-2-3-3 Biomechanical evaluation on a split-belt treadmill

Biomechanical data were collected after determining treadmill comfortable speed on an instrumented split-belt treadmill (Bertec Fit®; Bertec, OH, USA). For the stroke group, the initial speed was .2 m/s and for healthy participants, it was .6 m/s. The speed of the treadmill was increased by .1 m/s every 45 seconds as long as the participant perceived that the speed was comfortable. When the participant perceived that the speed is not comfortable anymore, the speed increased .05 m/s until the

participant confirmed again that he/she is uncomfortable with the speed. The speed before the perceived uncomfortable level was determined as the comfortable speed of the participant (Mieville, Lauzier, Betschart, Nadeau, & Duclos, 2018). Biomechanical data described in the next section were collected during 60 seconds of walking on the treadmill. To prevent falling during gait, a harness was used. However, this harness did not provide body weight support during gait to avoid interference with the collection of kinetic and kinematic data.

5-2-3-4 Instrumentation

Ground reaction forces (GRFs) and moments were sampled at 600 Hz. Three to six infrared markers were placed on each major body segment (head, trunk, pelvis, upper and lower arms, hands, thighs, shanks, and feet). A Certus motion analysis system (Northern Digital Inc., Waterloo, Canada) was used to record the position of these markers at a sampling frequency of 30 Hz. Anatomical landmarks and contours of the soles of the shoes were positioned relative to rigid bodies representing body segments and the feet, respectively, using a digitizing probe (Mieville et al., 2018). The data of GRF and trajectories of the markers were filtered with a fourth-order Butterworth zero-lag filter with a cut-off frequency of 10 and 6 Hz, respectively and resampled to 60 Hz.

5-2-3-5 Data reduction and analysis

The length and width of the BOS on the treadmill were calculated. The vertical projection or the actual position of the sole of the shoes to the ground was used to determine the potential BOS during gait at midstance (Van Meulen et al., 2016). During swing phases, the projection of the swing foot on the ground was determined

and the area between the feet was used to calculate the potential BOS (Van Meulen et al., 2016). For calculations of the BOS in the AP direction (length of BOS), first, the average distance between markers attached to the lateral malleoli was calculated at each time point during the gait cycles. Then, the average of the maximal distance between the markers attached to the lateral malleolus of the feet was determined for the 25 gait cycles. Then, the average of the distance between markers attached to the lateral malleoli of the feet was calculated at each time point for the gait cycles and was divided by the averaged maximal value of the 25 gait cycles, i.e., a relative length of BOS to the averaged maximal length of BOS. A similar procedure was used to calculate the averaged relative length of BOS to the maximal length of BOS in the ML direction during the different time points. For convenience, we used the length of the BOS and the width of the BOS instead of the averaged relative length of BOS to the maximal length of BOS and the averaged relative width of BOS to the maximal width of BOS, respectively. Because the values of BOS are relative, they are offered without any unit.

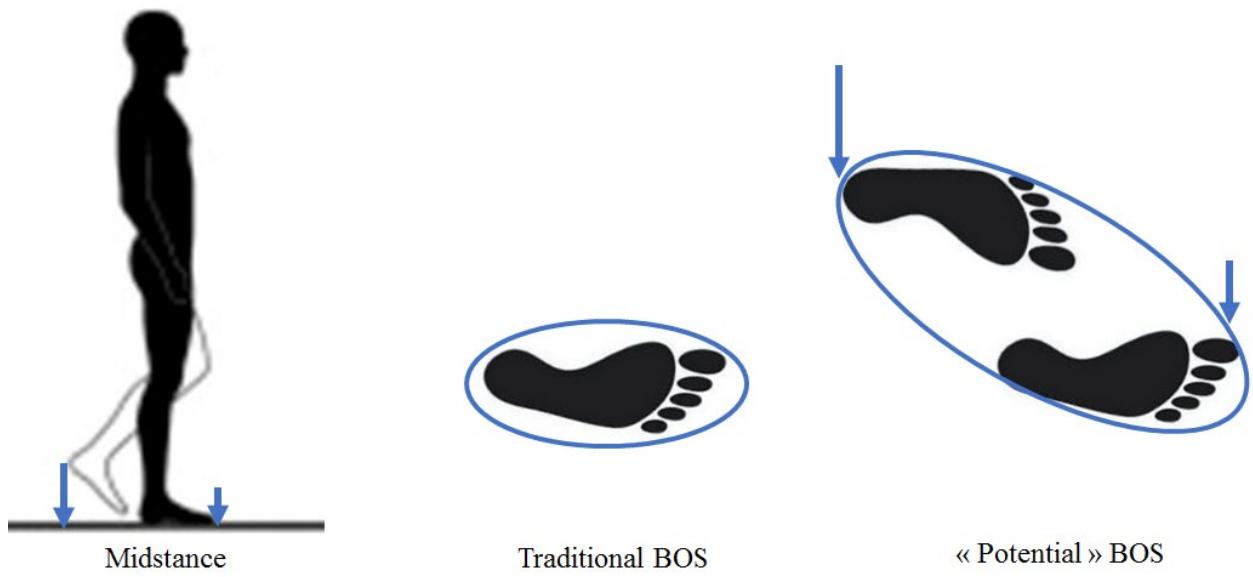


Figure 5.6. The potential base of support

The six time points of the gait cycle on both sides were left and right toe-offs (LTO, RTO), mid-stances (LMS, RMS) and heel contacts (LHC, RHC). Heel contacts and toe-offs were determined using the Teager-Kaiser energy operator method to determine gait cycles based on vertical ground reaction forces time series (Solnik et al., 2010). Midstance is defined as the half-duration between heel contact and toe-off on the same foot. The left toe-off time point corresponds to the end of the double support phase when the right foot is positioned more anteriorly than the left foot and all of the body weight is on the right side. The right midstance time point corresponds to a single support phase on the right side. The left heel contact corresponds to the beginning of the double support phase when the left foot is positioned more anteriorly

than the right foot but still majority of the weight of the body is on the right side. The opposite is true for right toe-off, left midstance and right heel contact.

The position of the global COP was determined using ground reaction forces and moments (Mieville et al., 2018). Using kinematic and anthropometric data based on Zatsiorky-Seluyanov anthropometric model (de Leva, 1996), a 3D link-segment model of the body was defined to determine the position and velocity of whole-body COM (Winter, 1990). The extrapolated COM (XCOM) was also calculated to take into account COM velocity (Hof, 2008).

Positions of the COP, COM and XCOM were expressed in percentage of the length and width of the BOS for each participant, with the reference at the most posterior and most leftward point of the potential BOS, respectively, at each time point in AP and ML directions. Then, the relative positions were averaged for each group at each time point in AP and ML directions. For example, on the mediolateral and anteroposterior axes, the relative position of COP of the healthy group at left toe-off are 79.3% and 75.8% respectively (Figure 5.7. (A) (green empty square)). In the case of Figure 5.7. Both values are exceeding 50% indicating that the relative position of the COP is close to the anterior and right lateral border of the BOS. It is possible to compare the relative positions of COP within the BOS (and other biomechanical variables) in AP and ML directions between the three groups at each time point in this way (Table 5.4, 5.5 and 5.6). The point of 50-50 of the BOS was used as the reference point for determining four quadrants within the BOS (Figure 5.7.). In the case of Figure 5.7. The dashed red lines, represent the normalized borders of the BOS determined for each cycle. The horizontal axis drawn at the point of zero toward 100

is the most posterior border of the BOS. The vertical vector is the left lateral border of the BOS. The horizontal line drawn from point 100 on the left Y-axis toward the right side is the most anterior border of the BOS. So, the BOS is limited posteriorly by the X-axis, on the left by the Y-axis, the horizontal line is drawn from the left at the point 100 on the left Y-axis to the right, and the right lateral border is drawn upward from the point 100 on the most posterior border. The dashed blue lines drawn from point 50 on the Y-axis and X-axis introduce the four quadrants of the BOS. The paretic side was set as the left side for all individuals post-stroke and the nonparetic side was set as the right side. Studies did not show the effect of leg dominancy on measures related to the position of COP (King & Wang, 2017; Teixeira, de Oliveira, Romano, & Correa, 2011; Velotta, Weyer, Ramirez, Winstead, & Bahamonde, 2011). Thus, the paretic and nonparetic sides of the stroke groups were compared to the left and right sides of healthy participants, respectively.

5-2-4 Statistics

Based on the normality of variables evaluated with the Shapiro Wilk test, one-way ANOVAs or nonparametric test Kruskal-Wallis were used. The factors age, sex, time post-stroke, overground and treadmill gait speeds, and scores of the TUG and CMSA were compared across groups (healthy, stroke-fast and stroke-slow). Post-hoc analyses between groups were performed using Scheffe's tests or Chi-Square test.

Similarly, one-way ANOVAs and post-hoc Scheffe tests were used to compare the length and width of and the relative positions of COP, COM and XCOM within the BOS for the three groups of participants. These ANOVAs were conducted

separately at each time point (left and right heel contacts, toe-offs, and mid-stances) in the AP and ML directions.

Correlations between scores of clinical measures (gait speeds, TUG, and CMSA) and biomechanical variables in stroke groups were calculated using Pearson or Spearman tests. Correlation coefficient .3 to .5, .5 to .7 and .7 to .9 were considered as low, moderate and high correlations respectively (Mukaka, 2012). Effect sizes (ES) were calculated using Cohen's d (Nakagawa & Cuthill, 2007). Effect sizes above .5 were considered as large effect sizes (Nakagawa & Cuthill, 2007). The statistical analysis was done using IBM SPSS statistics (version 26) predictive analytic software and the alpha level of .05 was used as the significant level.

5-2-5 Results

5-2-5-1 Participants

The results of one-way ANOVAs indicated a significant difference between groups for age ($F_{(2)}=13.01$, $p<.001$), overground gait speed ($F_{(2)}=80.09$, $p<.001$) and treadmill speed ($F_{(2)} = 83.92$, $p\leq .02$) (Table 1). Post-hoc analysis using Scheffe tests revealed that the healthy group was younger (stroke-fast: $p =.004$, stroke-slow $p=.001$), and walked at a faster comfortable self-selected speed (stroke-fast $p=.011$, stroke-slow $p=.001$). While age did not differ between stroke groups ($p=.341$), overground speed and treadmill speed were faster in the stroke-fast group than in the stroke-slow group ($p\leq.002$). There was not any difference between the three groups in the case of the number of females and males (Chi-Square test $p=.149$).

Between stroke groups, the time post-stroke and the CMSA leg did not differ ($P \geq .10$) but scores of CMSA foot ($p=.029$) and the TUG ($p=.001$) differed which indicate that functional balance (evaluated by TUG) and motor impairments of foot were worse in the stroke-slow group than the stroke-fast group.

Table 5.3 Within and between-group comparisons of general characteristics and clinical scores of the participants

	Healthy (n=15)	Stroke-fast (n=18)	Stroke-slow (n=20)
Age (years)	34.7 (10.7)	49.2 (14.1) *	54.7 (10.1) *
Sex (F/M)	7F / 8M	4F/14M	5F/15M
Time post-stroke (months)	N/A	114.9 (129.0)	88.4 (90.4)
Overground Comfortable Speed(m/s)	1.4 (.2)	1.2 (.1) *	.7 (.2) *§
Treadmill Comfortable Speed (m/s)	1.1 (.2)	.7 (.1) *	.5 (.1) *§
TUG (s.)	N/A	10.2 (1.8)	15.5 (5.7) §
CMSA Leg (/7)	N/A	5.7 (.7) [5-7]	4.5 (1.3) [3-6]
CMSA Foot (/7)	N/A	4.7 (1.7) [1-7]	3.2 (1.5) § [1-6]

Mean (standard deviation) are presented, as well as [range] for Chedoke-McMaster Stroke Assessment (CMSA) score. In bold, significant differences between groups. * represents a significant difference between the healthy group and stroke groups and, § represents a significant difference between stroke groups using Scheffe post hoc following one-way ANOVA. F: female, M: male, TUG: Timed Up and Go.

5-2-5-2 Biomechanical variables

5-2-5-2-1 Relative positions of COP, the projection of COM, and XCOM in BOS and BOS length and width

In all groups, at the right/non-paretic heel contact, the relative positions of COP and the projection of COM were in the left-back quadrant of the BOS although the relative position of the projection of COM is close to the centre of the BOS (Figure. 5.7.). The position of XCOM is located at the right side of the midline, closer to the anterior border of the BOS, but still within the BOS. Then, the relative positions of COP and XCOM move forward and to the right until left toe-off. In the healthy group, the relative position of the projection of COM moves forward and to the right until midstance but moves to the left (and closer to the midline without crossing the midline) at left toe-off. In stroke groups, the relative position of the projection of COM moves forward and to the right until the left toe-off but moves backward and to the right at right midstance. The opposite is true in the case of the relative positions of COP, the projection of COM and XCOM at left heel contact, left midstance and right toe-off.

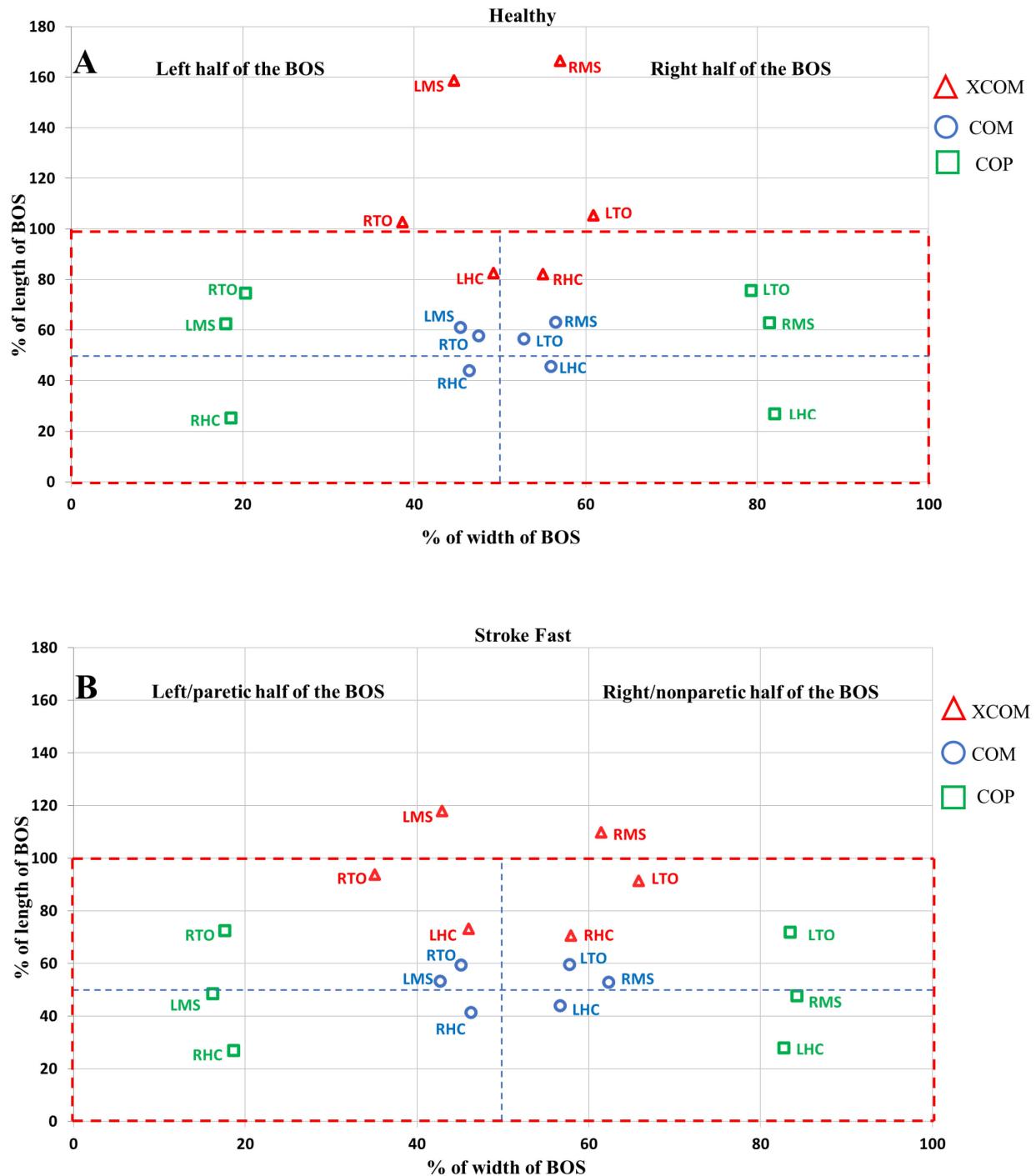
The length of the BOS at each time point during all gait cycles is presented in Table 5.4 in AP and ML directions. Significant differences were found during the right midstance in AP direction between all groups indicating that the length of the BOS was longer in stroke groups as compared to the healthy group while it was shorter in the stroke-fast group than the stroke-slow group ($p \leq .045$, $.85 \leq ES \leq 2.81$). At the left midstance, the averaged length of the BOS was longer in stroke groups as compared to the healthy group ($p \leq .001$, $1.30 \leq ES \leq 2.60$) with a trend toward a significant

difference between stroke groups indicating the averaged length of BOS was shorter in the stroke-fast group than the stroke-slow group ($p=.052$, $ES=1.41$). The length of the BOS was also shorter in the stroke-slow group than in the healthy group at right toe-off ($p=.017$, $ES=.95$). In the ML direction, the width of the BOS was wider in the stroke groups than the healthy group at the right/nonparetic midstance time point ($p\leq.012$, $.74\leq ES \leq .90$), without difference between the stroke groups ($p\geq.759$) and narrower only in the stroke-slow group than other groups at right heel contact ($p=.049$ between the stroke-slow group and healthy group, $p=.545$ between stroke groups, no significant ES).

Table 5.4 Between-group differences of mean \pm SD of the length and width of BOS in AP and ML directions at different time points

Groups		Time points of left half of BOS			Time points of right half of BOS		
		RTO	LMS	RHC	LTO	RMS	LHC
BOS	Healthy	83.5 \pm .03	36.2 \pm .03	95.9 \pm .01	83.5 \pm .03	35.0 \pm .04	94.2 \pm .02
	AP Stroke-Fast	81.0 \pm .04	41.0\pm.05*	93.0 \pm .07	76.0 \pm .12	46.0\pm.08*	94.3 \pm .04
ML	Stroke-Slow	79.5\pm.05*	49.0\pm.06*§	93.7 \pm .05	79.5 \pm .12	52.0\pm.07*§	91.0 \pm .07
	Healthy	91.5 \pm .03	91.0 \pm .06	95.2 \pm .02	91.0 \pm .05	91.0 \pm .06	94.1 \pm .03
	Stroke-Fast	92.3 \pm .04	92. \pm .05	93.3 \pm .04	91.5 \pm .03	95.2\pm.03*	94.2 \pm .03
	Stroke-Slow	91.2 \pm .06	91.0 \pm .07	92.0\pm.05*	91.4 \pm .06	96.2\pm.03*	93.2 \pm .04

The length/width of BOS at each time point is an averaged relative length/width of the BOS to the maximal length/width of the BOS at that time point during all gait cycles. The left side is the paretic side and the right side is the nonparetic side. In bold, significant differences between groups. * represents a significant difference with the healthy group using Scheffe post hoc following One-way ANOVA. § represents a significant difference between the stroke groups. RHC: Right Heel Contact, RMS: Right Midstance, LTO: Left Toe-Off, LHC: Left Heel Contact, LMS: Left Midstance, RTO: Right Toe-Off, AP: values in AP direction, ML: values in ML direction.



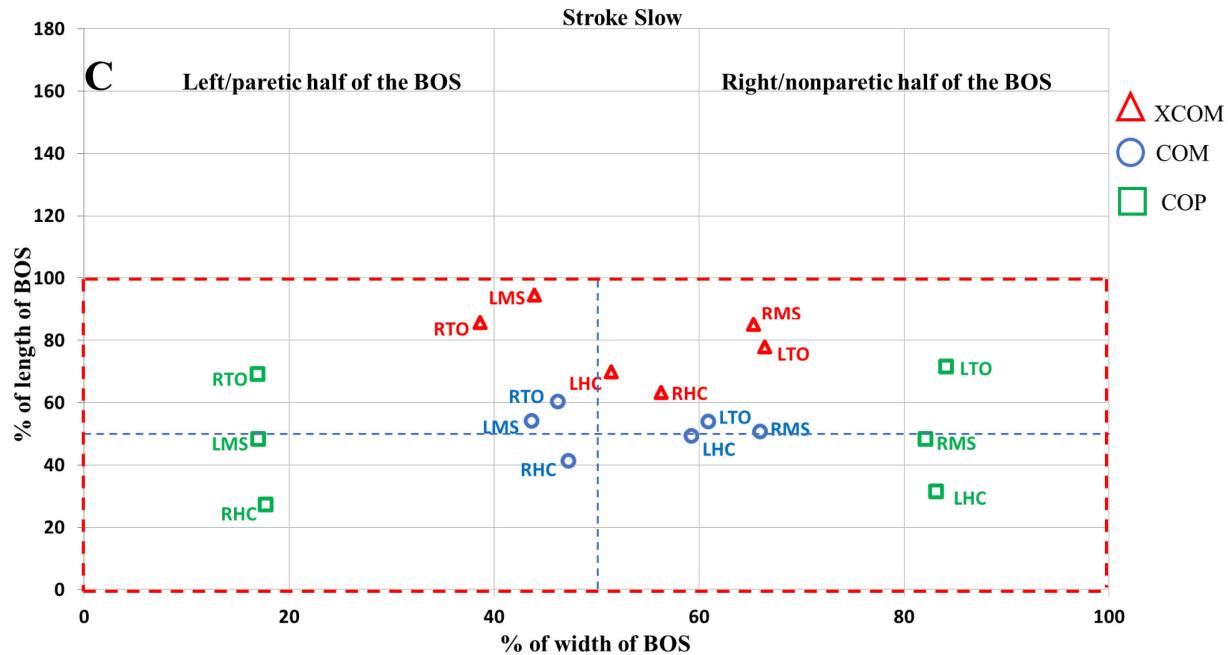


Figure 5.7. Representation of the mean the relative positions of COP, the projection of COM and XCOM of the healthy group (in A), stroke-fast group (in B) and stroke-slow group (in C) in AP and ML directions relative to the length and width of the BOS (in %) at a comfortable speed. The values on the Y and X axes are the percentages of the length and width of the estimated BOS determined at each time point of each gait cycle, respectively. RHC: Right Heel Contact, RMS: Right Midstance, LTO: Left Toe-Off, LHC: Left Heel Contact, LMS: Left Midstance, RTO: Right Toe-Off.

In general, the relative positions of the COP, the projection of COM and XCOM within the BOS in the stroke groups showed differences in AP direction during paretic (left) and nonparetic (right) midstance time points as compared to the left and right midstance time points of healthy participants, respectively (Figure. 5.7. and Table 5.5).

More specifically, in the AP direction, for both right and left midstance time points, the values of the relative positions of COP and the projection of COM in BOS in the stroke groups were closer to the posterior border of the BOS as compared to healthy ($p \leq .018$ between the stroke groups and healthy group, $1.22 \leq ES \leq 2.08$, post hoc $p \geq .611$ between the stroke groups) (Table 5.5). The length of the BOS of the stroke

groups was longer than the length of the BOS of the healthy group at midstance time points (Table 5.4). The length of the BOS of the stroke-slow group was longer than the length of the BOS of the stroke-fast group (Table 5.4). The relative position of COP within the BOS was also closer to the posterior border of the BOS in the stroke-slow group than in other groups at the right toe-off ($p \leq .007$ between stroke-slow and other groups, $ES \geq .97$ and $p = .595$ between the stroke-fast group and healthy group and $ES = .54$, and $ES = 1.27$ between the stroke-slow group and healthy group. However, the relative position of COM within the BOS was closer to the posterior border of the BOS only in the stroke-fast group, as compared to the healthy group at the right heel contact ($p = .034$ between the stroke-fast group and the healthy group, $ES = 1.30$).

In the ML direction, the relative positions of COP and the projection of COM within the BOS during right/nonparetic midstance as well as left toe-off were closer to the right/nonparetic lateral border of the BOS for the stroke groups as compared to the healthy group ($p \leq .010$ between the stroke groups and healthy group, $1.34 \leq ES \leq 1.92$, $p \geq .078$ between stroke groups) (Table 4). The relative position of COP was closer to the left/paretic lateral border of BOS in the stroke-slow group than in the healthy group at left midstance and right toe-off time points ($p \leq .035$, $.77 \leq ES \leq 1.19$).

The relative positions of XCOM projected onto the BOS in the AP direction at different time points in the stroke groups were significantly more posterior than the relative position of XCOM in the BOS of the healthy group, except for the stroke-fast group at right toe-off (30-40% more posterior at midstance time points and 15-20% more posterior at other time points) ($p \leq .021$ between the stroke groups and healthy

group, $.71 \leq ES \leq 3.44$) (Table 5.5). At right and left midstance time points, the relative position of XCOM was significantly more posterior in the stroke-slow group than in the stroke-fast group ($p \leq .027$ between stroke groups, $1.26 \leq ES \leq 1.31$) (Table 5.5). The relative position of XCOM in BOS in the ML direction was closer to the right/nonparetic lateral border of BOS in stroke groups than the healthy group at right midstance ($p \leq .020$ between stroke groups and healthy group, $1.11 \leq ES \leq 1.40$) and closer to the right/nonparetic lateral border of BOS only in the stroke-slow group at left toe-off ($p = .032$ between the stroke-slow group and healthy group, $ES = 1.03$) (Table 5.6).

Table 5.5 Between-group differences of mean and standard deviations of biomechanical variables at different time points in the AP direction

AP direction						
	Groups	Time points of left half of BOS			Time points of right half of BOS	
		RTO AP	LMS AP	RHC AP	LTO AP	RMS AP
COP	Healthy	74.7 ± 2.3	62.7 ± 7.1	25.4 ± 3.5	75.8 ± 2.6	62.9 ± 6.9
	Stroke-Fast	$73.4 \pm 2.6 \S$	$49.7 \pm 6.3^*$	27.1 ± 4.2	71.9 ± 5.3	$47.7 \pm 10.4^*$
	Stroke-Slow	$69.3 \pm 5.3^*$	$47.5 \pm 6.8^*$	27.3 ± 4.1	71.9 ± 5.0	$48.5 \pm 9.4^*$
COM	Healthy	57.8 ± 2.6	61.1 ± 4.4	44.1 ± 1.8	59.1 ± 2.3	63.3 ± 3.7
	Stroke-Fast	59.0 ± 3.5	$53.3 \pm 8.1^*$	$41.2 \pm 3.4^*$	59.1 ± 4.1	$52.8 \pm 8.3^*$
	Stroke-Slow	60.8 ± 4.2	$54.1 \pm 7.4^*$	41.8 ± 3.5	58.4 ± 6.7	$51.6 \pm 8.9^*$
XCOM	Healthy	102.7 ± 12.5	158.6 ± 27.3	82.2 ± 11.0	105.5 ± 13.0	166.5 ± 32.7
	Stroke-Fast	94.0 ± 10.0	$120.9 \pm 23.0^* \S$	$71.0 \pm 7.3^*$	$93.6 \pm 11.9^*$	$112.1 \pm 26.2^* \S$
	Stroke-Slow	$87.1 \pm 11.7^*$	$96.6 \pm 19.7^*$	$64.4 \pm 10.1^*$	$84.3 \pm 11.5^*$	$88.0 \pm 21.4^*$

Each value of relative positions of COP, the projection of COM and XCOM are normalized values to the length of BOS in %. The left side is the paretic side and the right side is the nonparetic side. In bold, significant differences between groups. * represents a significant difference with the healthy group and § represents a significant difference between the stroke groups. RHC: Right Heel Contact, RMS: Right Midstance, LTO: Left Toe-Off, LHC: Left Heel Contact, LMS: Left Midstance, RTO: Right Toe-Off, AP: values in the anteroposterior direction.

Table 5.6 Between-group differences of mean and standard deviations of biomechanical variables at different time points in ML direction

		ML direction					
		Time points of left half of BOS			Time points of right half of BOS		
Groups		RTO ML	LMS ML	RHC ML	LTO ML	RMS ML	LHC ML
COP (%)	Healthy	20.3±3.5	18.0±2.6	18.6±3.0	79.3±3.5	81.4±2.1	82.0±2.4
	Stroke-Fast	17.8±4.4	16.3±3.8	18.8±4.4	83.4±3.5*	84.2±2.9*	82.6±2.3
	Stroke-Slow	16.7±3.2*	15.1±2.5*	17.7±3.6	84.0±3.3*	85.1±2.5*	83.0±3.1
COM (%)	Healthy	47.4±2.0	45.3±3.3	46.4±1.7	52.8±5.0	56.5±2.3	56.0±1.7
	Stroke-Fast	45.6±3.7	43.0±5.0	46.5±4.0	57.7±3.8*	62.1±4.3*	56.7±3.1
	Stroke-Slow	45.5±3.5	43.1±3.4	46.8±3.1	60.5±4.2*	65.3±5.0*	58.4±3.3
XCOM (%)	Healthy	38.6±2.8	44.6±3.3	55.0±3.1	62.9±3.3	57.0±3.3	48.7±3.9
	Stroke-Fast	35.3±5.7	43.0±5.2	58.0±4.2	66.1±5.0	61.5±4.2*	45.1±5.5
	Stroke-Slow	37.6±5.1	43.7±3.7	56.6±5.9	67.5±5.8*	64.5±5.3*	48.7±5.1

Each value of relative positions of COP, the projection of COM and XCOM are normalized values to the width of BOS in %. In the ML direction, the further the value from the midline at 50%, the more lateral the position of the variable. The left side is the paretic side and the right side is the nonparetic side. In bold, significant differences between groups. * represents a significant difference with the healthy group. RHC: Right Heel Contact, RMS: Right Midstance, LTO: Left Toe-Off, LHC: Left Heel Contact, LMS: Left Midstance, RTO: Right Toe-Off, ML: values in the mediolateral direction.

In the AP direction and in the healthy group, the relative position of COP was close to the relative position of the projection of COM (Table 5.5). The relative position of the projection of COM within the BOS at midstance time points was more anterior than the relative position of the projection of COM within the BOS at toe-off time points (which are the time points before midstance time points) (Table 5.5). However, in the case of the stroke groups and compared to the healthy group, the relative position of COP was more posterior to the relative position of the projection of COM. Also, the relative position of the projection of COM within the BOS at

midstance time points was closer to the posterior border of BOS than the relative position of COM within the BOS at toe-off time points.

In both AP and ML directions, when the relative positions of COP, the projection of COM and XCOM within the BOS were at time points located in the right/nonparetic half of the BOS, the total number of significant differences between the biomechanical variables of the stroke-fast group and the healthy group identified in Table 5.5 and Table 5.6 is 10 and is 11 for the stroke-slow group. When the relative positions of COP, the projection of COM and XCOM within the BOS were at time points located in the left/paretic half of the BOS, the total number of differences between the biomechanical variables of the stroke-fast group and the healthy group is 6 and for the stroke-slow group is 8, which is evidently less than the total number for right/nonparetic half of the BOS. The stroke-slow group showed more differences with the healthy group in ML direction ($n=8$) than the stroke-fast group ($n=5$).

5-2-5-2-2 Correlations between biomechanical variables and clinical measures

All significant correlations between biomechanical variables and clinical measures were low (Spearman $-.446 \leq r \leq .404$) (Table 5). In AP direction, the length of BOS was correlated with TUG at midstance time points. The relative position of COP in BOS was correlated with TUG at right toe-off. The relative position of XCOM in BOS was correlated TUG at midstance time points, with TUG at toe-off time points. In ML direction, no correlations with the TUG were observed.

Table 5.7 Significant correlations between biomechanical and clinical variables in individuals post-stroke

Stroke group (n=38)	BOS LMS	BOS RMS	COP RTO	XCOM RTO	XCOM LMS	XCOM LTO	XCOM RMS	XCOM LHC	COM RMS	XCOM RMS
Along AP axis									Along ML axis	
CMSA Leg									r=-.328 p=.044	r=-.321 p=.049
CMSA Foot									r=.365 p=.024	r=.343 p=.035
TUG	r=.404 p=.012	r=.384 p=.017	r=-.446 p=.005		r=-.349 p=.032	r=-.375 p=.020	r=-.435 p=.006	r=.338 p=.038		

CMSA: Chedoke-McMaster Stroke assessment score, TUG: Time Up and Go, RHC: Right Heel Contact, RMS: Right Midstance, LTO: Left Toe-Off, LHC: Left Heel Contact, LMS: Left Midstance, RTO: Right Toe-Off

There was not any correlation between overground speed and treadmill speed in the three groups.

Overground speed showed a low negative correlation with the length of the BOS at right heel contact in the stroke-slow group ($r=-.478$, $p=.029$). In the ML direction, low positive correlation with the relative position of COP within the BOS at the right toe-off in the stroke-slow group ($r=.469$, $p=.037$) was found.

Treadmill speed showed moderate to high negative correlations ($p \leq .005$, $-.838 \leq r \leq -.602$) with the length of the BOS in the stroke groups at midstance time points, with the length of the BOS at the left toe-off time point in the stroke-slow group and moderate negative correlation ($p=.016$, $r=-.454$) at right midstance, with the width of BOS in the stroke-slow group. Also, the treadmill speed moderately correlated with the relative position of the projection of COM in the BOS in the AP direction at the right midstance time point ($p \leq .045$, $r=.530$) in the stroke-fast group,

moderate negative correlation ($p \leq .031$, $-.559 \leq r \leq -.484$) with the relative position of the projection of COM in the BOS in the AP direction in the stroke-slow group at right midstance and right toe-off time points and, high correlations ($p \leq .005$, $.685 \leq r \leq .873$) with the relative position of XCOM in the BOS in the AP direction in healthy and the stroke-fast group. The total correlation coefficient of the treadmill speed and the relative position of XCOM in the BOS was .872 (Figure 5.8).

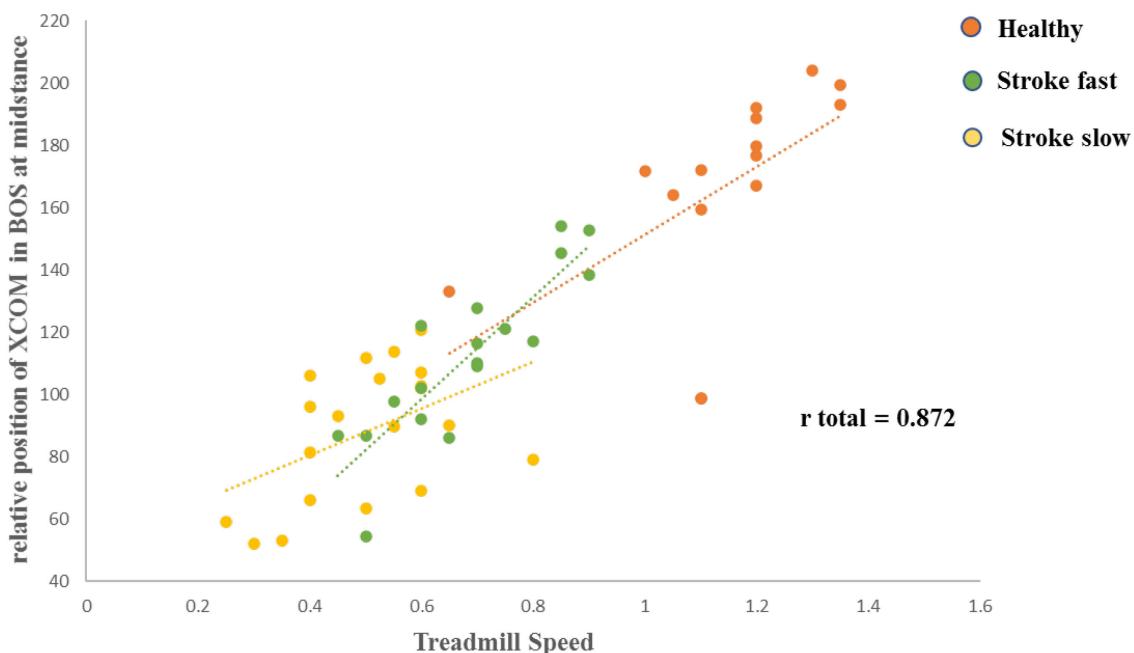


Figure 5.8. Correlation between the treadmill speed and the relative positions of XCOM in the BOS at the midstance time point in three groups

5-2-6 Discussion

This study aimed to compare the dimensions of BOS, relative positions of COP, and the projection of COM and XCOM in AP and ML directions between healthy, stroke-fast and stroke-slow groups as well as between the stroke groups. The biomechanical determinants of dynamic balance were compared at six different time

points at self-selected comfortable on-the-split-belt treadmill gait speed. The results indicate that both COP and the projection of COM showed more posterior relative positions in BOS in the stroke groups as compared to healthy participants, but this occurred only at midstance time points (Table 5.5). In contrast, the relative position of XCOM in BOS was more posterior in the stroke groups as compared to the healthy group at almost all time points except at right/nonparetic toe-off for the stroke-fast group (Table 5.5). Classically, the position of the foot on the ground is used to determine the BOS at midstance. In this study, the projection of the position of the swing foot during midstance was used to estimate the potential BOS. Based on our knowledge, using potential BOS at midstance time points is not reported in individuals at the chronic phase post-stroke. The purpose of this method is to study the contribution of the control of the swing foot to maintaining dynamic balance and transfer of weight (represented by COM) during gait. Thus, the potential BOS provides an opportunity to study the control of the transfer of weight through the position of the COP while one of the feet is not in contact with the ground. Additionally, assessing the relative position of the XCOM, as one of the biomechanical determinants of dynamic balance in the potential BOS increases our understanding of the control process of the velocity of COM.

The position of the COP is critical to maintaining balance during gait by controlling the acceleration of the COM (Hof, 2007; Hof et al., 2010; Jian et al., 1993; Winter, 1995). Different reasons may contribute to the relative positions of COP and the projection of COM in BOS closer to the posterior border in stroke groups than in the healthy group. One of the reasons is slower gait speed (Chisholm et al., 2011;

Choi & Kim, 2018; Clark et al., 2012; Mizelle et al., 2006; Weerdesteyn et al., 2008). Additionally, the difficulty of controlling motor aspects of the task such as taking more weight on the rearfoot instead of normal distributing the weight over the sole during gait and more anteriorly displaced trunk which determines the position of the COP and the projection of COM respectively (Forghany, Nester, Tyson, Preece, & Jones, 2019; Tesio & Rota, 2019). The more anterior relative position of the projection of COM than the relative position of COP in the stroke groups at midstance time points compared to almost equal relative positions of the COP and the projection of COM in BOS in the healthy group probably confirms the interpretation (Table 3). The more anterior relative position of COP in BOS in the stroke-fast group than the stroke-slow group at right toe-off could be attributed to more trunk progression and better function of gait in this group (Tesio & Rota, 2019).

In this study, we interpreted the values of XCOM of stroke participants closer to the values of the healthy group as better dynamic balance. The more posterior relative position of XCOM in BOS in the stroke groups than in the healthy group confirms a more conservative gait in participants of the stroke groups due to slower gait speed (Bierbaum et al., 2011; Van Meulen et al., 2016). At midstance time points, the XCOM of the healthy group and the stroke-fast group is evidently outside of the BOS which makes these time points unstable for only these groups. At these time points, the length of the BOS in the stroke groups is significantly longer than the length of BOS in the healthy group. The longer length of BOS in the stroke groups than in the healthy group at midstance time points could probably be interpreted as a strategy to maintain dynamic balance at midstance time points by keeping the relative

position of XCOM near the anterior border of BOS. As mentioned the position of the projection of the COM is used to calculate the position of the XCOM. Consequently, maintaining the position of XCOM near the anterior border of the BOS indicates that the position of the projection of the COM is within the BOS. Maintaining the position of the projection of the COM in the BOS is one of the requirements of dynamic balance during gait. Hence we interpreted the findings as a more conservative strategy to maintain balance during gait in the stroke groups.

Since gait speed impacts the relative position of XCOM in BOS, the slower speed may also explain why the positions of the XCOM were less anterior at almost all time points of gait for both stroke groups as compared to healthy in the AP direction (Table 5.5). However, only in healthy participants and the stroke-fast group, significant correlations were found between the relative position of XCOM in BOS and treadmill speed at all time points i.e., faster treadmill speed in the two groups was correlated to more anteriorly located relative position of XCOM in BOS. This finding is supported by the negative correlation between the TUG and the relative position of XCOM in BOS and the positive correlation between TUG and the length of the BOS at midstance time points. Since the length of the BOS in the stroke-slow group was longer than one of the stroke-fast group at midstance time points, a longer length of BOS may be a favoured strategy used by the stroke-slow group to keep the relative position of XCOM in BOS within the BOS.

The negative correlation between treadmill gait speed and the length of the BOS in individuals post-stroke in addition to the shorter length of the BOS in the stroke-fast group (Table 5.4) reflects that individuals post-stroke with faster speed

prefer to take a fast step (Hof et al., 2005; Van Meulen et al., 2016) with shorter length of the BOS instead of increasing the length of BOS to maintain the XCOM within the BOS i.e., probably faster cadence on both paretic and nonparetic sides. In sum, both stroke groups reduced their speed and increased the BOS length to maintain their XCOM near the anterior border of the BOS which are strategies that contribute to maintaining dynamic balance during the critical time points of midstance.

Further statistical analyses between treadmill speed and the relative position of XCOM in the BOS at all time points in three groups showed an overlap of regression lines. It means increasing speed in the stroke groups could lead to similar values of the relative position of XCOM in the BOS in both AP and ML directions in the healthy group and consequently the same correlations between the biomechanical determinants and treadmill speed. This probably supports the finding that individuals post-stroke walking faster than the overground speed of .93 m/s are significantly more likely able to return to work (Jarvis et al., 2019). The stroke-fast group in our study walks faster than the limit for walking in the community (i.e., 1 m/s) which is close to the threshold of .93. We can suggest that probably a speed higher than 1 m/s contributes to normalized biomechanical determinants and better dynamic balance.

The majority of differences in the values of the biomechanical variables between the stroke groups and healthy group in the AP direction occurred at midstance critical time points of midstance when the whole weight is on one foot. One may suggest the coordinated alterations of the relative positions of COP and the projection of COM in BOS in the stroke groups at midstance time points imply that the stroke groups increased their ability to control dynamic balance by the position of COP to

control the acceleration of COM (which is a derivative of the velocity of COM) and eventually XCOM specifically at the midstance time point. In other words, if COP controls the acceleration of the COM effectively, the rate of change of position of COP corresponds to the change of the position of COM, which is seen in Table 3. Interestingly, the relative position of the projection of COM at midstance time points in the stroke groups is closer to the posterior border of BOS than the relative position of the projection of COM at toe-off time points which indicates the effectiveness of the controlling role of the relative position of COP at midstance time points. Considering both stroke groups in both AP and ML directions (Table 5.5 and Table 5.6), the alterations of the biomechanical determinants of dynamic balance were more marked for the time points of the nonparetic side (time points of the right half of Fig 5.6.) than the time points of the paretic side. Observation of more alterations at the nonparetic side versus the paretic side in individuals post-stroke indicates the preference of contribution of the nonparetic side to dynamic balance through more coordination between altered biomechanical determinants (Buurke et al., 2020). Significant positive correlations were found between the motor impairments of the foot (CMSA foot) and the relative position of XCOM in BOS (Table 5.7) at midstance time points. These positive correlations suggest that the motor impairment of the foot may lead to a more conservative gait manifested as less distance between the relative position of XCOM in BOS and the anterior limit of BOS in the case of participants of the stroke groups with less severe motor impairments of the foot. The same is inferred in the case of left heel contact and right midstance time points (Table 5.7).

In the ML direction, compared to the AP direction, there were not many differences between the stroke groups and the healthy group. Moreover, there was no difference between the stroke groups. More laterally relative positions of the COP, the projection of COM and XCOM within the BOS in the stroke groups than healthy group occur at left/paretic toe-off and right/nonparetic midstance time points, except for the relative position of XCOM in BOS at left/paretic toe-off in the stroke-fast group. More laterally located relative position of XCOM in BOS at right/nonparetic midstance reveals worse mediolateral balance in the stroke groups (Van Meulen et al., 2016). Additionally, low negative correlations were found between more laterally positioned XCOM and the projection of COM during gait at right/nonparetic midstance and motor impairments of the leg. The finding probably implies the contribution of increased body sway in reduced dynamic balance in a group of individuals post-stroke with more motor impairment of the leg (Hak et al., 2013). Previously, the correlation between motor impairments of the leg and abnormal movement of the trunk in the ML direction was reported (De Bujanda, Nadeau, Bourbonnais, & Dickstein, 2003). The altered values of biomechanical parameters in addition to wider BOS at the right/nonparetic midstance time point probably support the contribution of coordinated interaction between the altered variables in the stroke groups for maintaining dynamic balance (Buurke, Lamoth, van der Woude, Hof, & den Otter, 2019). The left/paretic toe-off and right/nonparetic midstance time points are consecutive time points that correspond to the transition from bipedal to unipedal phase (Table 5.6). Individuals post-stroke tend to keep their weight closer to the nonparetic side than to the paretic side (Choi, Kim, Lee, & Cha, 2019) which may explain the more lateral position of COP and the projection of COM at left/paretic

toe-off (which the majority of the weight of the body is transferred to the right/nonparetic side) and right/nonparetic midstance. On the other hand, the closer relative position of COP in BOS to the lateral border of the BOS in the stroke groups than the healthy group at left/paretic toe-off without difference between the width of the BOS reveals that stroke groups transferred the weight further toward the lateral side of the nonparetic foot without more lateral displacement of the foot. This is the same as in the stroke-slow group at left/paretic midstance and right/nonparetic toe-off (which happens immediately before paretic midstance).

The concomitant more lateral relative position of COM in BOS and wider BOS which is found at right/nonparetic midstance in the stroke groups is a compensatory mechanism for maintaining dynamic balance (Clark et al., 2012). However, at left/paretic toe-off more lateral relative position of the projection of COM in BOS is not accompanied by wider BOS which means lower dynamic balance. This finding in the stroke-slow group is also supported by the more lateral relative position of XCOM in BOS. Devetak et al. (2019) reported the inability of individuals post-stroke to maintain the position of the projection of COM near the midline of BOS (Devetak et al., 2019). Association of more lateral projection of COM in individuals post-stroke at nonparetic midstance with more severe sensorimotor impairment of leg is in accordance with the finding of Devetak et al. (2019). Even in healthy participants, slower speeds than comfortable speed led to a closer relative position of the projection of COM in BOS to the lateral border of the BOS (Orendurff et al., 2004).

5-2-7 Limitations

In this study, participants in the healthy group were generally younger than participants in the stroke groups. Recently, a study reported that there was no significant difference between spatiotemporal parameters of gait at a comfortable speed between a group of men aged 31-40 years old and a group of men aged 51-60 years old (Lau et al., 2020). In the case of groups of women of the same age, only the single support time differed (Lau et al., 2020). Therefore, we assumed that the age difference between the healthy group and the stroke groups did not impact the results of our study. On the other hand, according to data collected in 2019 by the Government of Canada, stroke usually occurs after the age of 65 (Government of Canada, 2019). So, the stroke groups of the present study were younger than the average stroke survivors and their age was closer to the age of healthy participants.

Individuals post-stroke who participated in this study presented with moderate motor impairments of the foot and leg. More studies on individuals post-stroke with more severe gait abilities and motor impairments of the foot and leg are warranted to validate the findings of this study. Also, future studies should include data of other clinical measures like the sensory impairment level of the paretic and nonparetic limbs and the strength of important muscle groups like hip flexors and plantar flexors. Additionally, the article did not address the asymmetry which is a complicated concept. Thus, future studies can address this issue.

Due to differences between gait on the treadmill and overground gait (Tielke, Ahn, & Lee, 2019) and significant difference between treadmill speed and overground

speed in our study, generalization of findings of this study to overground walking must be done cautiously.

TUG is usually used for the evaluation of functional mobility in individuals at the chronic phase post-stroke, it does not cover all aspects of the dynamic balance. It remains to be determined if scores of a clinical test such as Mini-BESTest would be more correlated with the biomechanical parameters.

5-2-8 Conclusion

Coordinated interaction between altered relative positions of COP and the projection of COM in BOS in addition to keeping the relative position of XCOM in BOS near the anterior border of the BOS at the midstance time point probably reflects a strategy to maintain dynamic balance during gait. In the ML direction, the interaction between determinants of dynamic balance was found only at the right/nonparetic midstance time point. Significant correlations between XCOM (as one of the biomechanical determinants of dynamic balance), increasing the length of the potential BOS and gait speed were found. The correlations probably support the idea that the improvement of gait speed leads to the improvement of some of the contributing factors to dynamic balance including the biomechanical determinants in BOS and reaching values closer to normalized values.

Chapter 6 General discussion

Stroke may cause motor, sensory and cognitive impairments that potentially affect a person's mobility and limit his or her social participation. These impairments contribute to kinetic and kinematic alterations of gait patterns, particularly in the form of asymmetric weight-bearing and impaired weight transfer to paretic and nonparetic sides. These alterations may not only limit the spatiotemporal aspects of gait, but may also interrupt the complicated interplay between biomechanical determinants of dynamic balance and eventually lead to falls. Due to the high rate of falls during gait, different types of interventions involving mobility exercises or weight shifting exercises were developed and assessed to improve dynamic balance during this complex task. However, previous studies of the impact of these interventions have shown small effect sizes. A limited number of studies applied gait perturbations in individuals at the chronic phase post-stroke to improve dynamic balance. However, these studies involved the application of unpredictable gait perturbations with additional interventions/tasks or did not include a control group. The purpose of this thesis was to compare the effect of two interventions on balance and gait abilities in participants with hemiparesis at the chronic phase, namely intense and unpredictable perturbations during gait training and walking-only on the treadmill training. Also, the thesis aimed to improve our knowledge about the adaptation of the altered biomechanical determinants of dynamic balance by comparing these determinants between a group of healthy participants and two groups of individuals at the chronic phase post-stroke (one with comfortable self-selected speed faster than 1 m/s and another with comfortable self-selected speed slower than 1 m/s). In this chapter of the thesis, I

discuss the principal findings and the hypothesis of the thesis. Then, the limitations of the thesis, suggestions for future studies and the clinical implications of the findings are discussed.

6-1 Principal findings

The first study described in this thesis showed that intense and unpredictable perturbations during gait training in individuals at the chronic phase post-stroke can lead to improvement of dynamic balance as evaluated by the MiniBESTest compared to the walking-only on the treadmill training. During the training sessions, participants walked at their baseline comfortable treadmill speed between applied gait perturbations. Therefore, there were no additional interventions/tasks beside the application of unpredictable perturbations during gait. This allowed to isolate the impact of perturbations during the intervention. Therefore, it is possible to attribute the improvement of dynamic balance to the unpredictable perturbations applied during gait training. It is worthy to mention that participants in the randomized controlled trial increased their overground comfortable speed from .90 m/s (experimental group) and 1.0 m/s (comparison group) before perturbation training to 1.0 m/s and 1.1 m/s after perturbation training respectively (Table 5.2). The findings of the biomechanical study suggest that normalization of the biomechanical determinants of dynamic balance contributed to the improved balance and gait abilities found after gait perturbation training. In the case of individuals at the chronic phase post-stroke who walked faster than 1 m/s, values of extrapolated center of mass (XCOM) which is one of the measures of dynamic balance were closer to the values of XCOM observed in healthy participants at almost all time points of the gait cycle. This idea was supported

by the overlap of the regression lines illustrated using the values of the treadmill speed and the relative positions of XCOM in the BOS at midstance time points. We suggest that the perturbation training contributed to the normalization of the values of XCOM through the increase in gait speed.

6-2 Principles of intervention and their effects on adaptation and generalization

The intense and unpredictable perturbations during gait training was based on some of the principles of rehabilitation like the task-specificity principle, progressive augmentation of intensity, and repetition (Hubli & Dietz, 2013; Lamontagne & Fung, 2004; Mansfield et al. 2015b). According to the task-specificity principle, to reach a better level of dynamic balance during gait, it is necessary to apply intervention that targets the underlying mechanisms of balance improvement during the same task (Matjačić et al., 2018; Okubo et al., 2018). Execution of the fast and stable reactive postural responses in reaction to unpredictable perturbations is a critical factor for maintaining balance (Mansfield et al. 2015; McCrum et al., 2017). This ability is impaired in individuals at the chronic phase post-stroke (Dusane et al., 2021; Kajrolkar & Bhatt, 2016; Kajrolkar et al., 2014). Improvement of the use of feedback control due to a task-specific intervention in this population has been suggested to contribute to stable reactions (Dusane et al., 2021). The walking-only intervention in the comparison group did not target the mentioned underlying mechanisms of improvement of dynamic balance. Therefore, the walking-only intervention did not improve dynamic balance in the comparison group. On the other hand, improvement

of adjustment of factors that affect the biomechanical determinants of dynamic balance during gait through feedforward mechanisms (Marigold & Patla, 2002) could be attributed to the effects of the task-specific intervention. The point can explain the improvement of the anticipatory subsystem of the MiniBESTest after the perturbation intervention as well as walking-only intervention in the comparison group. In addition to applying a task-specific intervention, other characteristics of the training intervention like intensity and the number of perturbations are important.

We progressively increased the intensity of perturbations during training sessions according to the tolerance of the participants. Previous studies have shown that the more intense perturbations lead to higher amplitude and magnitude of reactive postural responses (Mansfield et al. 2015b) which probably can impact the reaction of both the paretic and nonparetic sides (Aruin et al., 2000; Dusane et al., 2021; Steib et al., 2017; Zadravec et al., 2020). As mentioned in the literature review Dusane and Bhatt (2021) and Matjačić et al. (2018) reported improvement of compensatory steps and more lateral placement of the paretic foot in reaction to the perturbations at higher intensities in their studies. Higher intensities of the perturbations contribute to better adaptation and generalization through the process of motor learning (i.e. transfer from the treadmill to overground) in older adults (Lee et al., 2018). Based on the findings of these studies (Dusane & Bhatt, 2021; Lee et al., 2018; Matjačić et al., 2018), it is possible to attribute the improvement of dynamic balance in our study to progressively increasing intensities of the perturbations. Participants in the comparison group during the walking-only intervention walked always at a constant speed. It indicates that the intensity of the intervention in comparison group was not augmented (i.e.

steady treadmill speed). The absence of augmentation of the intensity (gait speed) possibly affected the results of this group.

We applied a considerable number of perturbations and progressively increased the number of repetitions during the training sessions. It is suggested that a higher number of gait slip perturbations can contribute to better motor learning in individuals at the chronic phase post-stroke (Dusane & Bhatt, 2021). Also in older adults, a higher number of repetitions is postulated to contribute to the sustained effects of the intervention (Lee et al., 2020). Okubo et al. (2018) suggested that improvement of motor learning skills and muscle activation due to the high repetition of unpredictable gait perturbations contribute to the improvement of dynamic balance in young adults as well. Based on the findings of the previous studies, we can speculate that the high repetition of perturbations in our study led to the advantages of the perturbation intervention.

We used the MiniBESTest in the randomized controlled trial to evaluate the dynamic balance of participants who have been trained on the treadmill. The participants in the experimental group had improved scores of the MiniBESTest which reflect the improvement of dynamic balance. However, the dynamic balance did not improve in the comparison group after the walking-only intervention (Table 5.2). Improvement of the scores of the MiniBESTest in the experimental group indicates the transfer of the effects of the gait perturbations applied by a treadmill to overground conditions during evaluations done by the MiniBESTest, i.e. generalization. It is suggested that progressive increased intensity, repetition and unpredictability of the gait perturbations are responsible for the generalization of

improvement of dynamic balance. We suggest that the underlying mechanism for this generalization is the activation of some cerebral mechanisms that switch the learned motor patterns over a treadmill to overground conditions (Lee et al., 2018).

6-3 Justification of the perturbation protocol

Previous studies which tested the effect of unpredictable gait perturbations in individuals at the chronic phase post-stroke underscored the importance of an intervention to improve the reactive postural reactions on the paretic side (Dusane et al., 2021; Haarman et al., 2017; Kajrolkar & Bhatt, 2016; Kajrolkar et al., 2014; Punt et al., 2017; Sharafi et al., 2016). According to Bhatt (2015), the acquisition of motor skills on the paretic side is facilitated if the perturbations are first applied on the nonparetic side. Therefore, during each training session, we applied unpredictable perturbations on the nonparetic side before applying perturbations on the paretic side.

Based on the study of Okubo et al. (2018), applying both slip and trip perturbations in one training session would contribute to better results. Applying unpredictable slip perturbations during gait leads to sudden backward bending of the trunk immediately during perturbation (Okubo et al., 2018). Okubo suggested that after applying slips, participants adaptively shift their trunk (and consequently their COM) anteriorly in the AP direction (along AP axes). Thus, bending the trunk forward was an anticipated adaptation of posture based on feedforward mechanisms to shift the COM more anterior to prevent falling after the next unpredictable slip (Okubo et al., 2018). However, according to these authors, this shift of COM in AP direction reduces the ability of recovery of dynamic balance after a trip. Indeed, after a trip, an

anteriorly shifted COM in the AP direction (due to previous slips) would increase the probability of falling forward. It indicates that to adjust the effect of the adaptation resulting from slip perturbations, applying trip perturbations is necessary. According to the results of the study of Okubo et al. (2018), applying slip perturbations during gait training without trip perturbations restricted reaching a better level of motor learning and generalization (i.e. transfer from treadmill to overground) in the study of Dusane and Bhatt (2021). In our study, both faster-belt perturbations (which reproduced conditions like trips) and slower-belt perturbations (which reproduced conditions like slips) were applied at each training session. Based on the study of Okubo and colleagues, using both types of perturbations together during all the training sessions would optimize the improvement of dynamic balance.

6-4 Explanatory hypothesis for the results of unpredictable perturbations during gait training

6-4-1 The improvement of dynamic balance

The improvements achieved after gait perturbation training in the experimental group and the comparison group were explained in the randomized controlled trial. Unpredictable perturbation during gait training significantly improved the score of anticipatory activity, reactive postural control, and dynamic gait subsystems of the Mini-BESTest. We used the data of seventeen participants (ten participants in the experimental group in addition to the data of seven participants of the comparison group) who received the unpredictable gait perturbations and compared them with the data of eight participants of the comparison group who received walking-only

training. Improvement of the reactive postural control and dynamic gait subsystems on MiniBESTest after gait perturbation intervention indicated the improvement of both reactive postural responses and the anticipatory postural responses. The improvement support one of the hypotheses of the thesis. The comparison group after walking-only training improved the anticipatory subsystem of the MiniBESTest. Dusane and Bhatt (2021) reported reduced apprehension and the positive effect of the repeated experience of treadmill walking in individuals at the chronic phase post-stroke (Dusane & Bhatt, 2021). It is possible to suggest that such an effect reported by Dusane and Bhatt (2021) would be one of the reasons for the improvement of the anticipatory subsystem of the MiniBESTest in the comparison group after the walking-only intervention.

We used the scores of the subsystems of the MiniBESTest to compare participants who received the perturbation training with those who received the walking-only intervention. Originally, the MiniBESTest which is a short version of the BESTest, was designed to improve the BESTest, an instrument designed to analyze several postural control system that may contribute to balance in adults (Franchignoni et al, 2010). Factor analysis and Rasch analysis allowed to reduce the tool into a 14-item scale that measures a unidimensional construct of dynamic balance, i.e. the MiniBESTest. The 14 items of the MiniBESTest belong evenly to four of the six sections from the original BESTest that is: section III “Anticipatory Postural Adjustments” (sit to stand, rise to toes, stand on 1 leg); section IV “Postural Responses” (stepping in 4 different directions); section V “Sensory Orientation” (stance – eyes open; foam surface – eyes closed; incline – eyes closed); and section

VI “Balance during Gait” (gait during change speed, head turns, pivot turns, obstacles; cognitive “Get Up and Go” with dual-task). Previously Mansfield et al. (2018) compared the effects of two interventions between two groups using the scores of the subsystems of the MiniBESTest. In the case of using the data of post-perturbation training of both experimental and comparison groups together for the comparison between the subsystems of the MiniBESTest, notably, there was not any difference between the scores of MiniBESTest after walking-only intervention and before perturbation training as well as before the two interventions in the comparison group (Wilcoxon $p \geq .726$). It justifies that the effect of the walking-only intervention has completely worn off. Additionally, there was not any difference between the scores of MiniBESTest before perturbation training in both experimental and comparison groups (Mann-Whitney U $p = .184$). Moreover, the comparison was done using nonparametric tests which do not rely on the assumption of independence of data.

The reactive postural control subsystem of the MiniBESTest is composed of three components: compensatory stepping correction in the forward direction, compensatory stepping correction in the backward direction, and compensatory stepping correction along the ML axis (right and left directions) (Lofgren, Lenholm, Conradsson, Stahle, & Franzen, 2014). Previous studies that applied gait perturbations in participants with stroke at the chronic phase reported improvement of compensatory stepping evaluated by motion capture and laboratory systems (Dusane & Bhatt, 2021; Kajrolkar et al., 2014; Matjačić et al., 2018). Also, Mansfield et al. (2018) reported significant improvement in the reactive postural control subsystem of

MiniBESTest in both perturbation training and control groups. The findings of our study are in line with the findings of the perturbation group of the study of Mansfield.

The unpredictability of time, type and intensity of the perturbations was explained in the randomized controlled trial. The importance of unpredictability of type and time of the perturbations was emphasized by the previous studies (Bhatt et al., 2013; Okubo et al., 2018). According to the previous studies, increasing the unpredictability of the perturbations contribute to decreasing the reliance on feedback control and increasing the reliance on feedforward control during gait (Bhatt et al., 2012; Pai & Bhatt, 2007). The increased reliance on feedforward control happens due to the learned prediction of a potential perturbation after applying repeated unpredictable perturbations (Bhatt et al., 2012; Pai & Bhatt, 2007). This has been suggested to improve the dynamic balance during unperturbed gait (Bhatt et al., 2012; Pai & Bhatt, 2007). The improvement of the dynamic gait subsystem of Mini-BESTest in our study probably supports the suggestions of Pai et al. (2007) and Bhatt et al. (2012).

Foot placement is one of the most important factors affecting dynamic balance during gait, particularly in the ML direction (Balasubramanian et al., 2010). Inaccurate foot placement in individuals post-stroke contributes to reduced dynamic balance (Dean & Kautz, 2015). Haarman et al. (2017) reported a more laterally-placed paretic foot compared to the nonparetic foot in reaction to perturbation in the ML direction. Re-establishment of balance after unpredictable perturbations is based on the faster readjustment of the position of COM in the BOS through a fast and accurate reactive postural response (Krause et al., 2018). Thus, such a fast and accurate

reactive stepping contributes to control of the acceleration of the COM by the position of the COP (Hof et al., 2010; Winter, 1995). Previously, Skidmore reported reduced drop foot on the paretic side due to gait perturbation reproduced by changing the stiffness of the belt of the treadmill on the nonparetic side (Skidmore & Artermiadis, 2017). We probably can suggest that the improvement of fast and accurate foot placement could contribute to the improvement of the scores of both the reactive postural control and dynamic gait subsystems of MiniBESTest.

Findings from some studies suggest that an intervention that provides intensive multisensory stimulation would contribute to more improvements in balance abilities after stroke (Hsu et al., 2021; Lim, 2019; Weerdesteyn et al., 2008; Yelnik et al., 2008). This has also been found among persons with spinal cord injury (SCI) (Hubli & Dietz, 2013). Intense and unpredictable gait perturbations provide more challenges for the sensorimotor system (McCrumb, Karamanidis, Willems, Zijlstra, & Meijer, 2018). Altogether, probably stimulation of different sources of sensory information due to intense perturbations contributed to the improvements of dynamic balance and gait abilities.

6-4-2 The increase of gait speed after gait perturbation training in the experimental group

Only the participants in the experimental group of the randomized controlled trial study increased significantly their overground gait speed after applying unpredictable gait perturbations (Table 5.2). After perturbation training, the participants of the comparison group did not improve significantly their overground gait speed ($p=.075$). However, overground gait speed significantly increased after

perturbation training in the comparison group compared to post-walking-only training in the same group ($p=.018$ (Table 5.2)). Additionally, in the comparison group, the increased overground gait speed after perturbation training did not differ significantly from post-perturbation overground gait speed in the experimental group ($p=.807$ (Table 5.2)). Therefore, it is possible to say overground speed improved in the comparison group after perturbation training. Speed improvement after applying unpredictable gait perturbations in individuals at the chronic phase post-stroke has been reported by studies of Dusane and Bhatt (2021) and Punt et al. (2019). Dusane and Bhatt (2021) suggested that reduced apprehension and the positive effect of the repeated experience of treadmill walking on locomotor training contribute to treadmill speed improvement. It indicates that Dusane and Bhatt (2021) did not consider the contribution of the perturbation training to the treadmill speed improvement through the improvement of factors that impact gait speed like spatiotemporal parameters reported by Punt et al. (2019). Punt et al. (2019) mentioned that the increased gait speed in their study may have resulted from increasing treadmill speed during training sessions, the confounding factor that we controlled in our study. They reported increased gait speed and increased step length on the paretic and nonparetic sides in addition to reduced variability of stride time and step time on the paretic and nonparetic sides, and the variability of swing time on the paretic side after intervention (Punt et al., 2019). Based on the previous findings of a study conducted with older adults that showed that the gait variability is velocity-dependent, Punt and colleagues suggested that increased speed may contribute to the reduced variability of mentioned spatiotemporal parameters (Punt et al., 2019). We did not study the factors associated with the improvement of comfortable and fast overground gait

speed before and after the intervention. However, as reported in the biomechanical study (see chapter 5), moderate to high negative correlations were found between treadmill speed and the length of the BOS at midstance time points. This indicates that stroke individuals with faster gait speed kept smaller BOS at midstance time points.

Simultaneous improvement of dynamic balance and gait speed has been reported previously (Lee et al., 2018). Gait speed and dynamic balance evaluated with MiniBESTest correlate positively in individuals at the chronic phase post-stroke (Madhavan & Bishnoi, 2017). It is possible to postulate that different factors including improved power of joints of lower extremities or improved muscular coordination and consequently better propulsion of the body may contribute to the improvement of dynamic balance and speed in our study. As discussed in chapter 5, the values of the relative positions of the XCOM in BOS in AP direction in the stroke-fast group were close to the values of the healthy participants. Additionally, findings of the biomechanical study indicated that individuals post-stroke with faster gait speed than 1 m/s prefer a shorter swing phase than the individuals post-stroke with gait speed slower than 1 m/s. The shorter swing phase results in a smaller length of the potential BOS at midstance time points. It could be postulated that in addition to mechanisms explained previously in the discussion, unpredictable gait perturbations training contributed to the improvement of dynamic balance through the improvement of gait speed and normalization of the biomechanical determinants of dynamic balance. Generally, the findings support one of the hypotheses of the thesis presented in chapter 3.

6-5 Limitations

Despite its important and original contribution to our understanding of the impact of an intervention aiming to improve dynamic balance among individuals at the chronic phase post-stroke, as well as the biomechanical determinants of dynamic balance during gait in this population, this thesis has some limitations that should be considered.

1) Due to the absence of preliminary data, we were not able to estimate a priori, through power analysis, the optimal sample size in our randomized controlled pilot trial. However, the findings of this pilot trial will be helpful for the calculation of sample size and power analysis in future studies.

2) There was only one pretraining clinical evaluation in the randomized controlled pilot trial. A double baseline assessment to support the absence of any change in baseline scores of clinical measures is another limitation of the clinical trial of this project. The absence of any spontaneous improvement confirmed by such an assessment will support the effectiveness of intense and unpredictable gait perturbation training in the improvement of dynamic balance in the population. Moreover, the double baseline assessment provides the opportunity to evaluate the changes during the follow-up.

3) Two different unpredictable gait perturbation trials were applied during each training session. Time-unpredictable perturbations were applied during “repeated perturbation” trials which reproduced conditions like slips and trips. Time-, type- and intensity-unpredictable perturbations were applied during “unpredictable

perturbation” trials. Fifty percent of the highest intensity of applied faster-belt perturbations were used in “unpredictable perturbation” trials to reproduce conditions like trips. Fifty percent of the highest intensity of applied slower-belt perturbations were used in “unpredictable perturbation” trials to reproduce conditions like slips. The intensity of the applied faster-belt and slower-belt perturbations in “repeated trials” increased during each training session. For example, if the highest intensity of faster-belt “repeated perturbations” at the 3rd and 5th sessions were 180% and 200% of the comfortable treadmill speed respectively, the 50% of the highest intensity used for “unpredictable perturbation” trials differed for the 3rd and 5th sessions consequently. Thus, the amount of 50% increased according to the tolerance of the participants as well. But we did not increase the fixed amount of 50% during the training sessions. For instance, we did not apply “unpredictable perturbation” trials of 70% of the highest intensity of faster-belt “repeated perturbation” trials in addition to the trials of 50% of the highest intensity of the faster-belt “repeated perturbation”. Adding such trials probably would result in different findings. Other more specific limitations regarding each of the two studies are presented in chapter 5.

6-6 Future studies

This thesis contributes to the progression of knowledge in neurological rehabilitation. However, the following cases were beyond the scope of the thesis and should be targeted by future studies.

- 1) We did not examine the effect of intense and unpredictable gait perturbation during gait training on fall rates. Falls can interfere with activities of daily living for a long time and eventually mortality (Dusane et al., 2021). Around 73% of persons

with stroke fall (Pollock et al., 2011). The prevalence of falls after stroke is 1.77 times more than its prevalence in healthy older adults (Nevisipour, Grabiner, & Honeycutt, 2019). Stroke survivors tend to be multiple fallers, particularly individuals with slower gait speed (Batchelor et al., 2012). Fractures and fear of falling are among the physical and psychological consequences of falls (Weerdesteyn et al., 2008). Falling is the cause of 23% -50% of fractures in individuals post-stroke (Harris, Eng, Marigold, Tokuno, & Louis, 2005), among them hip fractures are the most frequent (Ramnemark, Nyberg, Borssén, Olsson, & Gustafson, 1998). Treatment of consequences of falls after stroke is very expensive (Honeycutt et al., 2016). Longitudinal studies on the effect of such an intervention on fall rate incidence in individuals at the chronic phase post-stroke are warranted.

2) Participants of the randomized controlled trial had a relatively high level of balance confidence at baseline. However, the intense and unpredictable perturbation training during gait improved the balance confidence of the participants in our study. It would be interesting to assess the feasibility of the intervention with individuals with lower levels of balance confidence.

3) The majority of falls occur along lateral axes in the ML direction (Weerdesteyn et al., 2008). unfortunately, we did not have access to technology to apply and study gait perturbations in the ML direction, unlike Matjačić et al. (2018). Future studies should investigate the effect of such gait perturbations on balance and gait abilities in ML direction using instrumented treadmills and technologies like robot-assisted perturbed-balance training.

4) We did not examine if the effect of perturbations in the AP direction could be transferred to the ML direction. Thus, studying the specific effect of gait perturbation training in the AP direction on the improvement of dynamic balance in the ML direction would be an important purpose for future studies.

5) Although some studies previously reported the importance of booster training sessions, we did not include it in the randomized controlled pilot trial. Previous studies reported more retention of the advantages of gait perturbation training if the intervention included “booster” training session(s) a while after the end of the intervention in both older adults and individuals post-stroke (Bhatt et al., 2012; Dusane & Bhatt, 2021; Mansfield et al., 2018). However, it seems some factors affect the characteristics of the booster training sessions. For example, it is suggested that with the sufficient intensity of the perturbations at the first training session, it is not necessary to have a booster training session up to 4 months after the last training session in healthy young participants (Bhatt & Pai, 2009). The characteristics of the booster training session(s) like the best time after the end of the main training sessions and the interval between the booster training sessions would be interesting objectives for future studies.

6) More biomechanical and electromyographic studies are necessary to assess the relative importance of each of the mechanisms involved in the improvement of the randomized controlled trial, such as the improvements in the paretic and the nonparetic side, interlimb coordination, adaptation and motor learning (Krasovsky et al., 2013; Mansfield, Wong, McIlroy, et al., 2015; Zadravec et al., 2020). The answer to this important question will guide on how the activation and participation of the

paretic side in responses to challenges to dynamic balance. Also, such studies assist to prioritize the mechanisms of dynamic balance in this population. Previously, Sharafi et al. (2016) reported the pattern of muscle activation on both paretic and nonparetic sides similar to the muscle activation pattern of healthy participants. Using non-negative matrix factorization to study the characteristics of muscle synergies during gait may provide useful information regarding the coordination of muscles (Rabbi et al., 2020).

Additionally, as the margin of stability (MOS) is one of the biomechanical predictors of falls (Hak et al., 2013), studying MOS in addition to other fall predictors will improve our knowledge regarding the effect of the intervention on reducing fall rates in individuals at the chronic phase post-stroke. Hak et al. (2013) and Buurke et al. (2020) previously reported the inability of simultaneous re-establishing of stability along both AP and ML axes in reaction to unpredictable gait perturbations in this population. Altogether, addressing the type of strategies used to maintain dynamic balance before and after perturbations in participants who improved their dynamic balance compared to participants who did not will provide more opportunities to improve fall prevention interventions.

6-7 Clinical implications

The findings of the thesis have several implications for clinical practice pertaining to the evaluation of dynamic balance in individuals at the chronic phase post-stroke and the selection of effective rehabilitation interventions for improving dynamic balance.

6-7-1 Evaluation of dynamic balance

Due to the high incidence of stroke, there is an increasing number of individuals at the chronic phase post-stroke in different countries. It is necessary to provide opportunities for clinicians to select effective interventions (Arienti et al., 2019). Unfortunately, accurate and regular assessment of different aspects of the dynamic balance of the stroke survivors is not a part of the rehabilitation process in clinical settings. Clinical measures for the assessment of reactive balance control are not commonly available (Inness et al., 2015). Consequently, the clinical measures which are commonly used for balance evaluation mainly assess voluntary movements of limbs (Inness et al., 2015). On the other hand, even in research settings, a clinical measure like MiniBESTest which is specifically developed for the evaluation of dynamic balance is not used frequently (Arienti et al., 2019). An overview of systematic reviews regarding interventions aimed to improve dynamic balance in individuals post-stroke revealed that the MiniBESTest was not used in almost all of the 51 included systematic reviews (Arienti et al., 2019). The lack of precise evaluation of the outcomes of different rehabilitation interventions makes it difficult to improve current interventions applied frequently is not possible. Altogether, in addition to applying effective interventions, regular clinical evaluations using accurate assessment tools to document the improvement of dynamic balance are suggested.

6-7-2 Effective interventions for improvement of dynamic balance

The prevalence of impairments in the dynamic balance after stroke has been reported from 16.7% to 83% (Khan & Chevidikunnan, 2021). This impaired dynamic balance contributes to the reduced level of mobility (Alcantara, Alonso, & Speciali, 2017) and social participation (Göktaş, Colak, Kar, & Ekici, 2020). This highlights the importance of rehabilitation interventions targeting the improvement of dynamic balance. The results of the randomized controlled trial support that applying unpredictable perturbations during gait training with enough intensity and repetition contributes to the improvement of dynamic balance in individuals at the chronic phase post-stroke. To be effective, the intervention must also include both types of perturbations, namely slips and trips. Such intervention in clinical settings may contribute to more improvement of dynamic balance and reduced falls rate in this population. We used an instrumented split-belt treadmill to reproduce conditions like slip and trip. However, this instrument is very expensive and not available in clinical settings. Recently, Dusane and Bhatt (2021) used an ordinary treadmill to apply unpredictable slip perturbation during gait training in individuals at the chronic phase post-stroke. Thus, it is possible to add this kind of intervention to the rehabilitation process of individuals post- stroke.

Chapter 7 Conclusion

Previous studies reported that unpredictable perturbations during gait training was a promising intervention for the improvement of dynamic balance in different populations. However, a limited number of studies addressed the effects of unpredictable gait perturbations on dynamic balance during gait in individuals at the chronic phase post-stroke. In the randomized controlled trial study presented in this thesis, the intensity and number of repetitions of the unpredictable task-specific perturbations were increased progressively according to the tolerance of the participants. Compared to previous studies, we isolated the effect of intense and unpredictable perturbations during gait. The intervention improved dynamic balance and gait abilities in persons with stroke at the chronic phase. The significant improvement of scores of the reactive postural control and dynamic gait subsystems of the MiniBESTest support the contribution of unpredictable perturbation during gait training to the improvement of both feedback and feedforward mechanisms of control of dynamic balance. Gait speed which is related to dynamic balance improved only in the experimental group (from .9 m/s to 1.05 m/s). In the second study, the participants in the stroke-fast group walked at the overground speed ≥ 1 m/s which is reported as a threshold for functional mobility in the community. The values of some of the biomechanical determinants of the dynamic balance of the stroke-fast group were close to the values of healthy participants. We suggest that the improvement in gait speed due to the unpredictable gait perturbation training could play a role in the normalization of the XCOM as one of the biomechanical determinants of dynamic balance, particularly at midstance time points. Due to the importance of improvement

of dynamic balance and gait abilities in the rehabilitation of individuals with hemiparesis post-stroke, further research on the impact of unpredictable perturbations during gait training is necessary.

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Appendices

Appendix I Questionnaires for the clinical trial

CAHIER D'ÉVALUATION CLINIQUE (PRE-

Sujet _____ Projet : CD_PH_15E Date _____ Initiales _____

Section A : Pré-éligibilité du participant

Section B : Informations générales

Section C : Histoire de santé

Section D : Évaluation de la peur de chuter

Section E : Tonus musculaire

Section F : Échelle de confiance en l'équilibre (ABC scale)

Section G : Test de marche naturelle et rapide sur 10 mètres

Section H : Coordination

SECTION I: Questionnaire De Réintégration à La Vie Normale

SECTION J : Évaluation De La Force (BIODEX)

SECTION K: Évaluation De La Balance Dynamique (Mini-BESTest)

SECTION L: Short Feedback Questionnaire »- modifié pour perturbations (SFQ-Mp)

Sujet _____ Projet : CD_PH_15E Date _____ Initiales _____

SECTION A : PRÉ-ÉLIGIBILITÉ DU SUJET

CRITÈRES D'INCLUSION	Oui	Non
1.1 Âge : 18-70 ans		
1.2 Premier AVC unilatéral depuis plus de 6 mois		
1.3 Être autonome à la marche sans aide technique sur de courtes distances		
1.4 Tolérer 2 à 3 heures d'activités avec repos		
1.5 Marcher à une vitesse naturelle inférieure ou égale à 1 m/s		

CRITÈRES D'EXCLUSION	Oui	Non
2.1 ATCD de pathologie générale affectant l'équilibre ou les capacités physiques		
2.3 Risque d'ostéoporose ou ostéoporose avérée		
2.4 Valeur au miniBESTest inférieure aux normes		
2.6 Difficulté de compréhension (aphasie grave)		
2.7 Dépression majeure (cote > 10 au GDS-15 items)		
2.8 Déficit cognitif important (score < 24/30 au Folstein Mini-Mental)		
2.9 Déficit sensoriel important aux pieds (incapable de détecter un monofilament de 5.18 ou < et/ou vibration de 128 Hz pour 5 sec.)		
2.10 Douleur générale importante (>2 cm sur échelle visuelle analogue de 10 cm)		
2.11 Présence d'héminégligence (test des cloches) et de l'héminégligence		
2.12 Problème cardio-pulmonaire non contrôlé		
2.13 Atteinte cérébelleuse		
2.14 Autres problèmes de santé importants non reliés à l'AVC		
3. ÉLIGIBILITÉ DU SUJET	Oui	Non
Pour être éligible, les réponses aux questions de la section 1 doivent être <i>OUI</i> et celles de la section 2 doivent être <i>NON</i>		
SECTION B : INFORMATIONS GÉNÉRALES		
1. DONNÉES SOCIO-DÉMOGRAPHIQUES		
1.1 Sexe	<input type="checkbox"/> Féminin	<input type="checkbox"/> Masculin
1.2 Langue usuelle	<input type="checkbox"/> Français	<input type="checkbox"/> Anglais
1.3 Date de naissance (jj/mm/aa)		
1.4 État civil	<input type="checkbox"/> célibataire <input type="checkbox"/> marié(e) ou conjoint de fait <input type="checkbox"/> divorcé(e) <input type="checkbox"/> veuf (ve)	

1.5 Occupation	<input type="checkbox"/> travail extérieur <input type="checkbox"/> études <input type="checkbox"/> bénévolat <input type="checkbox"/> retraite <input type="checkbox"/> aucune activité
Si vous travaillez, que faites-vous?	
1.6 Vivez-vous seul?	<input type="checkbox"/> Oui <input type="checkbox"/> Non
Si non avec qui?	
Personne à contacter en cas d'urgence?	
Téléphone :	
1.7 Activités : parmi les activités suivantes lesquelles pratiquez-vous de façon régulière ?	<input type="checkbox"/> activités ménagères <input type="checkbox"/> bénévolat <input type="checkbox"/> loisirs <input type="checkbox"/> sports <input type="checkbox"/> aucune activité
1.8 Description des activités de loisir	
1. Sur une échelle de 1 à 10, comment évaluez-vous votre niveau d'activité physique ? (1 = pas d'activités et 10 = très actif) 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5 <input type="checkbox"/> 6 <input type="checkbox"/> 7 <input type="checkbox"/> 8 <input type="checkbox"/> 9 <input type="checkbox"/> 10 <input type="checkbox"/>	
2. Dans une semaine typique, combien de fois par semaine faites-vous de l'activité physique ? jamais <input type="checkbox"/> 1 - 2 x <input type="checkbox"/> 3 - 4 x <input type="checkbox"/> 5 - 7x <input type="checkbox"/>	
3. Dans une semaine typique, combien d'heures consaciez-vous en moyenne a ces activités ? <input type="checkbox"/> 1-2 heures <input type="checkbox"/> 3-5 heures <input type="checkbox"/> 6-8 heures <input type="checkbox"/> 9-13 heures <input type="checkbox"/> > 14 heures	
4. Quelles sont ces activités ? _____	
SECTION C : HISTOIRE DE SANTÉ	
1. HISTOIRE DE LA MALADIE ACTUELLE	
1.1 Date de l'AVC (jj/mm/aa)	
1.2 Côté de l'hémiplégie	<input type="checkbox"/> Droit <input type="checkbox"/> Gauche
1.3 Avez-vous subi une opération pour ce problème?	<input type="checkbox"/> Oui <input type="checkbox"/> Non
1.4 Région de l'atteinte (artères)	<input type="checkbox"/> cérébrale antérieure <input type="checkbox"/> cérébrale postérieure <input type="checkbox"/> cérébrale moyenne <input type="checkbox"/> vertébro-basilaire <input type="checkbox"/> communicante ant <input type="checkbox"/> communicante post <input type="checkbox"/> autre, spécifiez

1.5 Examen qui confirme l'atteinte	<input type="checkbox"/> ultrason (Doppler) <input type="checkbox"/> CT-Scan <input type="checkbox"/> IRM <input type="checkbox"/> angiographie <input type="checkbox"/> EEG <input type="checkbox"/> autre, spécifier	
1.6 Médicaments (combien et lesquels?)	<input type="checkbox"/> Oui, précisez : <input type="checkbox"/> Non	
1.7 Avez-vous eu des traitements pour votre AVC?	<input type="checkbox"/> Oui <input type="checkbox"/> Non	
Si oui, où et lesquels?		
1.8 Avez-vous des traitements présentement?	<input type="checkbox"/> Oui, précisez : <input type="checkbox"/> Non	
1.9 Actuellement, utilisez-vous une orthèse?	<input type="checkbox"/> Aucune, spécifiez depuis quand (jj/mm/aa/) : ____ / ____ <input type="checkbox"/> Oui, quel type?	
1.10 Actuellement, utilisez-vous une aide technique?	<input type="checkbox"/> Aucune, spécifiez depuis quand (jj/mm/aa/) : ____ / ____ <input type="checkbox"/> Oui, quel type?	
2. CONDITION DE SANTÉ GÉNÉRALE		
2.1 Avez-vous une ou plusieurs des conditions suivantes ?		
Problème cardiaque	<input type="checkbox"/> Oui	<input type="checkbox"/> Non
Problème pulmonaire	<input type="checkbox"/> Oui	<input type="checkbox"/> Non
Hypertension artérielle	<input type="checkbox"/> Oui	<input type="checkbox"/> Non
Problème rénal	<input type="checkbox"/> Oui	<input type="checkbox"/> Non
Problème musculo-squelettique	<input type="checkbox"/> Oui	<input type="checkbox"/> Non
Cancer	<input type="checkbox"/> Oui	<input type="checkbox"/> Non
Problème de vision	<input type="checkbox"/> Oui	<input type="checkbox"/> Non
Diabète	<input type="checkbox"/> Oui	<input type="checkbox"/> Non
Autre	<input type="checkbox"/> Oui	<input type="checkbox"/> Non
	<input type="checkbox"/> Oui, précisez	<input type="checkbox"/> Non

2.2 Avez-vous déjà été hospitalisé(e) pour une autre raison que votre AVC?	<input type="checkbox"/> Oui, précisez	<input type="checkbox"/> Non
2.3 Avez-vous d'autres informations sur votre santé dont nous devons être au courant?	<input type="checkbox"/> Oui , précisez	<input type="checkbox"/> Non
2.4 Quelle est votre jambe dominante ?	<input type="checkbox"/> droitier(ère) <input type="checkbox"/> gaucher(ère)	
2. OSTEOPOROSE		
2.1. Avez vous de l'ostéoporose ?	OUI	NON
2.2. Avez-vous déjà eu une ou plusieurs des conditions suivantes ?		
- découverte ou confirmation radiologique d'une fracture vertébrale	OUI	NON
- fracture survenue sans traumatisme majeur (excepté crâne, orteils, doigts et rachis cervical)	OUI	NON
- prenez vous des corticoïdes (prise orale ou injection) pour une durée > trois mois consécutifs,(dose >7,5 mg/jour d'équivalent prednisone) ?	OUI	NON
- hyperthyroïdie évolutive non traitée, hypercorticisme, hyperparathyroïdie primitive,ostéogenèse imparfaite	OUI	NON
- déficit en hormones sexuelles (dont ablation testiculaire)	OUI	NON
2.3. Chez la femme ménopausée uniquement		
- histoire de fracture du col fémoral sans traumatisme majeur chez un parent au premier degré	OUI	NON
- indice de masse corporelle < 19 kg/m ²	OUI	NON
- ménopause avant 40 ans, quelle qu'en soit la cause	OUI	NON

<p>- avez-vous déjà pris des corticoïdes (prise orale ou injection) pendant au moins 3 mois consécutifs, à une dose \geq 7,5 mg/jour d'équivalent prednisone ?</p>	OUI	NON
---	-----	-----

Si une seule des réponses est OUI, le patient n'est pas éligible à l'étude.

SECTION D : PEUR DE CHUTER	
1. Avez-vous peur de chuter ? Si oui, à quelle fréquence	<input type="checkbox"/> presque jamais <input type="checkbox"/> parfois <input type="checkbox"/> souvent <input type="checkbox"/> très souvent <input type="checkbox"/> constamment
1.2 Avez-vous chuté durant les douze mois passés ? Si oui, combien de fois et dans quelle(s) situation(s) ?	<input type="checkbox"/> presque jamais <input type="checkbox"/> parfois <input type="checkbox"/> souvent <input type="checkbox"/> très souvent <input type="checkbox"/> constamment
2. Évitez-vous certaines activités à cause de cette peur ?	<input type="checkbox"/> Oui <input type="checkbox"/> Non, jamais
2.1 Si oui, à quelle fréquence ?	<input type="checkbox"/> presque jamais <input type="checkbox"/> parfois <input type="checkbox"/> souvent <input type="checkbox"/> très souvent <input type="checkbox"/> constamment
2.2 Par exemple, quelles activités ?	
SECTION E : TONUS MUSCULAIRE (Levin & Hui Chan Scale)	
1. Membre inférieur parétique	

1.1 Test d'Ashworth	Hanche	Genou	Cheville	Ashworth standard Cheville
Position d'évaluation :				
<input type="checkbox"/> couchée	<input type="checkbox"/> 0	<input type="checkbox"/> 0	<input type="checkbox"/> 0	aucune résistance
<input type="checkbox"/> assise	<input type="checkbox"/> 2	<input type="checkbox"/> 2	<input type="checkbox"/> 2	résistance normale
	<input type="checkbox"/> 4	<input type="checkbox"/> 4	<input type="checkbox"/> 4	légèrement augmentée
	<input type="checkbox"/> 6	<input type="checkbox"/> 6	<input type="checkbox"/> 6	modérément augmentée
	<input type="checkbox"/> 8	<input type="checkbox"/> 8	<input type="checkbox"/> 8	résistance maximale

Cotation standard de l'échelle d'Ashworth :

0 : Tonus normal.

1 : Légère augmentation du tonus musculaire qui se manifeste par un ressaut ou une résistance minime en fin d'amplitude lorsque le segment est mobilisé en flexion ou en extension, en abduction ou en adduction.

2 : Augmentation plus nette du tonus musculaire sur une amplitude plus importante. Néanmoins, le segment peut être mobilisé facilement.

3 : Augmentation considérable du tonus musculaire. La mobilisation passive du membre est difficile.

4 : Le membre est fixé en flexion ou en extension, en abduction ou en adduction. Clonus. Limitation articulaire.

1.2 Réflexe tendineux	Genou	Cheville	
Position d'évaluation :			
<input type="checkbox"/> couchée	<input type="checkbox"/> 0	<input type="checkbox"/> 0	0 = aucune réponse
<input type="checkbox"/> assise	<input type="checkbox"/> 1	<input type="checkbox"/> 1	1 = réponse normale
	<input type="checkbox"/> 2	<input type="checkbox"/> 2	2 = légèrement hyperactif
	<input type="checkbox"/> 3	<input type="checkbox"/> 3	3 = modérément hyperactif
	<input type="checkbox"/> 4	<input type="checkbox"/> 4	4 = hyperactivité maximale

1.3 Clonus de la cheville parétique	<input type="checkbox"/> 1	1 = pas élicité
Position d'évaluation :	<input type="checkbox"/> 2	2 = 1 - 3 battements
<input type="checkbox"/> couchée	<input type="checkbox"/> 3	3 = 3 - 10 battements
<input type="checkbox"/> assise	<input type="checkbox"/> 4	4 = clonus continu

Score total hanche : _____ genou : _____ cheville : _____

SECTION F : CONFIANCE EN L'ÉQUILIBRE (Échelle ABC)

0% 10 20 30 40 50 60 70 80 90 100%

Pas

Pleinement

confiant(e)

confiant(e)

Jusqu'à quel point êtes-vous confiant que vous pourrez garder votre équilibre lorsque :

1. vous marchez dans la maison ? ____ %
2. vous montez ou descendez les escaliers ? ____ %
3. vous vous penchez pour ramasser une pantoufle sur le plancher, à l'entrée d'un placard? ____ %
4. vous vous étirez pour prendre une petite boîte de conserve sur une étagère à hauteur des yeux ? ____ %
5. vous vous tenez sur la pointe des pieds pour aller chercher quelque chose au-dessus de votre tête? ____ %
6. vous êtes monté(e) sur une chaise pour aller chercher quelque chose ? ____ %
7. vous balayez le plancher ? ____ %
8. vous sortez de la maison pour aller vers une auto stationnée dans l'entrée ? ____ %
9. vous montez ou descendez de l'auto ? ____ %
10. vous traversez un terrain de stationnement pour vous rendre au centre d'achat ?
____ %

11. vous montez ou descendez un plan incliné ? ____ %
12. vous marchez dans un centre d'achat bondé de gens pressés ? ____ %
13. vous êtes bousculé(e) par des gens en marchant dans le centre d'achat ? ____ %
14. vous montez ou descendez d'un escalier roulant en tenant la rampe ? ____ %
15. vous montez ou descendez d'un escalier roulant sans pouvoir tenir la rampe parce que vous avez les bras chargés de paquets ? ____ %
16. vous marchez sur un trottoir glacé ? ____ %

Cotation : ____ % / 16 = ____

SECTION G : TEST DE MARCHE À VITESSE NATURELLE ET MAXIMALE SUR 10 MÈTRES sur Gaitrite			
1. Temps pour marcher 10 mètres à vitesse naturelle	# 1.	.	sec.
Aide ambulatoire <input type="checkbox"/> aucune <input type="checkbox"/> canne <input type="checkbox"/> marchette	# 2.	.	sec.
2. Temps pour marcher 10 mètres à vitesse maximale	# 1.	.	sec.
Aide ambulatoire <input type="checkbox"/> aucune <input type="checkbox"/> canne <input type="checkbox"/> marchette	# 2.	.	sec.
3. Vitesse naturelle moyenne sur 10 mètres (m/s)	.		m/s
4. Vitesse maximale moyenne sur 10 mètres (m/s)	.		m/s
SECTION H : COORDINATION (LEMOCOT)			

Directives

Côté dominant suivi du côté non-dominant

- Vous devez toucher à ces 2 cibles, l'une après l'autre, comme ceci pendant 20secondes. Vous devez être le plus précis possible tout en allant aussi vite que vous le pouvez
- Pratiquez-vous pendant quelques secondes
- Vous êtes prêt. À mon signal. Allez-y!

1. Membre inférieur

Nombre de fois que le gros orteil touche la cible en 20 sec.	Gauche #1 _____ #2 _____	Droite #1 _____ #2 _____
--	---------------------------------------	---------------------------------------

Dysmétrie	Gauche <input type="checkbox"/> 0 <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3	Droite <input type="checkbox"/> 0 <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3
------------------	--	--

0 : dysmétrie très marquée, le sujet n'atteint jamais la cible

1 : dysmétrie modérée, le sujet atteint la cible la moitié du temps

2 : dysmétrie légère, le sujet atteint la cible plus que les trois quart du temps
3 : aucune dysmétrie, le mouvement va d'une cible à l'autre sans sortir de sa trajectoire

Tremblements	Gauche <input type="checkbox"/> 0 <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3	Droite <input type="checkbox"/> 0 <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3
---------------------	--	--

0 : tremblement très marqué, rendant le mouvement presque impossible

1 : tremblement modéré, affectant la qualité de la trajectoire à suivre

2 : tremblement léger, affectant peu la qualité du mouvement

3 : aucun tremblement, le mouvement va d'une cible à l'autre sans tremblement.

SECTION I: QUESTIONNAIRE DE RÉINTÉGRATION À LA VIE NORMALE

	Oui	Partiellement	Non	N/A
1. Je me déplace autant que je le veux dans mon logement	0	1	2	--
2. Je me déplace autant que je le veux dans mon entourage(magasins, banque, etc.)	0	1	2	--
3. Je suis apte à voyager à l'extérieur de la ville autant que je le désire	0	1	2	--
4. Je suis satisfait(e) de la façon dont mes soins personnels sont accomplis (m'habiller, me laver, me nourrir)	0	1	2	--

5. La plupart de mes journées sont consacrées à une activité qui m'est nécessaire ou importante (du ménage, du bénévolat, des études, un emploi)	0	1	2	--
6. Je participe aux activités récréatives selon mon désir (passer temps, sports, artisanat, lectures, télévision, jeux, ordinateur, etc.)	0	1	2	--
7. Je participe aux activités sociales autant que je le veux (avec la famille, des amis ou des relations/amis de travail)	0	1	2	--
8. Dans le milieu familial, je maintiens un rôle qui répond à mes besoins et les besoins des membres de ma famille (« famille » se rapporte aux gens avec qui vous vivez ou n'habitez pas mais que vous voyez de façon régulière)	0	1	2	--
9. En général, je me sens à l'aise dans mes relations personnelles	0	1	2	--
10. En général, je me sens à mon aise quand je suis en compagnie des autres	0	1	2	--
11. Je sens que je peux faire face aux épreuves de la vie quand elles se déclarent	0	1	2	--

SECTION J : ÉVALUATION DE LA FORCE (BIODEX)

Rate of Torque Development (RTD) and maximal strength in knee flexion and extension bilaterally.

SECTION K: ÉVALUATION DE LA Balance Dynamique (Mini-BESTest)			
Age	50-59	60-69	
Mini-Bestest Normative score mean(SD)	26.3(1.1)	24.7(2.2)	

1. Sit to stand

(2) Normal: Stable for 3 s with maximum height .

(1) Moderate: Comes to stand WITH use of hands on first attempt.

(0) Severe: Impossible to stand up from chair without assistance, OR several attempts with use of hands.

2. RISE TO TOES

(2) Normal: Stable for 3 s with maximum height.

(1) Moderate: Heels up, but not full range (smaller than when holding hands), OR noticeable instability for 3 s.

(0) Severe: ≤3 s.

3. STAND ON ONE LEG

Left Time in Seconds Trial 1: _____ Trial 2: _____

(2) Normal: 20 s.

(1) Moderate: < 20 s.

(0) Severe: Unable.

Right Time in Seconds. Trial 1: _____ Trial 2: _____

(2) Normal: 20 s.

(1) Moderate: < 20 s.

(0) Severe: Unable.

To score each side separately use the trial with the longest time.

To calculate the sub-score and total score use the side [left or right] with the lowest numerical score[i.e. the worse side].

4. Compensatory stepping correction – forward

(2) Normal: Recovers independently a single, large step (second realignment step is allowed)

(1) Moderate: More than one step used to recover equilibrium.

(0) Severe: No step, OR would fall if not caught, OR falls spontaneously.

5. Compensatory stepping correction – backward

(2) Normal: Recovers independently a single, large step.

(1) Moderate: More than one step used to recover equilibrium.

(0) Severe: No step, OR would fall if not caught, OR falls spontaneously.

6. Compensatory stepping correction – lateral

Left

(2) Normal: Recovers independently with 1 step (crossover or lateral OK).

(1) Moderate: Several steps to recovers equilibrium.

(0) Severe: Falls, or cannot step.

Right

(2) Normal: Recovers independently with 1 step (crossover or lateral OK).

(1) Moderate: Several steps to recovers equilibrium.

(0) Severe: Falls, or cannot step.

Use the side with the lowest score to calculate sub-score and total score.

7. Stance Eyes open, firm surface (Feet together)

Time in seconds: _____

(2) Normal: 30 s.

(1) Moderate: < 30 s.

(0) Severe: Unable.

8. Stance Eyes closed, foam surface (feet together)

Time in seconds: _____

(2) Normal: 30 s.

(1) Moderate: <30 s.

(0) Severe: Unable.

9. Incline – eyes closed

Time in seconds: _____

(2) Normal: Stands independently 30 s and aligns with gravity.

(1) Moderate: Stands independently <30 s, OR aligns with surface.

(0) Severe: Unable.

10. Change In gait Speed

(2) Normal: Significantly changes walking speed without imbalance.

(1) Moderate: Unable to change walking speed or imbalance.

(0) Severe: Unable to achieve significant change in speed AND signs of imbalance.

11. Walk With Head Turns – Horizontal

(2) Normal: performs head turns with no change in gait speed and good balance.

(1) Moderate: performs head turns with reduction in gait speed.

(0) Severe: performs head turns with imbalance.

12. Walk With Pivot Turns

(2) Normal: Turns with feet close, FAST (≤ 3 steps) with good balance.

(1) Moderate: Turns with feet close SLOW (≥ 4 steps) with good balance.

(0) Severe: Cannot turn with feet close at any speed without imbalance.

13. Step over obstacles

(2) Normal: Able to step over box with minimal change of speed and with goodbalance.

(1) Moderate: Steps over shoe boxes but touches box, OR displays cautious behaviour by slowing gait.

(0) Severe: Cannot step over shoe boxes, OR hesitates, OR steps around box.

14. Timed get Up & Go (tug) and cognitive get up & go with Dual Task:

TUG: _____ seconds; Dual Task TUG: _____ seconds

(2) Normal: No noticeable change between sitting and standing in backward counting and no change in gait speed compared with TUG with dual task.

(1) Moderate: Dual task affects either counting OR walking.

(0) Severe: Stops counting while walking OR stops walking while counting.

When scoring item 14, if subject's gait speed slows more than 10% between the TUG without and with a Dual Task the score should be decreased by a point.

CAHIER D'ÉVALUATION CLINIQUE (Profil)

Sujet _____ Projet : CD_PH_15E Date _____ Initiales _____

Section A : Évaluation de la douleur Section B :

Mini-Mental State Examination

Section C : Tests pour l'héminégligence et l'hémianopsie Section D :

Échelle gériatrique de la dépression

Section E : Tests de sensibilité

Section F : Chedoke-McMaster Stroke

Assessment Section G : Amplitudes articulaires

SECTION A : DOULEUR

1. Douleur au membre inférieur

1.1 Au repos (mm)

aucune
douleur

douleur
extrême

1.2 À l'activité (mm)	
aucune douleur	douleur extrême
1.3 Type, durée et localisation	

SECTION B : MINI-MENTAL STATE EXAMINATION (MMSE)

J'aimerais maintenant vous poser quelques questions pour vérifier votre mémoire, votre attention et votre concentration. Certaines d'entre elles vont voussembler faciles, d'autres plus difficiles.

TEST	0	1
1. En quelle année sommes-nous ?		
2. Quelle est la saison ?		
3. Quelle est la date ?		
4. Quel jour de la semaine sommes-nous ?		
5. Quel est le mois ?		
6. Pouvez-vous me dire dans quel pays nous sommes ?		
7. Dans quelle province sommes-nous ?		
8. Dans quelle ville (ou village) sommes-nous ?		
9. Quel est le nom de la rue ou l'adresse de l'endroit où nous sommes ?		
10. À quel étage sommes-nous ?		

Enregistrement :

Je vais vous dire trois mots dont vous devez vous rappeler. Répétez-les quandj'aurai fini de les dire tous les trois.

11. Chemise

12. Bleu

13. Honnêteté

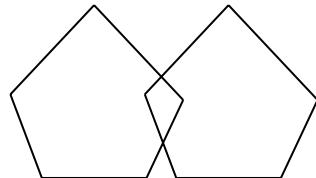
Quels sont les trois mots que je viens de dire ?

(Donner 1 point pour chaque réponse correcte au premier essai. Nommer les mots jusqu'à quatre fois pour que le sujet les sache.)

TEST	0	1	2	3	4	5										
14. Veuillez maintenant épeler le mot « MONDE » à l'endroit. Maintenant épelez-le à l'envers, en commençant par la dernière lettre. <i>(Si le répondant est incapable d'épeler le mot « MONDE » à l'endroit, épelez-le une fois avec un intervalle de temps de 1,5 seconde entre chaque lettre.)</i>	<input type="radio"/>															
<table border="1" style="margin-left: auto; margin-right: auto;"> <tr><td>E</td><td></td></tr> <tr><td>D</td><td></td></tr> <tr><td>N</td><td></td></tr> <tr><td>O</td><td></td></tr> <tr><td>M</td><td></td></tr> </table> <i>(Nombre de lettres données dans le bon ordre.)</i>	E		D		N		O		M		<input type="radio"/>					
E																
D																
N																
O																
M																
Quels sont les trois mots que je vous ai demandé de mémoriser un peu plus tôt ? 15. Chemise 16. Bleu 17. Honnêteté <i>(Donner 1 point pour chaque réponse.)</i>	<input type="radio"/>	<input type="radio"/>														
18. <i>(Présenter une montre.)</i> Comment cet objet s'appelle-t-il ?	<input type="radio"/>	<input type="radio"/>														
19. <i>(Présenter un crayon.)</i> Comment cet objet s'appelle-t-il ?	<input type="radio"/>	<input type="radio"/>														
20. <i>J'aimerais que vous répétiez une phrase après moi.</i> <i>« Pas de si ni de mais »</i> <i>(Ne permettre qu'un seul essai.)</i>	<input type="radio"/>	<input type="radio"/>														
21. Montrer « Fermez les yeux » et dites « S'il vous plaît, faites ceci » <i>(Donner 1 point si la personne ferme les yeux.)</i>	<input type="radio"/>	<input type="radio"/>														

TEST	0	1	2	3	4	5
22. Je vais vous donner une feuille de papier. Prenez-la de la main gauche (ou main non dominante), pliez-la en deux et mettez-la sur vos genoux. <i>(Lire toutes les instructions, puis tendre la feuille de papier. Ne pas répéter les instructions ou guider la personne. Donner 1 point par étape correcte.)</i>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
a)main non dominante b) plier la feuille c) sur les genoux	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
23. J'aimerais que vous écriviez une phrase complète sur cette feuille de papier. <i>(Ne pas dicter la phrase. La personne doit écrire la phrase spontanément. Elle doit contenir un sujet, un verbe et doit avoir un sens. La grammaire, la ponctuation ou l'orthographe ne comptent pas.)</i>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
24. Voici un dessin. Je veux que vous copiez ce dessin sur la même feuille. <i>(Donner 1 point si les figures à cinq côtés s'intersectent pour former une figure à quatre côtés et si tous les angles sont conservés. Les tremblements ou rotations ne comptent pas.)</i>	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
ADDITIONNER LES POINTS	30					

Commentaires (exemples : distractions survenues lors de la passation du test et questions associées, items qui n'ont pu être faits et la cause...) :



Note : Si le résultat est inférieur à 24, le sujet est non admissible

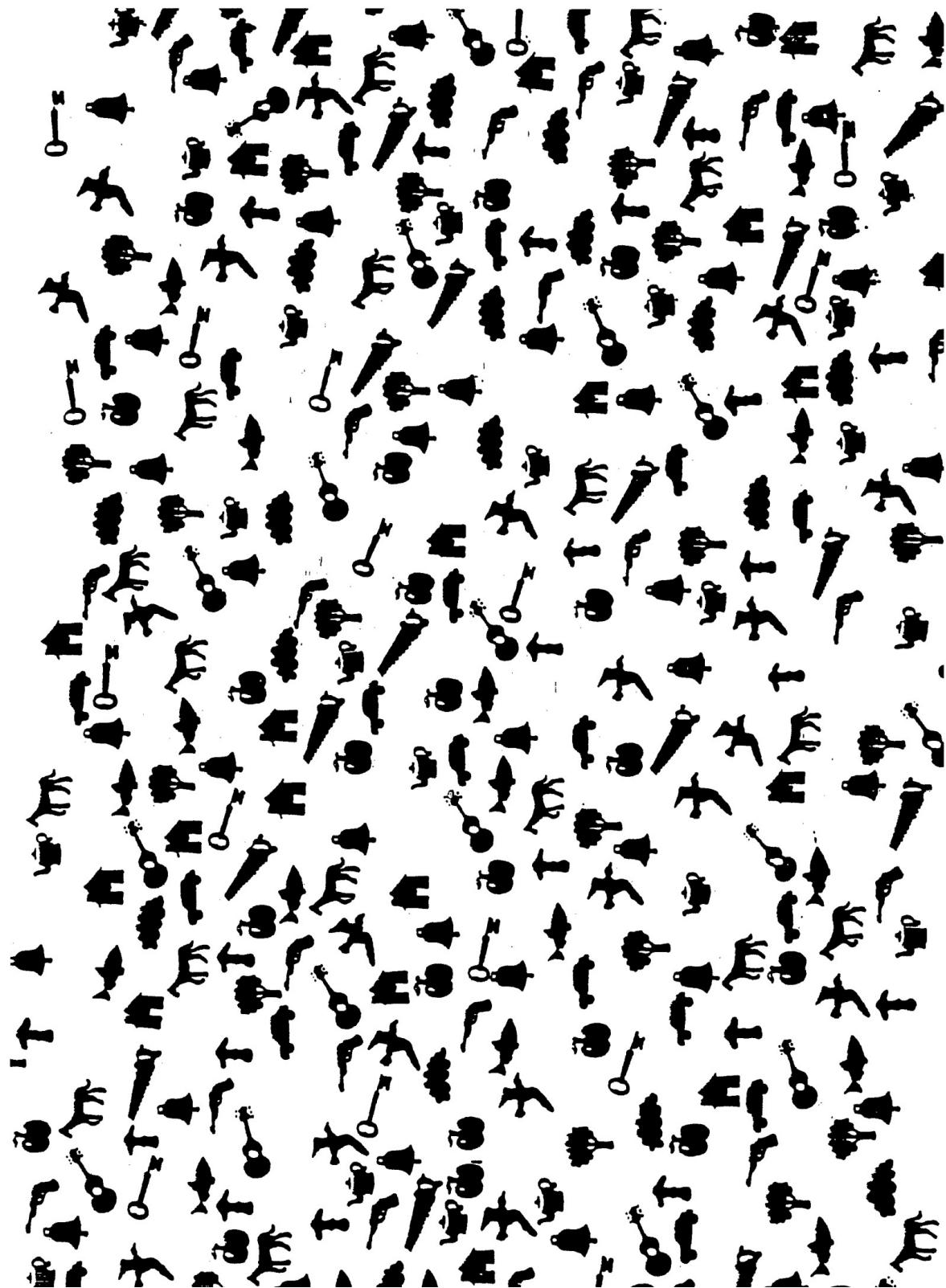
SECTION C : TESTS POUR L'HÉMINÉGLIGENCE et L'HÉMIANOPSIE**1. Test de barrage des cloches (héminégligence)****1.1 Temps final où le sujet croit avoir entouré toutes les cloches.**

_____ sec

1.2 La colonne de la première cloche entourée**1.3 Les omissions totales (gauches, droites et centrales)****1.4 La différence des omissions gauches et droites(OG-OD)****1.5 Les erreurs de sélection totales (faux positifs)****1.6 La différence des erreurs gauches et droites(EG-ED)**

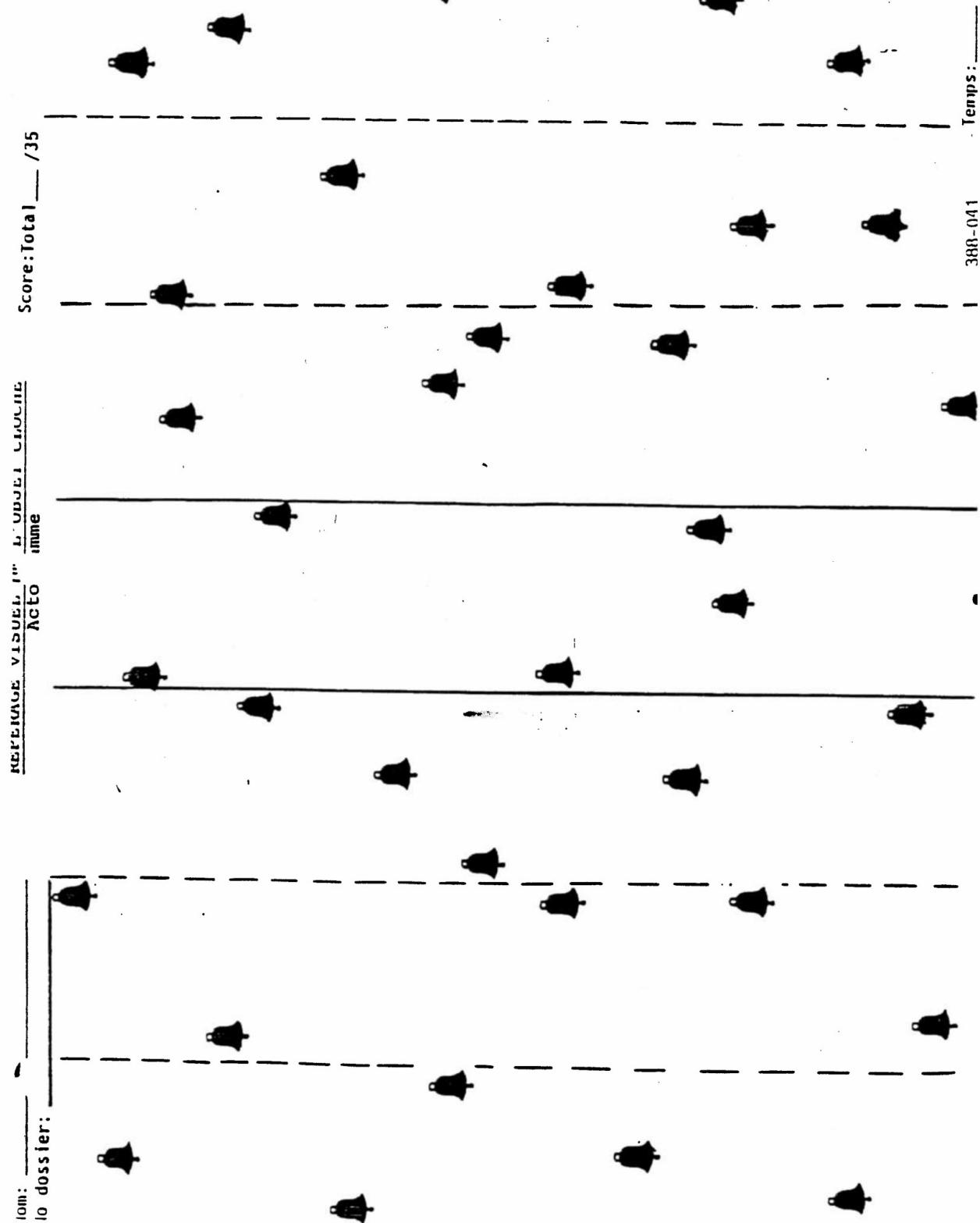
Note : une omission totale de plus de 6 cloches ou un temps de passation de plus de 6 minutes indiquent des troubles diffus de l'attention et une différence d'omission gauche- droite > 6 cloches indique la présence d'une héminégligence selon les normes de Rousseau et al. (2001).

2. Test de l'objet en mouvement dans le champs visuel (hémianopsie)**2.1 Le sujet perçoit le crayon environ au même endroit dans ses champs visuels droit et gauche** **2.2 Le sujet perçoit le crayon plus tard dans son champ visuel gauche**



nom: _____
le dossier: _____

REFÉRENCE VISUELLE /
L'UNIVERS CROQUE
Score:Total _____ /35



380-041

Temps: _____

SECTION D : ÉCHELLE GÉRIATRIQUE DE LA DÉPRESSION

Choisissez la meilleure réponse décrivant comment vous vous sentiez la semaine passée

1. Êtes-vous fondamentalement satisfait-e de la vie que vous menez?	<input type="checkbox"/> Oui (0) <input type="checkbox"/> Non (1)
2. Avez-vous abandonné un grand nombre d'activités et d'intérêts?	<input type="checkbox"/> Oui (1) <input type="checkbox"/> Non (0)
3. Est-ce que vous sentez un vide dans votre vie?	<input type="checkbox"/> Oui (1) <input type="checkbox"/> Non (0)
4. Vous ennuyez-vous souvent?	<input type="checkbox"/> Oui (1) <input type="checkbox"/> Non (0)
5. Avez-vous, la plupart du temps, un bon moral?	<input type="checkbox"/> Oui (0) <input type="checkbox"/> Non (1)
6. Craignez-vous qu'il vous arrive quelque chose de grave?	<input type="checkbox"/> Oui (1) <input type="checkbox"/> Non (0)
7. Êtes-vous heureux/heureuse la plupart du temps?	<input type="checkbox"/> Oui (0) <input type="checkbox"/> Non (1)
8. Éprouvez-vous souvent un sentiment d'impuissance?	<input type="checkbox"/> Oui (1) <input type="checkbox"/> Non (0)
9. Préférez-vous rester chez vous au lieu de sortir pour faire de nouvelles activités?	<input type="checkbox"/> Oui (1) <input type="checkbox"/> Non (0)
10. Avez-vous l'impression d'avoir plus de problèmes de mémoire que la majorité des gens?	<input type="checkbox"/> Oui (1) <input type="checkbox"/> Non (0)
11. Pensez-vous qu'il est merveilleux de vivre à l'époque actuelle?	<input type="checkbox"/> Oui (0) <input type="checkbox"/> Non (1)
12. Vous sentez-vous plutôt inutile dans votre état actuel?	<input type="checkbox"/> Oui (1) <input type="checkbox"/> Non (0)
13. Vous sentez-vous plein-e d'énergie?	<input type="checkbox"/> Oui (0) <input type="checkbox"/> Non (1)
14. Avez-vous l'impression que votre situation est désespérée?	<input type="checkbox"/> Oui (1) <input type="checkbox"/> Non (0)
15. Pensez-vous que la plupart des gens vivent mieux que vous?	<input type="checkbox"/> Oui (1) <input type="checkbox"/> Non (0)

Résultats : Additionner les réponses inscrites dans la colonne de droite.

Total=____/15

Normal Légèrement dépressif	3 +/- 2 7 +/- 3 12 +/- 2
<i>Très dépressif</i>	

Référence de l'instrument : Sheikh, J.I., Yesavage, J.A. Geriatic Depression Scale : recent

evidence and development of a shorter version. Clin. Gerontol. 1968; 5 : 165-173.

Traduction française par : Bourque, Blanchard et Vézina (1990)

SECTION E : SENSIBILITÉ

1. Toucher léger : Sous la malléole externe

Procédure : débuter par le #2,

Si pas détecté, allez à #1

Si détecté, allez à #3 et suivre à #4.

G D

1. Filament # 6.65 _____/3 _____/3
2. Filament # 5.18 _____/3 _____/3
3. Filament # 4.31 _____/3 _____/3
4. Filament # 4.17 _____/3 _____/3

Résultats :

#1 : si pas détecté = anesthésie #2 :

Pied G : _____

si pas détecté = déficit sévère#3 : si

P / NP

pas détecté = hypoesthésie

Pied D : _____

#4 : si détecté = limite supérieur de la normale

P / NP

3. Sens de mouvement : chevilles et hallux

Demandez au participant si le membre bouge vers le haut ou vers le bas

G : P NP **D :** P NP

Chevilles (Flexion-extension)

_____ / 10

_____ / 10

Hallux (Flexion-extension)

_____ / 10

_____ / 10

4. Vibration

Diapason 128 Hz (au niveau de la malléole externe)

Temps de sensation de la vibration :

Cheville gauche : P / NP

#1. _____ sec. #2. _____ sec.

Temps moyen : _____ sec.

Cheville droite : P / NP

#1. _____ sec. #2. _____ sec.

Temps moyen : _____ sec.

SECTION F : CHEDOKE-MCMASTER STROKE ASSESSMENT pour le membre inférieur parétique

LEG			FOOT	
1		<input type="checkbox"/> not yet stage 2		<input type="checkbox"/> not yet stage 2
2	Crook lying	<input type="checkbox"/> Resistance to passive hip or knee flexion <input type="checkbox"/> Facilitated hip flexion <input type="checkbox"/> Facilitated extension	Crook lying	<input type="checkbox"/> Resistance to passive D-F <input type="checkbox"/> Facilitated D-F or toe extension <input type="checkbox"/> Facilitated plantarflexion
3		<input type="checkbox"/> <u>Abduction</u> : adduction to neutral <input type="checkbox"/> Hip flexion to 90° <input type="checkbox"/> Full extension	Supine Sit	<input type="checkbox"/> Plantarflexion > ½ range <input type="checkbox"/> Some dorsiflexion <input type="checkbox"/> Extension of toes
4	Supine Sit	<input type="checkbox"/> Hip flexion to 90°, then ext. synergy <input type="checkbox"/> Bridging hip with equal weightbearing <input type="checkbox"/> Knee flexion beyond 100°		<input type="checkbox"/> Some eversion <input type="checkbox"/> Inversion <input type="checkbox"/> <u>Leg crossed</u> ; D-F than P-flexion
5	Crook lying Sit Stand	<input type="checkbox"/> Ext. synergy, then flexion synergy <input type="checkbox"/> Raise thigh off bed <input type="checkbox"/> Hip extension with knee flexion	Stand	<input type="checkbox"/> <u>Leg crossed</u> : toe ext. with ankle P-F <input type="checkbox"/> <u>Sitting with knee extended</u> : ankle P-F, then D-F. <input type="checkbox"/> <u>Heel on floor</u> : eversion
6	Sit Stand	<input type="checkbox"/> Lift foot off floor 5 x 5 sec. <input type="checkbox"/> Full range internal rotation <input type="checkbox"/> Trace a pattern : forward, side, back, return		<input type="checkbox"/> <u>Heel on floor</u> : tap foot 5x in 5 sec <input type="checkbox"/> <u>Foot off floor</u> : circumduction quickly <input type="checkbox"/> <u>Heel straight, heel off floor</u> : eversion
7	Stand	<input type="checkbox"/> <u>Unsupported</u> : rapid high stepping 10x in 5 sec. <input type="checkbox"/> <u>Unsupported</u> : trace a pattern quickly : forward, side, back, return and reverse <input type="checkbox"/> <u>On weak leg with support</u> : hop on weak leg		<input type="checkbox"/> Heel touching forward, then toe touching behind repeat 5x in 10 sec <input type="checkbox"/> <u>Foot off floor</u> : circumduction quickly, reverse <input type="checkbox"/> Up on toes, then back on heels 5x
Stage of leg ____ / 7			Stage of foot ____ / 7	

SECTION G : AMPLITUDES ARTICULAIRES ACTIVES des membres inférieurs

Gauche <input type="checkbox"/> P / <input type="checkbox"/> NP	Hanche	Droit <input type="checkbox"/> P / <input type="checkbox"/> NP
	Flexion	
	Extension	
	Abduction	
	Adduction	
	Rotation interne	
	Rotation externe	
	Genou	
	Flexion	
	Extension	
	Cheville	
	Flexion dorsale	
	Flexion plantaire	
	Pronation	
	Supination	
	Orteils	

Appendix II Ethics Certification for the randomized controlled trial study

Comité d'éthique de la recherche
des établissements du CRIR



Montréal, le 15 décembre 2014

Monsieur Cyril Duclos, Ph.D.
CRIR- site de l'IRGLM
6300, avenue Darlington
Montréal (Québec) H3S 2J4

- Centre de réadaptation Constance-Lethbridge
- Centre de réadaptation Lucie-Brunneau
- Hôpital juif de réadaptation
- Institut de réadaptation Gingras-Lindsay-de-Montréal
- Institut Nazareth et Louis-Braille
- Institut Raymond-Dewar

- Partenaires
- Centre de réadaptation en déficience physique Le Bouclier
 - Centre de réadaptation Estrie
 - Centre de réadaptation MAB-Mackay

Objet : Émission de votre certificat d'éthique
Notre dossier : CRIR-998-0914

Monsieur,

Veuillez trouver, ci-joint, une copie du certificat d'éthique qui a été décerné pour votre projet de recherche intitulé « Des perturbations imprédictibles pendant la marche pour améliorer l'équilibre, la confiance et la participation de personnes hémiaparétiques chroniques : étude pilote ». Ce certificat, ainsi que les documents approuvés, sont également disponibles sur la plateforme de soumission des projets de recherche.

Accès : <http://ethique.crir.ca/acceschercheur/>

Ce certificat est valable pour un an. Le CÉR demande à être informé de toute modification qui pourrait être apportée au projet de recherche mentionné ci-dessus (Formulaire M à compléter via la plateforme).

De plus, nous vous demandons de contacter la personne suivante afin de l'aviser du début de votre projet de recherche :

- Institut de réadaptation Gingras-Lindsay-de-Montréal
Isabelle David
(514) 340-2085, poste 4618

Veuillez recevoir, Monsieur Duclos, mes cordiales salutations.

[REDACTED]

Me Anik Nolet
Coordonnatrice à l'éthique de la recherche
des établissements du CRIR
■ (514) 527-4527, poste 2649
■ anolet.crir@sss.s.gouv.qc.ca

AN/cl

Pièces jointes : certificat d'éthique et copie des documents approuvés

c.c. : Isabelle David, IRGLM

Comité désigné en vertu de l'article 21 du Code civil du Québec

2275, avenue Laurier Est
Montréal (Québec) H2H 2N8 Canada
T (514) 527-4527 (2643)
F (514) 521-4058
www.crir.ca

Certificat d'éthique

Par la présente, le comité d'éthique de la recherche des établissements du CRIR (CÉR) atteste qu'il a évalué, lors de sa réunion du 11 novembre 2014, le projet de recherche CRIR-998-0914 intitulé :

« Des perturbations imprédictibles pendant la marche pour améliorer l'équilibre, la confiance et la participation de personnes hémiparétiques chroniques : étude pilote ».

Présenté par: Cyril Duclos, Ph.D.

Le présent projet répond aux exigences éthiques de notre CÉR. Le Comité autorise donc sa mise en œuvre sur la foi des documents suivants :

- Lettre de présentation du projet au CÉR datée du 22 septembre 2014 ;
- Formulaire A;
- Formulaire d'évaluation du Centre de réadaptation Constance-Lethbridge, daté du 7 octobre 2014, mentionnant que le projet est acceptable sur le plan de la convenance institutionnelle ;
- Formulaire d'évaluation du Centre de réadaptation Lucie-Bruneau, daté du 24 octobre 2014, mentionnant que le projet est acceptable sur le plan de la convenance institutionnelle ;
- Formulaire d'évaluation de l'Institut de réadaptation Gingras-Lindsay de Montréal, daté du 3 octobre 2014, mentionnant que le projet est acceptable sur le plan de la convenance institutionnelle ;
- Preuve d'octroi d'une subvention de 20 000 \$ du Partenariat entre la Fondation Canadienne de Physiothérapie et le Réseau Provincial de Recherche en Adaptation Réadaptation du FRQ-S;
- Évaluation scientifique réalisée par l'organisme subventionnaire;
- Budget;
- Protocole de recherche;
- Formulaire de consentement rédigé en français (version du 15 décembre 2014);
- Affiche de recrutement rédigée en français (version du 15 décembre 2014).

Ce projet se déroulera dans le site du CRIR suivant :

- Institut de réadaptation Gingras-Lindsay.

Ce certificat est valable pour un an. En acceptant le présent certificat d'éthique, le chercheur s'engage à :

1. Informer, dès que possible, le CÉR de tout changement qui pourrait être apporté à la présente recherche ou aux documents qui en découlent (Formulaire M) ;

2. Notifier, dès que possible, le CÉR de tout incident ou accident lié à la procédure du projet ;
3. Notifier, dès que possible, le CÉR de tout nouveau renseignement susceptible d'affecter l'intégrité ou l'éthicité du projet de recherche, ou encore, d'influer sur la décision d'un sujet de recherche quant à sa participation au projet ;
4. Notifier, dès que possible, le CÉR de toute suspension ou annulation d'autorisation relative au projet qu'aura formulée un organisme de subvention ou de réglementation ;
5. Notifier, dès que possible, le CÉR de tout problème constaté par un tiers au cours d'une activité de surveillance ou de vérification, interne ou externe, qui est susceptible de remettre en question l'intégrité ou l'éthicité du projet ainsi que la décision du CÉR ;
6. Notifier, dès que possible, le CÉR de l'interruption prématuée, temporaire ou définitive du projet. Cette modification doit être accompagnée d'un rapport faisant état des motifs à la base de cette interruption et des répercussions sur celles-ci sur les sujets de recherche ;
7. Fournir annuellement au CÉR un rapport d'étape l'informant de l'avancement des travaux de recherche (formulaire R) ;
8. Demander le renouvellement annuel de son certificat d'éthique ;
9. Tenir et conserver, selon la procédure prévue dans la *Politique portant sur la conservation d'une liste des sujets de recherche*, incluse dans le cadre réglementaire des établissements du CRIR, une liste des personnes qui ont accepté de prendre part à la présente étude ;
10. Envoyer au CÉR une copie de son rapport de fin de projet / publication ;
11. En vertu de l'article 19.2 de la *Loi sur les services de santé et les services sociaux*, obtenir l'autorisation du Directeur des services professionnels de l'établissement sollicité avant d'aller consulter les dossiers des usagers de cet établissement, le cas échéant.



Me Michel T. Giroux
Président du CÉR

Date d'émission
15 décembre 2014

Composition du comité d'éthique de la recherche des établissements du CRIR

M. Simon Coulombe / M. Kenneth Southall (membre substitut)	Une personne possédant une vaste connaissance du domaine psychosocial en réadaptation
Dre Céline Lamarre / Mme Imen Khelia (membre substitut)	Une personne possédant une vaste connaissance du domaine biomédical en réadaptation
Mme Saïda El Haïli / Mme Isabelle Fournier (membre substitut)	Clinicien détenant une vaste connaissance des déficits sensoriel visuels ou auditifs
Mme Mariama Touré / M. Dany Gagnon (membre substitut)	Clinicienne détenant une vaste connaissance des déficits moteurs ou neurologiques
M. Yanick Farmer / Me Delphine Roigt (membre substitut)/ M. Frédéric Tremblay (membre substitut)	Une personne spécialisée en éthique
Me Michel T. Giroux / Me Nathalie Lecocq (membre substitut)	Une personne spécialisée en droit
Mme Monique Provost / Mme Marie-Claude Lavigne (membre substitut)	Une personne non affiliée à l'établissement et provenant de la clientèle des personnes adultes et aptes
Mme Diane L. Gaumond / Mme Dominique Labrèche (membre substitut)	Une personne non affiliée à l'établissement et provenant de la clientèle des personnes mineures ou inaptes
M. Michel Sinotte /	Une personne siégeant à titre de représentante du public
Mme Suzette McMaster Clément	Une personne siégeant à titre de représentante du public
Mme Frédérique Courtois	Représentante de l'Université du Québec à Montréal
M. Cyril Duclos	Représentant de l'Université de Montréal
Mme Jadranka Spahija	Représentante de l'Université McGill
Me Anik Nolet	Secrétaire du CÉR et membre non-votant

Certificat d'éthique (Renouvellement)

Aux fins de renouvellement, le Comité d'éthique de la recherche des établissements du CRIR, selon la procédure d'évaluation accélérée en vigueur, a examiné le projet de CRIR-998-0914 intitulé :

« Des perturbations imprédictibles pendant la marche pour améliorer l'équilibre, la confiance et la participation de personnes hémiparétiques chroniques : étude pilote ».

Présenté par: Cyril Duclos, Ph.D.

Le présent projet répond aux exigences éthiques de notre CÉR. Ce projet se déroule dans le site du CRIR suivant :

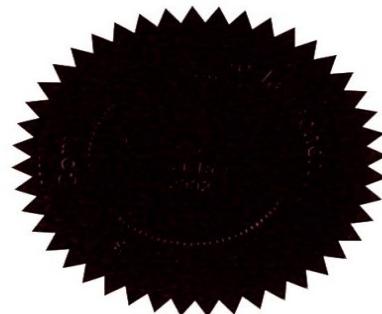
- Institut de réadaptation Gingras-Lindsay de Montréal du CIUSSS du Centre-Sud-de-l'Île-de-Montréal

Ce certificat est valable pour un an. En acceptant le présent certificat d'éthique, le chercheur s'engage à :

1. Informer, dès que possible, le CÉR de tout changement qui pourrait être apporté à la présente recherche ou aux documents qui en découlent (Formulaire M) ;
2. Notifier, dès que possible, le CÉR de tout incident ou accident lié à la procédure du projet ;
3. Notifier, dès que possible, le CÉR de tout nouveau renseignement susceptible d'affecter l'intégrité ou l'éthicité du projet de recherche, ou encore, d'influer sur la décision d'un sujet de recherche quant à sa participation au projet ;
4. Notifier, dès que possible, le CÉR de toute suspension ou annulation d'autorisation relative au projet qu'aura formulée un organisme de subvention ou de réglementation ;
5. Notifier, dès que possible, le CÉR de tout problème constaté par un tiers au cours d'une activité de surveillance ou de vérification, interne ou externe, qui est susceptible de remettre en question l'intégrité ou l'éthicité du projet ainsi que la décision du CÉR ;
6. Notifier, dès que possible, le CÉR de l'interruption prématuée, temporaire ou définitive du projet. Cette modification doit être accompagnée d'un rapport faisant état des motifs à la base de cette interruption et des répercussions sur celles-ci sur les sujets de recherche ;
7. Fournir annuellement au CÉR un rapport d'étape l'informant de l'avancement des travaux de recherche (formulaire R) ;

8. Demander le renouvellement annuel de son certificat d'éthique ;
9. Tenir et conserver, selon la procédure prévue dans la *Politique portant sur la conservation d'une liste des sujets de recherche*, incluse dans le cadre réglementaire des établissements du CRIR, une liste des personnes qui ont accepté de prendre part à la présente étude ;
10. Envoyer au CÉR une copie de son rapport de fin de projet / publication.

[REDACTED]
Me Michel T. Giroux
Président du CÉR



Date d'émission
15 décembre 2016

FORMULAIRE R

Titre: Des perturbations imprédictibles pendant la marche pour améliorer l'équilibre, la confiance et la participation de personnes hémiparétiques chroniques : étude pilote
Dossier: CRIR-998-0914
Chercheur principal: Cyril Duclos

INFORMATIONS GÉNÉRALES**État du projet**

- Projet en cours
- Projet terminé
- Projet qui n'a pas démarré
- Projet abandonné

Déroulement du projet (En quelques lignes, décrire à quelle étape est rendu le projet)

Le projet est actuellement en cours, avec 9 participants hémiparétiques recrutés et ayant terminé l'entraînement par perturbation, ainsi que la période de suivi de 6 semaines. Le recrutement est actuellement en pause pour les participants hémiparétiques, du fait des conditions climatiques, qui affecteraient les réponses

Dates

Date du début effectif du projet(jour/mois/année)

Date prévue de la fin du projet(jour/mois/année)

RECRUTEMENT

Nb. sujets approchés	Nb. sujets recrutés	Nom de l'établissement
0	0	CRCL
0	0	INLB
0	0	IRGLM
0	0	CRLB
0	0	IRD
0	0	HJR
0	0	CRDP Le Bouclier Lanaudière
0	0	CRDP Le Bouclier Laurentides
0	0	CR Estrie
0	0	CMR
0	0	Centre de réadaptation MAB-Mackay
0	0	IRDPQ
0	0	Villa médica (si le projet y est)
9	0	liste de participants à des étuc
0	0	

**APPROUVÉ PAR LE CÉR
DES ÉTABLISSEMENTS DU CRIR**

LE : 3 avril 2017

0
0

0
0

DÉTAILS

Nombre de sujets ayant retiré leur participation de l'étude

0

Motif de ce retrait

--

Réactions indésirables ou incidents survenus en cours d'année et description des moyens mis en place auprès des sujets pour y remédier

--

Autres informations jugées pertinentes

Aucune chute dans le harnais n'a eu lieu lors des entraînements ou des évaluations
--

Le comité d'éthique de la recherche des établissements du CRIR demande à ce que vous lui transmettiez une copie de toute publication découlant du présent projet.

Appendix III Consent form for individuals post-stroke in the randomized controlled trial

Des perturbations imprédictibles pendant la marche pour améliorer l'équilibre, la confiance et la participation de personnes hémiparétiques chroniques : étude pilote



Formulaire de consentement pour ma participation à un projet de recherche

TITRE DU PROJET

Des perturbations imprédictibles pendant la marche pour améliorer l'équilibre, la confiance et la participation de personnes hémiparétiques chroniques : étude pilote

(Unpredictable perturbations during gait to improve balance performance, confidence and participation in persons with hemiparesis at a chronic stage: a pilot study)

RESPONSABLE

Cyril Duclos, Ph.D. Professeur adjoint, École de réadaptation, Université de Montréal ; Chercheur, Centre de recherche interdisciplinaire en réadaptation (CRIR), Institut de réadaptation Gingras-Lindsay-de-Montréal (IRGLM)

CO-CERCHEURS et COLLABORATEURS

Laurent Bouyer, Ph.D. Professeur titulaire, Université Laval

Isabelle David, M.Sc. Clinicienne, IRGLM

Joseph-Omer Dyer, Ph.D. Professeur adjoint, Université de Montréal

Andréanne Juneau, M.Sc. Clinicienne, Rehabilitation Center Constance-Lethbridge

Dahlia Kairy, Ph.D. Professeur adjoint, Université de Montréal

Anouk Lamontagne, Ph.D. Professeur agrégée, McGill University

FINANCEMENT DU PROJET

Partenariat Fondation Canadienne de Physiothérapie – Réseau Provincial de Recherche en Adaptation Réadaptation du Fonds de Recherche Québec-Santé (FPC-REPAR/FRQS)

PREAMBULE

Nous vous demandons de participer à un projet de recherche qui porte sur l'évaluation de votre équilibre lors de perturbations à la marche, ainsi la possibilité d'améliorer votre équilibre à la marche en utilisant ces perturbations lors d'un entraînement. Avant d'accepter de participer à ce projet de recherche, veuillez prendre le temps de comprendre et de considérer attentivement les renseignements qui suivent.

Ce formulaire de consentement vous explique le but de cette étude, les procédures, les avantages, les risques et inconvénients, de même que les personnes avec qui communiquer au besoin. Le présent formulaire de consentement peut contenir des mots que vous ne comprenez pas. Nous vous invitons à poser toutes les questions que vous jugerez utiles au chercheur et aux autres membres du personnel affecté au projet de recherche et à leur demander de vous expliquer tout mot ou renseignement qui n'est pas clair.

OBJECTIF DU PROJET

Le présent projet vise à décrire les réactions posturales lors de perturbations de la marche chez des personnes ayant une hémiparésie suite à un accident vasculaire cérébral.

Le projet vise aussi à déterminer l'efficacité d'un programme d'entraînement utilisant de telles perturbations sur l'équilibre, la confiance et la participation aux activités de la communauté d'un sous-groupe de participants. Les modifications des réactions posturales suite à cet entraînement seront également évaluées.

NATURE DE VOTRE PARTICIPATION

Votre participation implique au minimum une séance de 4 heures au laboratoire de pathokinésiologie et d'analyse des activités fonctionnelles au 4e étage de l'Institut de réadaptation Gingras-Lindsay-de-Montréal (IRGLM). Lors de cette séance, différents tests cliniques seront réalisés pour déterminer votre niveau de fonction sensorielle et motrice, d'équilibre. Au cours de ces tests, vous aurez à faire différentes tâches, comme vous lever, marcher, tenir debout yeux fermés, en vous penchant le plus loin possible ou sur un seul pied, etc, faire des mouvements du pied ou de la jambe ou indiquer votre perception des mouvements produits à la cheville par l'évaluateur. Ces tâches permettent de coter vos performances selon des méthodes éprouvées. Différentes questions vous seront posées au moyen de questionnaires pour déterminer votre confiance en votre équilibre et votre niveau de participation à des

activités dans la communauté. Vous serez exclu de l'étude si certaines performances sont très faibles.

Par la suite, au cours de la même séance, nous évaluerons la position de votre corps et ses mouvements pendant que vous marchez sur un tapis roulant sans puis avec perturbation. Pour cela, nous collerons, à l'aide de ruban adhésif, des marqueurs sur différentes parties de votre corps (pieds, jambes, cuisses, bassin, tronc, tête et bras), permettant l'enregistrement de vos mouvements à l'aide d'un système de caméras infrarouges. Des électrodes permettant de mesurer l'activité musculaire seront également placées sur 8 muscles de vos membres inférieurs (4 de chaque côté). Ces électrodes ne produisent pas de choc électrique. Des caméras vidéographiques seront utilisées pour avoir une image des tâches que vous allez réaliser. Après cette installation, nous vous demanderons de marcher à votre vitesse naturelle. Des perturbations pouvant vous déstabiliser seront également produites en changeant la vitesse d'une des courroies du tapis. Il faudra faire de votre mieux pour garder votre équilibre, un intervalle vous laissant suffisamment de temps pour rétablir votre équilibre étant offert entre les perturbations. Des pauses vous seront offertes au besoin.

Veuillez noter que pour ces sessions expérimentales, vous devrez porter des shorts et des chaussures de marche afin de faciliter la réalisation de l'expérimentation.

Pour un sous-groupe de participants, un entraînement de l'équilibre, utilisant les mêmes perturbations à la marche que dans la séance décrite ci-dessus, sera proposé au cours de neuf séances de 30 minutes, réparties sur 3 semaines, pendant lesquelles vous devrez marcher pendant 20 minutes. Des perturbations d'intensité progressive, puis imprédictibles seront appliquées durant ces 20 minutes. L'intensité des perturbations augmentera entre les 9 séances, en fonction des performances des participants. Des pauses vous seront offertes au besoin. Cet entraînement commencera 2 semaines après la séance d'évaluation initiale. Certains tests d'équilibre et questionnaires seront ré-évalués à la première séance d'entraînement, d'une durée d'une heure, pour bien établir vos capacités initiales.

Pour le groupe ayant participé à l'entraînement, la séance d'évaluation initiale sera répétée dans son intégralité (4 heures) après la période d'entraînement, et un entretien téléphonique aura lieu 6 semaines après la fin de l'entraînement pour suivre les changements éventuels de votre confiance et de votre participation aux activités communautaires.

D'autre sous-groupe de participants ne fera que marche à vitesse confortable sur le tapis roulant pendant 3 semaines (9 sessions totalement) sans perturbation. L'allocation de participants aux deux groupes sera aléatoire et il n'y a aucune assurance de participer dans un groupe particulier.

AVANTAGES PERSONNELS POUVANT DÉCOULER DE VOTRE PARTICIPATION

En tant que participant, les seuls avantages que vous retirerez de votre participation seront une évaluation clinique de votre fonction sensori-motrice et de votre équilibre et la satisfaction d'avoir contribué à l'avancement de la science. Les participants du groupe d'entraînement pourraient voir une amélioration de leur équilibre, de leur confiance et de leur participation sociale, mais aucune évidence n'est encore disponible sur cet entraînement puisque vous serez les premiers patients à le recevoir.

RISQUES ET INCONVÉNIENTS PERSONNELS POUVANT DÉCOULER DE VOTRE PARTICIPATION

Un harnais de sécurité sera en place pour éviter que vous chutiez jusqu'au sol en cas de perte d'équilibre importante lors des perturbations, pour réduire les risques de blessure.

La pose d'électrodes peut nécessiter le rasage de poils sur les surfaces de peau où elles seront placées. À ce titre, les règles d'hygiène les plus strictes (rasoirs à usage unique, ruban hypo-allergène, nettoyage de la peau avec de l'alcool) seront appliquées. Par ailleurs, malgré l'application de ces mesures d'hygiène, il se pourrait que la peau où les électrodes ou les marqueurs sont placées soit irritée. Dans un tel cas, une lotion calmante sera appliquée sur votre peau. Si l'irritation cutanée persiste plus de 24 heures, vous devrez aviser un des responsables du projet et consulter un médecin.

Il est également entendu que votre participation à cette étude n'aura aucun effet sur les éventuels services dont vous pourriez bénéficier à l'Institut de réadaptation Gingras-Lindsay-de-Montréal ou ailleurs.

Il se peut que les efforts demandés lors de l'évaluation en laboratoire ou l'entraînement provoquent une certaine fatigue mais celle-ci ne sera que temporaire. Il est entendu que si vous êtes fatigué durant la session, vous pourrez vous reposer en tout temps avant de continuer.

De plus, les déplacements de votre domicile au site de recherche et la durée des sessions peuvent représenter un inconvénient pour certaines personnes.

AUTORISATION D'UTILISER LES RÉSULTATS

Vous acceptez que l'information recueillie puisse être utilisée aux fins de communication scientifique, professionnelle et d'enseignement. Il est entendu que l'anonymat sera respecté à votre égard.

CONFIDENTIALITE

Il est entendu que les observations effectuées en ce qui vous concerne, dans le cadre du projet de recherche décrit ci-dessus, demeureront strictement confidentielles. À cet effet, tous les renseignements personnels recueillis à votre sujet au cours de l'étude seront codifiés et conservés sous clé dans une filière à l'IRGLM par le responsable de l'étude pour une période de 5 ans suivant la fin du projet. Seuls les membres de l'équipe de recherche y auront

accès. Cependant, à des fins de contrôle du projet de recherche, votre dossier pourrait être consulté par une personne mandatée par le CER des établissements du CRIR ou par le Ministère de la Santé et des Services Sociaux, qui adhèrent à une politique de stricte confidentialité. Après cette période de 5 ans, les renseignements personnels seront détruits.

INFORMATIONS CONCERNANT LE PROJET

On devra répondre, à votre satisfaction, à toute question que vous poserez à propos du projet de recherche auquel vous acceptez de participer. Pour toute information ou question, vous pourrez communiquer avec monsieur Cyril Duclos, Ph.D. en neurosciences et sciences biomédicales (réadaptation) au numéro de téléphone 514-340-2085 au poste 3048.

Si vous avez des questions sur vos droits et recours ou sur votre participation à ce projet de recherche, vous pouvez communiquer avec Me Anik Nolet, coordonnatrice à l'éthique de la recherche des établissements du CRIR au (514) 527-4527 poste 2643 ou par courriel à l'adresse : anolet.crir@ssss.gouv.qc.ca

Pour obtenir ces informations, vous pouvez également contacter le commissaire local aux plaintes de votre établissement.

RETRAIT DE VOTRE PARTICIPATION

Il est entendu que votre participation au projet de recherche décrit ci-dessus est tout à fait libre et volontaire. Il est également entendu que vous pourrez, à tout moment, mettre un terme à votre participation sans aucun préjudice. Les données et vidéo collectées jusqu'à votre retrait seront conservées à moins de demande contraire de votre part.

CLAUSE DE RESPONSABILITÉ

Il est entendu qu'en acceptant de participer à cette étude, vous ne renoncez à aucun de vos droits ni ne libérez les chercheurs et les institutions impliquées de leurs obligations légales et professionnelles.

INDEMNITÉ COMPENSATOIRE

Une indemnité compensatoire de 50\$ sera offerte aux participants en contrepartie des contraintes et inconvénients découlant de leur participation à l'évaluation en laboratoire, et 10\$ par session d'entraînement.



INSTITUT DE RÉADAPTATION
Gingras-Lindsay-de-Montréal



CONSENTEMENT

Je déclare avoir lu et compris le présent projet, la nature et l'ampleur de ma participation, ainsi que les risques auxquels je m'expose tels que présentés dans le présent formulaire. J'ai eu l'occasion de poser toutes les questions concernant les différents aspects de l'étude et de recevoir des réponses à ma satisfaction.

Je, soussigné(e), accepte volontairement de participer à cette étude. Je peux me retirer en tout temps sans préjudice d'aucune sorte. Je certifie qu'on m'a laissé le temps voulu pour prendre ma décision.

J'accepte d'être contacté(e) par le même chercheur pour participer à d'autres études scientifiques menées dans le même domaine de recherche :

Durant la prochaine année

Durant les 2 prochaines années

Durant les 3 prochaines années

J'accepte que les données recueillies au cours de cette étude soient utilisées pour d'autres publications scientifiques demeurant en lien (même domaine de recherche) avec le présent projet.

oui non

Une copie signée de ce formulaire d'information et de consentement doit m'être remise.

Nom du sujet

Signature de l'intéressé (e)

Fait à Montréal, le _____

ENGAGEMENT DU CHERCHEUR

Je, soussigné (e), _____, certifie :

- avoir expliqué au signataire les termes du présent formulaire;
- avoir répondu aux questions qu'il m'a posées à cet égard;

(c) lui avoir clairement indiqué qu'il reste, à tout moment, libre de mettre un terme à sa participation au projet de recherche décrit ci-dessus;

et (d) que je lui remettrai une copie signée et datée du présent formulaire.

Signature du responsable du projet ou de son représentant

Fait à Montréal, le _____.

Appendix IV Consent form for healthy participants of the biomechanical study

Des perturbations imprédictibles pendant la marche pour améliorer l'équilibre, la confiance et la participation de personnes hémiparétiques chroniques : étude pilote



Formulaire de consentement pour ma participation à un projet de recherche

TITRE DU PROJET

Des perturbations imprédictibles pendant la marche pour améliorer l'équilibre, la confiance et la participation de personnes hémiparétiques chroniques : étude pilote

(Unpredictable perturbations during gait to improve balance performance, confidence and participation in persons with hemiparesis at a chronic stage: a pilot study)

RESPONSABLE

Cyril Duclos, Ph.D. Professeur adjoint, École de réadaptation, Université de Montréal ; Chercheur, Centre de recherche interdisciplinaire en réadaptation (CRIR), Institut de réadaptation Gingras-Lindsay-de-Montréal (IRGLM)

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Isabelle David, M.Sc. Clinicienne, IRGLM

Joseph-Omer Dyer, Ph.D. Professeur adjoint, Université de Montréal

Andréanne Juneau, M.Sc. Clinicienne,
Rehabilitation Center

Constance-Lethbridge

Dahlia Kairy, Ph.D. Professeur adjoint, Université de Montréal

Anouk Lamontagne, Ph.D. Professeur agrégée, McGill University

FINANCEMENT DU PROJET

Partenariat Fondation Canadienne de Physiothérapie – Réseau Provincial de Recherche en Adaptation Réadaptation du Fonds de Recherche Québec-Santé (FPC-REPAR/FRQS)

PREAMBULE

Nous vous demandons de participer à un projet de recherche qui porte sur l'évaluation de votre équilibre lors de perturbations à la marche. Avant d'accepter de participer à ce projet de recherche, veuillez prendre le temps de comprendre et de considérer attentivement les renseignements qui suivent.

Ce formulaire de consentement vous explique le but de cette étude, les procédures, les avantages, les risques et inconvénients, de même que les personnes avec qui communiquer au besoin. Le présent formulaire de consentement peut contenir des mots que vous ne comprenez pas. Nous vous invitons à poser toutes les questions que vous jugerez utiles au chercheur et aux autres membres du personnel affecté au projet de recherche et à leur demander de vous expliquer tout mot ou renseignement qui n'est pas clair.

OBJECTIF DU PROJET

Le présent projet vise à décrire et quantifier les réactions posturales lors de perturbations de la marche chez des personnes sains, afin de les comparer à celles obtenues chez des patients hémiparétiques suite à un accident vasculaire cérébral.

NATURE DE VOTRE PARTICIPATION

Votre participation implique au minimum une séance de 4 heures au laboratoire de pathokinésiologie et d'analyse des activités fonctionnelles au 4e étage de l'Institut de réadaptation Gingras-Lindsay-de-Montréal (IRGLM). Lors de cette séance, différents tests cliniques seront réalisés pour déterminer votre niveau de fonction sensorielle et motrice, d'équilibre. Au cours de ces tests, vous aurez à faire différentes tâches, comme vous lever, marcher, tenir debout yeux fermés, en vous penchant le plus loin possible ou sur un seul pied, etc, faire des mouvements du pied ou de la jambe ou indiquer votre perception des mouvements produits à la cheville par l'évaluateur. Ces tâches permettent de coter vos performances selon des méthodes éprouvées. Différentes questions vous seront posées au moyen de questionnaires pour déterminer votre confiance en votre équilibre et votre niveau de participation à des

activités dans la communauté. Vous serez exclu de l'étude si certaines performances sont très faibles.

Par la suite, au cours de la même séance, nous évaluerons la position de votre corps et ses mouvements pendant que vous marchez sur un tapis roulant sans puis avec perturbation. Pour cela, nous collerons, à l'aide de ruban adhésif, des marqueurs sur différentes parties de votre corps (pieds, jambes, cuisses, bassin, tronc, tête et bras), permettant l'enregistrement de vos mouvements à l'aide d'un système de caméras infrarouges. Des électrodes permettant de mesurer l'activité musculaire seront également placées sur 10 muscles de vos membres inférieurs et de votre dos (5 de chaque côté). Ces électrodes ne produisent pas de choc électrique. Des caméras vidéographiques seront utilisées pour avoir une image des tâches que vous allez réaliser. Après cette installation, nous vous demanderons de marcher à votre vitesse naturelle. Des perturbations pouvant vous déstabiliser seront également produites en changeant la vitesse d'une des courroies du tapis. Il faudra faire de votre mieux pour garder votre équilibre, un intervalle vous laissant suffisamment de temps pour rétablir votre équilibre étant offert entre les perturbations. Des pauses vous seront offertes au besoin.

Veuillez noter que pour ces sessions expérimentales, vous devrez porter des shorts et des chaussures de marche afin de faciliter la réalisation de l'expérimentation.

AVANTAGES PERSONNELS POUVANT DÉCOULER DE VOTRE PARTICIPATION

En tant que participant, les seuls avantages que vous retirerez de votre participation seront une évaluation clinique de votre fonction sensori-motrice et de votre équilibre et la satisfaction d'avoir contribué à l'avancement de la science.

RISQUES ET INCONVÉNIENTS PERSONNELS POUVANT DÉCOULER DE VOTRE PARTICIPATION

Un harnais de sécurité sera en place pour éviter que vous chutiez jusqu'au sol en cas de perte d'équilibre importante lors des perturbations, pour réduire les risques de blessure.

La pose d'électrodes peut nécessiter le rasage de poils sur les surfaces de peau où elles seront placées. À ce titre, les règles d'hygiène les plus strictes (rasoirs à usage unique, ruban hypo-allergène, nettoyage de la peau avec de l'alcool) seront appliquées. Par ailleurs, malgré l'application de ces mesures d'hygiène, il se pourrait que la peau où les électrodes ou les marqueurs sont placées soit irritée. Dans un tel cas, une lotion calmante sera appliquée sur votre peau. Si l'irritation cutanée persiste plus de 24 heures, vous devrez aviser un des responsables du projet et consulter un médecin.

Il se peut que les efforts demandés lors de l'évaluation en laboratoire provoquent une certaine fatigue mais celle-ci ne sera que temporaire. Il est

entendu que si vous êtes fatigué durant la session, vous pourrez vous reposer en tout temps avant de continuer.

De plus, le déplacement de votre domicile au site de recherche et la durée de la session peuvent représenter un inconvénient pour certaines personnes.

AUTORISATION D'UTILISER LES RÉSULTATS

Vous acceptez que l'information recueillie puisse être utilisée aux fins de communication scientifique, professionnelle et d'enseignement. Il est entendu que l'anonymat sera respecté à votre égard.

CONFIDENTIALITE

Il est entendu que les observations effectuées en ce qui vous concerne, dans le cadre du projet de recherche décrit ci-dessus, demeureront strictement confidentielles. À cet effet, tous les renseignements personnels recueillis à votre sujet au cours de l'étude seront codifiés et conservés sous clé dans une filière à l'IRGLM par le responsable de l'étude pour une période de 5 ans suivant la fin du projet. Seuls les membres de l'équipe de recherche y auront accès. Cependant, à des fins de contrôle du projet de recherche, votre dossier pourrait être consulté par une personne mandatée par le CER des établissements du CRIR ou par le Ministère de la Santé et des Services Sociaux, qui adhèrent à une politique de stricte confidentialité. Après cette période de 5 ans, les renseignements personnels seront détruits.

INFORMATIONS CONCERNANT LE PROJET

On devra répondre, à votre satisfaction, à toute question que vous poserez à propos du projet de recherche auquel vous acceptez de participer. Pour toute information ou question, vous pourrez communiquer avec monsieur Cyril Duclos, Ph.D. en neurosciences et sciences biomédicales (réadaptation) au numéro de téléphone 514-340-2085 au poste 3048.

Si vous avez des questions sur vos droits et recours ou sur votre participation à ce projet de recherche, vous pouvez communiquer avec Me Anik Nolet, coordonnatrice à l'éthique de la recherche des établissements du CRIR au (514) 527-4527 poste 2643 ou par courriel à l'adresse : anolet.crir@ssss.gouv.qc.ca

Pour obtenir ces informations, vous pouvez également contacter le commissaire local aux plaintes de votre établissement.

RETRAIT DE VOTRE PARTICIPATION

Il est entendu que votre participation au projet de recherche décrit ci-dessus est tout à fait libre et volontaire. Il est également entendu que vous pourrez, à tout moment, mettre un terme à votre participation sans aucun préjudice. Les données et vidéo collectées jusqu'à votre retrait seront conservées à moins de demande contraire de votre part.

CLAUSE DE RESPONSABILITÉ

Il est entendu qu'en acceptant de participer à cette étude, vous ne renoncez à aucun de vos droits ni ne libérez les chercheurs et les institutions impliquées de leurs obligations légales et professionnelles.

INDEMNITÉ COMPENSATOIRE

Une indemnité compensatoire de 50\$ sera offerte aux participants en contrepartie des contraintes et inconvénients découlant de leur participation à l'évaluation en laboratoire.



INSTITUT DE RÉADAPTATION
Gingras-Lindsay-de-Montréal



CONSENTEMENT

Je déclare avoir lu et compris le présent projet, la nature et l'ampleur de ma participation, ainsi que les risques auxquels je m'expose tels que présentés dans le présent formulaire. J'ai eu l'occasion de poser toutes les questions concernant les différents aspects de l'étude et de recevoir des réponses à ma satisfaction.

Je, soussigné(e), accepte volontairement de participer à cette étude. Je peux me retirer en tout temps sans préjudice d'aucune sorte. Je certifie qu'on m'a laissé le temps voulu pour prendre ma décision.

J'accepte d'être contacté(e) par le même chercheur pour participer à d'autres études scientifiques menées dans le même domaine de recherche :

Durant la prochaine année

Durant les 2 prochaines années

Durant les 3 prochaines années

J'accepte que les données recueillies au cours de cette étude soient utilisées pour d'autres publications scientifiques demeurant en lien (même domaine de recherche) avec le présent projet.

oui non

Une copie signée de ce formulaire d'information et de consentement doit m'être remise.

Nom du sujet

Signature de l'intéressé (e)

Fait à Montréal, le _____

ENGAGEMENT DU CHERCHEUR

Je, soussigné (e), _____, certifie :

- (a) avoir expliqué au signataire les termes du présent formulaire;
- (b) avoir répondu aux questions qu'il m'a posées à cet égard;
- (c) lui avoir clairement indiqué qu'il reste, à tout moment, libre de mettre un terme à sa participation au projet de recherche décrit ci-dessus;
- et (d) que je lui remettrai une copie signée et datée du présent formulaire.

Signature du responsable du projet ou de son représentant

Fait à Montréal, le _____.

Appendix V Ethics certificate for the second study (CRIR_616_0411) linked to the biomechanical manuscript

3. Notifier, dès que possible, le CÉR de tout nouveau renseignement susceptible d'affecter l'intégrité ou l'éthicité du projet de recherche, ou encore, d'influer sur la décision d'un sujet de recherche quant à sa participation au projet ;
4. Notifier, dès que possible, le CÉR de toute suspension ou annulation d'autorisation relative au projet qu'aura formulée un organisme de subvention ou de réglementation ;
5. Notifier, dès que possible, le CÉR de tout problème constaté par un tiers au cours d'une activité de surveillance ou de vérification, interne ou externe, qui est susceptible de remettre en question l'intégrité ou l'éthicité du projet ainsi que la décision du CÉR ;
6. Notifier, dès que possible, le CÉR de l'interruption prématuree, temporaire ou définitive du projet. Cette modification doit être accompagnée d'un rapport faisant état des motifs à la base de cette interruption et des répercussions sur celles-ci sur les sujets de recherche ;
7. Fournir annuellement au CÉR un rapport d'étape l'informant de l'avancement des travaux de recherche (formulaire R) ;
8. Demander le renouvellement annuel de son certificat d'éthique ;
9. Tenir et conserver, selon la procédure prévue dans la *Politique portant sur la conservation d'une liste des sujets de recherche*, incluse dans le cadre réglementaire des établissements du CRIR, une liste des personnes qui ont accepté de prendre part à la présente étude ;
10. Envoyer au CÉR une copie de son rapport de fin de projet / publication ;
11. En vertu de l'article 19.2 de la *Loi sur les services de santé et les services sociaux*, obtenir l'autorisation du Directeur des services professionnels de l'établissement sollicité avant d'aller consulter les dossiers des usagers de cet établissement, le cas échéant.

[REDACTED]

Président du CÉR



Date d'émission
17 juin 2011

Certificat d'éthique

Par la présente, le comité d'éthique de la recherche des établissements du CRIR (CÉR) atteste qu'il a évalué, lors de sa réunion du 14 juin 2011, le projet de recherche CRIR-616-0411 intitulé:

« Comparaison de la marche asymétrique et symétrique chez les personnes hémiplégiques chroniques ».

Présenté par: **Sylvie Nadeau, Ph.D.**
Sélena Lauzière, M.Sc., pht
Carole Miéville, M.Sc

Le présent projet répond aux exigences éthiques de notre CÉR. Le Comité autorise donc sa mise en œuvre sur la foi des documents suivants :

- Lettre d'introduction datée du 30 mai 2011 ;
- Formulaire A daté du 26 avril 2011 ;
- Formulaire d'évaluation de l'Institut de réadaptation Gingras-Lindsay de Montréal, daté du 5 mai 2011, mentionnant que le projet est acceptable sur le plan de la convenance institutionnelle ;
- Grille d'évaluation scientifique du projet de recherche datée du 16 mai 2011 ;
- Budget ;
- Protocole de recherche intitulé « Comparaison de la marche asymétrique et symétrique chez les personnes hémiplégiques chroniques » ;
- Formulaire de consentement destiné aux participants hémiplégiques (versions anglaise et française du 17 juin 2011) ;
- Formulaire de consentement destiné aux participants en santé (version française du 17 juin 2011) ;
- Lettre d'invitation à participer à une étude pour le recrutement de personnes hémiplégiques suite à un AVC ;
- Cahier d'évaluation clinique.

Ce projet se déroulera dans le site du CRIR suivant : Institut de réadaptation Gingras-Lindsay de Montréal

Ce certificat est valable pour un an. En acceptant le présent certificat d'éthique, le chercheur s'engage à :

1. Informer, dès que possible, le CÉR de tout changement qui pourrait être apporté à la présente recherche ou aux documents qui en découlent (Formulaire M) ;
2. Notifier, dès que possible, le CÉR de tout incident ou accident lié à la procédure du projet ;

Appendix VI Consent form for individuals post-stroke of the second study (CRIR_616_0411) linked to the biomechanical manuscript

Comparaison de la marche asymétrique et symétrique chez les personnes



INSTITUT DE RÉADAPTATION
Gingras-Lindsay-de-Montréal



Formule de consentement pour votre participation à un projet de recherche

TITRE DU PROJET :

Comparaison de la marche asymétrique et symétrique chez les personnes hémiparétiques chroniques

RESPONSABLE :

Sylvie Nadeau, pht, Ph.D Chercheure, Centre de recherche interdisciplinaire en réadaptation (CRIR), Institut de réadaptation Gingras Lindsay de Montréal (IRGLM), Laboratoire de pathokinésiologie et d'analyse des activités fonctionnelles. Professeure titulaire à l'Université de Montréal, École de réadaptation. Chercheure responsable du projet.

CO-CERCHEURS :

Cyril Duclos, Ph.D. Chercheur, CRIR, IRGLM

Séléna Lauzière, pht, M.Sc. Candidate au doctorat, CRIR, IRGLM
Carole Miéville, M.Sc. Candidate au doctorat, CRIR, IRGLM

Rachid Aissaoui, Ing, Ph.D. Chercheur associé au CRIR, site IRGLM et École de technologie supérieure

PRÉAMBULE

Nous vous demandons de participer à un projet de recherche qui implique différentes évaluations se déroulant au laboratoire de pathokinésiologie au 4^e étage de l'IRGLM. Ces évaluations visent à étudier l'effet de la marche symétrique

sur la stabilité, le coût énergétique et les niveaux d'effort musculaire produits aux membres inférieurs.

Avant d'accepter de participer à ce projet de recherche, veuillez prendre le temps de comprendre et de considérer attentivement les renseignements suivants.

Ce formulaire de consentement vous explique le but de cette étude, les procédures, les avantages, les risques et inconvénients, de même que les personnes avec qui communiquer au besoin.

Le présent formulaire de consentement peut contenir des mots que vous ne comprenez pas. Nous vous invitons à poser toutes les questions que vous jugerez utiles au chercheur et aux autres membres du personnel affecté au projet de recherche et à leur demander de vous expliquer tout mot ou renseignement qui n'est pas clair.

DESCRIPTION DU PROJET ET SES OBJECTIFS

Des problèmes locomoteurs sont fréquemment rencontrés chez les personnes ayant une hémiplégie suite à un accident vasculaire cérébral (AVC). Le plus souvent, leur performance est caractérisée par une diminution de la vitesse de marche et par une asymétrie des mouvements entre les deux jambes. Cependant, sur demande, ces personnes peuvent habituellement effectuer la tâche à une vitesse plus élevée et de façon plus symétrique que ce qu'elles font de façon naturelle. La question qui nous intéresse ici est de comprendre pourquoi les personnes hémiplégiques utilisent une stratégie asymétrique alors qu'elles ont les capacités de marcher plus symétriquement. Les résultats de nos travaux antérieurs suggèrent que la perception de l'effort produit afin de réussir la tâche pourrait expliquer la stratégie de mouvements choisie. L'objectif du présent projet est de déterminer les effets réels et perçus d'une marche symétrique sur la stabilité posturale, le coût énergétique et les niveaux d'effort musculaire afin de déterminer si ces facteurs sont explicatifs de la performance motrice mesurée en laboratoire et en clinique chez les individus hémiplégiques. Un objectif secondaire est d'évaluer l'effet de la marche prolongée sur la symétrie du patron de marche, la stabilité, l'effort global et les niveaux d'effort musculaire.

Pour répondre à ces objectifs, 20 participants avec une hémiplégie chronique consécutive à un AVC unilatéral seront recrutés dans deux établissements de réadaptation: l'Institut de réadaptation Gingras-Lindsay-de-Montréal (IRGLM) et l'Hôpital de réadaptation Villa Medica.

NATURE ET DURÉE DE LA PARTICIPATION

Cette étude comporte deux séances d'évaluation qui auront lieu dans un intervalle d'une à deux semaines. Toutes les évaluations seront réalisées au laboratoire de pathokinésiologie et d'analyse de tâches fonctionnelles du site IRGLM.

Lors de la **première séance**, qui durera environ trois (3) heures, un(e) physiothérapeute évaluera votre santé, votre condition physique ainsi que votre habileté à réaliser diverses activités fonctionnelles via des questionnaires et différents tests standardisés. Ces tests évalueront vos mouvements au niveau des jambes, votre sensibilité, votre équilibre ainsi que votre capacité à réaliser

quelques épreuves fonctionnelles. De plus, votre capacité à réduire l'asymétrie de votre patron de marche de façon volontaire sera évaluée par une simple méthode de calcul utilisant l'empreinte du pas sur le sol. Il est possible que suite aux résultats de l'évaluation clinique, nous constatons que vous ne répondez pas totalement au type de participants que nous recherchons pour cette étude. S'il en est ainsi, votre participation s'arrêtera après cette première séance et on vous remettra une indemnité compensatoire couvrant vos frais de transport et de stationnement pour cette visite.

Si vous répondez au type de participants recherchés pour l'étude, vous serez invité(e) à réaliser différents types d'effort avec vos jambes. Ces tests serviront à évaluer votre force musculaire avec un appareil appelé dynamomètre. Il s'agit d'un appareil qui permet de mesurer précisément la force maximale lors de poussées avec différentes parties de vos jambes contre l'appareil. Pour cette évaluation de la force, vous serez assis ou couché et des courroies vous stabiliseront et empêcheront les mouvements de certaines parties de votre corps (voir photo 1). Au total, vous aurez à réaliser environ 76 contractions d'une durée d'environ 5 secondes chacune avec différents muscles de vos jambes avec des reposfréquents.

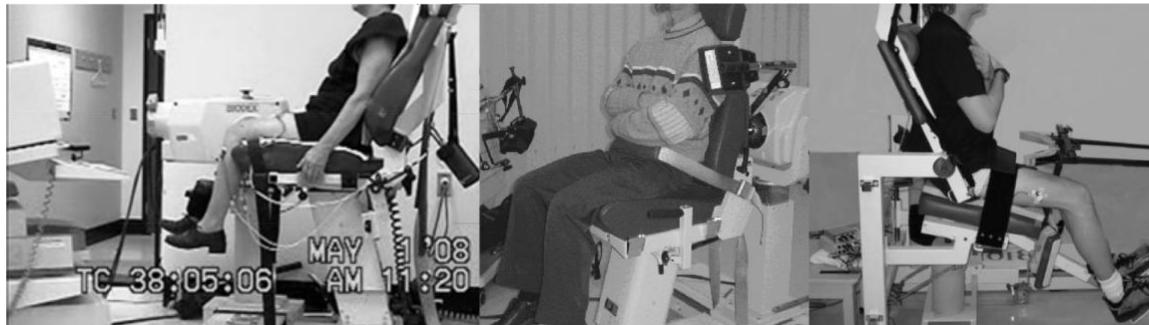


Photo 1. Dynamomètre Biodex et courroies de stabilisation

Finalement, une séance de familiarisation sur le tapis roulant à double courroie sera effectuée avec le port d'un masque nommé Cosmed qui sert à mesurer votre consommation d'oxygène (voir photo 2). Cette familiarisation vous permettra d'expérimenter les différentes conditions de marche utilisées lors de la 2^e visite sur le tapis roulant à double courroie (voir photo 3). Comme son nom l'indique, ce tapis roulant possède deux courroies distinctes qui peuvent se déplacer à des vitesses différentes. Ainsi, il permet de faire varier la vitesse de déplacement d'une jambe différemment par rapport à l'autre. Le tapis roulant possède des barres d'appui des deux côtés et également une barre d'appui à l'avant. Ainsi, malgré qu'il vous soit demandé de marcher sur le tapis roulant sans prendre appui avec vos mains, vous pourrez vous stabiliser sur ses barres en cas de déséquilibre. De plus, vous serez encadré en tout temps de deux personnes qui assureront votre sécurité.

Photo 2. Système d'acquisition des paramètres cardiorespiratoires (COSMED)



Photo 3. Tapis roulant à double courroie

Lors de la **deuxième séance**, qui durera également trois (3) heures, vous aurez à effectuer plusieurs conditions de marche différentes sur le tapis roulant à double courroie. Ainsi, il y aura des conditions où les courroies se déplaceront à la même vitesse et une condition où elles se déplaceront à des vitesses différentes. On vous demandera également de tenter de marcher de façon plus symétrique. Pour ce faire, vous recevrez la consigne de "marchez avec une longueur de pas la plus symétrique possible" et un physiothérapeute donnera des consignes spécifiques telles que "placez le pied gauche/droit plus loin" pour essayer d'obtenir la symétrie la meilleure possible. De plus, il vous sera demandé de marcher lors d'une période prolongée afin d'évaluer les changements dans votre performance motrice lorsque vos muscles sont fatigués. Lors de ces conditions, l'activité de vos muscles sera enregistrée avec des électrodes que nous collerons sur les muscles de vos jambes. Nous mesurerons simultanément les forces que vous produisez sous les pieds à l'aide de plates-formes de forces qui sont situées sous le tapis roulant. Des marqueurs seront collés sur différentes parties de votre corps (pieds, jambes, cuisses, bassin, tronc), pour permettre l'enregistrement de vos mouvements à l'aide d'un système de caméras infrarouges. Tous les essais seront aussi enregistrés à l'aide de deux caméras vidéo afin de nous fournir une image de la manière dont vous exécutez les tâches. Lors de certaines de ces tâches, nous vous demanderons de cocher l'effort, la stabilité et le niveau d'effort musculaire que vous percevez lorsque vous exécutez les diverses tâches locomotrices. Des périodes de repos (2 périodes de repos de 20 minutes) vous seront accordés entre les différentes conditions. Des repos additionnels s'ajouteront au besoin, selon votre endurance physique.

AVANTAGES PERSONNELS POUVANT DÉCOULER DE VOTRE PARTICIPATION

En tant que participant, vous ne retirerez aucun avantage de votre implication au projet de recherche. Par ailleurs, votre participation aura contribué à l'avancement de la recherche dans le domaine de la réadaptation des personnes avec un AVC.

RISQUES POUVANT DÉCOULER DE VOTRE PARTICIPATION

Il est entendu que votre participation à ce projet ne vous fait courir, sur le plan médical, aucun risque que ce soit. Toutefois, dans quelques cas, une irritation cutanée pourrait survenir à l'endroit où ont été collées les électrodes. Si tel est le cas, une lotion calmante sera appliquée. Si l'irritation cutanée persiste plus de 24 heures, vous devrez aviser un des responsables du projet et consulter un médecin. De plus, le risque de pertes d'équilibre lors de la marche ne peut être complètement éliminé. Cependant, lors des moments les plus instables (lorsqu'il y a changement des vitesses des courroies), vous aurez l'autorisation de vous tenir sur les barres d'appui puisqu'aucun n'enregistrement n'est effectué durant cette période. De plus, deux personnes seront à vos côtés afin d'assurer votre sécurité. Le tapis roulant, étant composé de barres d'appui des deux côtés et en avant de vous, vous permettra de vous stabiliser à tout moment lors des différentes conditions de marche au cas où vous auriez une période de déséquilibre.

Il est également entendu que votre participation à cette étude ne nuira d'aucune manière à tout traitement médical ou de réadaptation auquel vous êtes soumis ou pourriez éventuellement être soumis à l'Institut de réadaptation Gingras-Lindsay de Montréal ou à l'Hôpital de réadaptation Villa Medica.

INCONVÉNIENTS PERSONNELS POUVANT DÉCOULER DE VOTRE PARTICIPATION

Il se peut que les efforts demandés lors de l'évaluation en laboratoire provoquent tout au plus une certaine fatigue mais celle-ci ne sera que temporaire. Par ailleurs, les déplacements occasionnés pour la séance d'évaluation peuvent constituer un inconvénient pour certaines personnes.

La pose d'électrodes pour enregistrer l'activité musculaire peut nécessiter le rasage des poils sur les surfaces de la peau où elles seront placées. A ce titre, les règles d'hygiène les plus strictes (rasoirs et collettes à usage unique, nettoyage de la peau avec de l'alcool) seront mises en place.

ACCÈS À VOTRE DOSSIER MÉDICAL

Vous acceptez que les personnes responsables de ce projet aient accès à votre dossier médical de l'Institut de réadaptation Gingras-Lindsay de Montréal. Nous préleverons à votre dossier certaines informations sur votre état de santé, sur les tests et mesures réalisés par les cliniciens en lien avec les évaluations décrites plus haut.

AUTORISATION D'UTILISER RÉSULTATS

Vous acceptez que l'information recueillie puisse être utilisée pour des fins de communication scientifique, professionnelle et d'enseignement. Il est entendu que l'anonymat sera respecté à votre égard.

CONFIDENTIALITÉ

Il est entendu que les observations effectuées en ce qui vous concerne, dans le cadre du projet de recherche décrit ci-dessus, demeureront strictement confidentielles. À cet effet, tous les renseignements personnels recueillis à votre sujet au cours de l'étude seront codifiés et conservés sous clé dans une filière du laboratoire de pathokinésiologie et d'analyse d'activités fonctionnelles de l'IRGLM par le responsable de l'étude pour une période de 5 ans suivant la fin du projet. Seuls les membres de l'équipe de recherche y auront accès. Après cette période de 5 ans, ces renseignements seront détruits. Cependant, à des fins de contrôle du projet de recherche, votre dossier pourrait être consulté par une personne mandatée par le CÉR des établissements du CRIR, qui adhère à une politique de stricte confidentialité.

INFORMATIONS CONCERNANT LE PROJET

Pour votre satisfaction, nous nous appliquerons à répondre à toutes les questions que vous poserez à propos du projet de recherche auquel vous acceptez de participer. Pour toutes informations ou questions, vous pourrez communiquer avec Sylvie Nadeau, Ph.D. en sciences biomédicales (réadaptation) responsable du projet, au numéro de téléphone 514- 340-2111 au poste 2179.

Si vous avez des questions sur vos droits et recours ou sur votre participation à ce projet de recherche, vous pouvez communiquer avec Me Anik Nolet, coordonnatrice à l'éthique de la recherche des établissements du CRIR au (514) 527-4527 poste 2643 ou par courriel à l'adresse : anolet.crir@ssss.gouv.qc.ca

PARTICIPATION VOLONTAIRE ET RETRAIT DE VOTRE PARTICIPATION

Il est entendu que votre participation au projet de recherche décrit ci-dessus est tout à fait libre et volontaire. Il est également entendu que vous pourrez, à tout moment, mettre un terme à votre participation sans aucun préjudice et sans que cela n'affecte les services de santé auxquels vous aurez droit à l'Institut de Réadaptation Gingras-Lindsay-de-Montréal ou à l'Hôpital de réadaptation Villa Medica. En cas de retrait de votre part, les documents audiovisuels et écrits vous concernant seront détruits.

CLAUSE DE RESPONSABILITÉ :

Il est entendu qu'en acceptant de participer à cette étude, vous ne renoncez à aucun de vos droits ni ne libérez les chercheurs et les institutions impliquées de leurs obligations légales et professionnelles.

INDEMNITÉ COMPENSATOIRE

Une somme de 50\$ vous sera remise à chacune des visites (1^e et 2^e) afin de compenser pour les dépenses encourues par votre participation à ce projet de recherche.

CONSENTEMENT

Je déclare avoir lu et compris le présent projet, la nature et l'ampleur de ma participation, ainsi que les risques auxquels je m'expose tels que présentés dans le présent formulaire. J'ai eu l'occasion de poser toutes les questions concernant les différents aspects de l'étude et de recevoir des réponses à ma satisfaction.

Je, soussigné(e), accepte volontairement de participer à cette étude. Je peux me retirer en tout temps sans préjudice d'aucune sorte. Je certifie qu'on m'a laissé le temps voulu pour prendre ma décision et je sais qu'une copie de ce formulaire figurera dans mon dossier médical.

J'accepte d'être contacté (e) dans le futur par le même chercheur principal pour d'autres études dans un domaine de recherche connexe :

- non
- oui (pour une durée d'un an) *
- oui (pour une durée de deux ans) *oui (pour une durée de cinq ans) *

* Notez que si vous cochez l'une de ces trois cases, vos coordonnées personnelles seront conservées par le chercheur principal pour la période à laquelle vous avez consenti.

J'accepte que les données recueillies au cours de cette étude soient utilisées pour d'autres publications scientifiques demeurant en lien (même domaine de recherche) avec le présent projet.

oui non

Une copie signée de ce formulaire d'information et de consentement doit m'être remise.

Nom du sujet

Signature de l'intéressé (e)

Fait à _____,

le _____, 20 _____.

ENGAGEMENT DU CHERCHEUR

Je, soussigné(e), _____, certifie

- (a) avoir expliqué au signataire les termes du présent formulaire;
- (b) avoir répondu aux questions qu'il m'a posées à cet égard;
- (c) lui avoir clairement indiqué qu'il reste, à tout moment, libre de mettre un terme à sa participation au projet de recherche décrit ci-dessus;
- et (d) que je lui remettrai une copie signée et datée du présent formulaire.

Signature du responsable du projet

ou de son représentant Fait à _____, le 20 _____.

Appendix VII Consent form for healthy participants of the second study (CRIR_616_0411) linked to the biomechanical manuscript

Comparaison de la marche asymétrique et symétrique chez les personnes



INSTITUT DE RÉADAPTATION
Gingras-Lindsay-de-Montréal



Formule de consentement pour votre participation à un projet de recherche

TITRE DU PROJET :

Comparaison de la marche asymétrique et symétrique chez les personnes hémiparétiques chroniques

RESPONSABLE :

Sylvie Nadeau, pht, Ph.D Chercheure, Centre de recherche interdisciplinaire en réadaptation (CRIR), Institut de réadaptation Gingras Lindsay de Montréal (IRGLM), Laboratoire de pathokinésiologie et d'analyse des activités fonctionnelles. Professeure titulaire à l'Université de Montréal, École de réadaptation. Chercheure responsable du projet.

CO-CERCHEURS :

Cyril Duclos, Ph.D. Chercheur, CRIR, IRGLM

Séléna Lauzière, pht, M.Sc. Candidate au doctorat, CRIR, IRGLM
Carole Miéville, M.Sc. Candidate au doctorat, CRIR, IRGLM

Rachid Aissaoui, Ing, Ph.D. Chercheur associé au CRIR, site IRGLM et École de technologie supérieure

PRÉAMBULE

Nous vous demandons de participer à un projet de recherche qui implique différentes évaluations se déroulant au laboratoire de pathokinésiologie au 4^e étage de l'IRGLM. Ces évaluations visent à étudier l'effet de la marche symétrique

sur la stabilité, le coût énergétique et les niveaux d'effort musculaire produits aux membres inférieurs.

Avant d'accepter de participer à ce projet de recherche, veuillez prendre le temps de comprendre et de considérer attentivement les renseignements suivants.

Ce formulaire de consentement vous explique le but de cette étude, les procédures, les avantages, les risques et inconvénients, de même que les personnes avec qui communiquer au besoin.

Le présent formulaire de consentement peut contenir des mots que vous ne comprenez pas. Nous vous invitons à poser toutes les questions que vous jugerez utiles au chercheur et aux autres membres du personnel affecté au projet de recherche et à leur demander de vous expliquer tout mot ou renseignement qui n'est pas clair.

DESCRIPTION DU PROJET ET SES OBJECTIFS

Des problèmes locomoteurs sont fréquemment rencontrés chez les personnes ayant une hémiplégie suite à un accident vasculaire cérébral (AVC). Le plus souvent, leur performance est caractérisée par une diminution de la vitesse de marche et par une asymétrie des mouvements entre les deux jambes. Cependant, sur demande, ces personnes peuvent habituellement effectuer la tâche à une vitesse plus élevée et de façon plus symétrique que ce qu'elles font de façon naturelle. La question qui nous intéresse ici est de comprendre pourquoi les personnes hémiplégiques utilisent une stratégie asymétrique alors qu'elles ont les capacités de marcher plus symétriquement. Les résultats de nos travaux antérieurs suggèrent que la perception de l'effort produit afin de réussir la tâche pourrait expliquer la stratégie de mouvements choisie. L'objectif du présent projet est de déterminer les effets réels et perçus d'une marche symétrique sur la stabilité posturale, le coût énergétique et les niveaux d'effort musculaire afin de déterminer si ces facteurs sont explicatifs de la performance motrice mesurée en laboratoire et en clinique chez les individus hémiplégiques. Un objectif secondaire est d'évaluer l'effet de la marche prolongée sur la symétrie du patron de marche, la stabilité, l'effort global et les niveaux d'effort musculaire.

Pour répondre à ces objectifs, 20 participants avec une hémiplégie chronique consécutive à un AVC unilatéral seront recrutés dans deux établissements de réadaptation: l'Institut de réadaptation Gingras-Lindsay-de-Montréal (IRGLM) et l'Hôpital de réadaptation Villa Medica.

NATURE ET DURÉE DE LA PARTICIPATION

Cette étude comporte deux séances d'évaluation qui auront lieu dans un intervalle d'une à deux semaines. Toutes les évaluations seront réalisées au laboratoire de pathokinésiologie et d'analyse de tâches fonctionnelles du site IRGLM.

Au début de la séance, un(e) physiothérapeute évaluera votre santé, votre condition physique ainsi que votre habileté à réaliser quelques activités fonctionnelles via des tests standardisés.

Vous serez invité(e) à réaliser différents types d'effort avec vos jambes. Ces tests serviront à évaluer votre force musculaire avec un appareil appelé dynamomètre. Il s'agit d'un appareil qui permet de mesurer précisément la force maximale lors de poussées avec différentes parties de vos jambes contre l'appareil. Pour cette évaluation de la force, vous serez assis ou couché et des courroies vous stabiliseront et empêcheront les mouvements de certaines parties de votre corps (voir photo 1). Au total, vous aurez à réaliser environ 76 contractions d'une durée d'environ 5 secondes chacune avec différents muscles de vos jambes avec des repos fréquents.



Photo 1. Dynamomètre Biodex et courroies de stabilisation

Finalement, une séance de familiarisation sur le tapis roulant à double courroie sera effectuée avec le port d'un masque nommé Cosmed qui sert à mesurer votre consommation d'oxygène (voir photo 2). Cette familiarisation vous permettra d'expérimenter les différentes conditions de marche utilisées lors de la 2^e visite sur le tapis roulant à double courroie (voir photo 3). Comme son nom l'indique, ce tapis roulant possède deux courroies distinctes qui peuvent se déplacer à des vitesses différentes. Ainsi, il permet de faire varier la vitesse de déplacement d'une jambe différemment par rapport à l'autre. Le tapis roulant possède des barres d'appui des deux côtés et également une barre d'appui à l'avant. Ainsi, malgré qu'il vous soit demandé de marcher sur le tapis roulant sans prendre appui avec vos mains, vous pourrez vous stabiliser sur ses barres en cas de déséquilibre. De plus, vous serez encadré en tout temps de deux personnes qui assureront votre sécurité.

Photo 2. Système d'acquisition des paramètres cardiorespiratoires (COSMED)



Photo 3. Tapis roulant à double courroie

Par la suite, vous aurez à effectuer plusieurs conditions de marche différentes sur le tapis roulant à double courroie. Ainsi, il y aura des conditions où les courroies se déplaceront à la même vitesse et une condition où elles se déplaceront à des vitesses différentes. Dans cette condition, votre marche deviendra asymétrique avec une jambe se déplaçant plus vite que l'autre. De plus, il vous sera demandé de marcher lors d'une période prolongée afin d'évaluer les changements dans votre performance motrice lorsque vos muscles sont fatigués. Lors de ces conditions, l'activité de vos muscles sera enregistrée avec des électrodes que nous collerons sur les muscles de vos jambes. Nous mesurerons simultanément les forces que vous produisez sous les pieds à l'aide de plates-formes de forces qui sont situées sous le tapis roulant. Des marqueurs seront collés sur différentes parties de votre corps (pieds, jambes, cuisses, bassin, tronc), pour permettre l'enregistrement de vos mouvements à l'aide d'un système de caméras infrarouges. Tous les essais seront aussi enregistrés à l'aide de deux caméras vidéo afin de nous fournir une image de la manière dont vous exécutez les tâches. Lors de certaines de ces tâches, nous vous demanderons de cocher l'effort, la stabilité et le niveau d'effort musculaire que vous percevez lorsque vous exécutez les diverses tâches locomotrices. Des périodes de repos (2 périodes de repos de 20 minutes) vous seront accordés entre les différentes conditions si nécessaire. Des repos additionnels s'ajouteront au besoin, selon votre endurance physique.

AVANTAGES PERSONNELS POUVANT DÉCOULER DE VOTRE PARTICIPATION

En tant que participant, vous ne retirerez aucun avantage de votre implication au projet de recherche. Par ailleurs, votre participation aura contribué à l'avancement de la recherche dans le domaine de la réadaptation des personnes avec un AVC.

RISQUES POUVANT DÉCOULER DE VOTRE PARTICIPATION

Il est entendu que votre participation à ce projet ne vous fait courir, sur le plan médical, aucun risque que ce soit. Toutefois, dans quelques cas, une irritation cutanée pourrait survenir à l'endroit où ont été collées les électrodes. Si tel est le cas, une lotion calmante sera appliquée. Si l'irritation cutanée persiste plus de 24 heures, vous

devrez aviser un des responsables du projet et consulter un médecin. De plus, le risque de pertes d'équilibre lors de la marche ne peut être complètement éliminé. Cependant, lors des moments les plus instables (lorsqu'il y a changement des vitesses des courroies), vous aurez l'autorisation de vous tenir sur les barres d'appui puisqu'aucun enregistrement n'est effectué durant cette période. De plus, deux personnes seront à vos côtés afin d'assurer votre sécurité. Le tapis roulant, étant composé de barres d'appui des deux côtés et en avant de vous, vous permettra de vous stabiliser à tout moment lors des différentes conditions de marche au cas où vous auriez un déséquilibre.

INCONVÉNIENTS PERSONNELS POUVANT DÉCOULER DE VOTRE PARTICIPATION

Il se peut que les efforts demandés lors de l'évaluation en laboratoire provoquent tout au plus une certaine fatigue mais celle-ci ne sera que temporaire. Par ailleurs, les déplacements occasionnés pour la séance d'évaluation peuvent constituer un inconvénient pour certaines personnes.

La pose d'électrodes pour enregistrer l'activité musculaire peut nécessiter le rasage des poils sur les surfaces de la peau où elles seront placées. A ce titre, les règles d'hygiène les plus strictes (rasoirs et collerettes à usage unique, nettoyage de la peau avec de l'alcool) seront mises en place.

AUTORISATION D'UTILISER LES RÉSULTATS

Vous acceptez que l'information recueillie puisse être utilisée pour des fins de communication scientifique, professionnelle et d'enseignement. Il est entendu que l'anonymat sera respecté à votre égard.

CONFIDENTIALITÉ

Il est entendu que les observations effectuées en ce qui vous concerne, dans le cadre du projet de recherche décrit ci-dessus, demeureront strictement confidentielles. À cet effet, tous les renseignements personnels recueillis à votre sujet au cours de l'étude seront codifiés et conservés sous clé dans une filière du laboratoire de pathokinésiologie et d'analyse d'activités fonctionnelles de l'IRGLM par le responsable de l'étude pour une période de 5 ans suivant la fin du projet. Seuls les membres de l'équipe de recherche y auront accès. Après cette période de 5 ans, ces renseignements seront détruits. Cependant, à des fins de contrôle du projet de recherche, votre dossier pourrait être consulté par une personne mandatée par le CÉR des établissements du CRIR, qui adhère à une politique de stricte confidentialité.

INFORMATIONS CONCERNANT LE PROJET

Pour votre satisfaction, nous nous appliquerons à répondre à toutes les questions que vous poserez à propos du projet de recherche auquel vous acceptez de participer. Pour toutes informations ou questions, vous pourrez communiquer avec Sylvie Nadeau, Ph.D. en sciences biomédicales (réadaptation) responsable du projet, au numéro de téléphone 514-340-2111 au poste 2179.

Si vous avez des questions sur vos droits et recours ou sur votre participation à ce projet de recherche, vous pouvez communiquer avec Me Anik Nolet, coordonnatrice à l'éthique de la recherche des établissements du CRIR au (514) 527-4527 poste 2643 ou par courriel à l'adresse : anolet.crir@ssss.gouv.qc.ca

PARTICIPATION VOLONTAIRE ET RETRAIT DE VOTRE PARTICIPATION

Il est entendu que votre participation au projet de recherche décrit ci-dessus est tout à fait libre et volontaire. Il est également entendu que vous pourrez, à tout moment,

mettre un terme à votre participation sans aucun préjudice. En cas de retrait de votre part, les documents audiovisuels et écrits vous concernant seront détruits.

CLAUSE DE RESPONSABILITÉ :

Il est entendu qu'en acceptant de participer à cette étude, vous ne renoncez à aucun de vos droits ni ne libérez les chercheurs et les institutions impliquées de leurs obligations légales et professionnelles.

INDEMNITÉ COMPENSATOIRE

Une somme de 50\$ vous sera remise suite à votre visite afin de compenser pour les dépenses encourues par votre participation à ce projet de recherche.

CONSENTEMENT

Je déclare avoir lu et compris le présent projet, la nature et l'ampleur de ma participation, ainsi que les risques auxquels je m'expose tels que présentés dans le présent formulaire. J'ai eu l'occasion de poser toutes les questions concernant les différents aspects de l'étude et de recevoir des réponses à ma satisfaction.

Je, soussigné(e), accepte volontairement de participer à cette étude. Je peux me retirer en tout temps sans préjudice daucune sorte. Je certifie qu'on m'a laissé le temps voulu pour prendre ma décision et je sais qu'une copie de ce formulaire figurera dans mon dossier médical.

J'accepte d'être contacté (e) dans le futur par le même chercheur principal pour d'autres études dans un domaine de recherche connexe :

non

oui (pour une durée d'un an) *

oui (pour une durée de deux ans) *

oui (pour une durée de cinq ans) *

* Notez que si vous cochez l'une de ces trois cases, vos coordonnées personnelles seront conservées par le chercheur principal pour la période à laquelle vous avez consenti.

J'accepte que les données recueillies au cours de cette étude soient utilisées pour d'autres publications scientifiques demeurant en lien (même domaine de recherche) avec le présent projet.

oui non

Une copie signée de ce formulaire d'information et de consentement doit m'être remise.

Nom du sujet Signature de l'intéressé (e)

Fait à _____, le _____, 20_____.

ENGAGEMENT DU CHERCHEUR

Je, soussigné(e), _____, certifie

- (a) avoir expliqué au signataire les termes du présent formulaire;
- (b) avoir répondu aux questions qu'il m'a posées à cet égard;
- (c) lui avoir clairement indiqué qu'il reste, à tout moment, libre de mettre un terme à sa participation au projet de recherche décrit ci-dessus;
- et (d) que je lui remettrai une copie signée et datée du présent formulaire.

Signature du responsable du projet
ou de son représentant

Fait à _____, le _____ 20___.

Appendix VIII Published abstracts

1- International congress of Society of Posture and Gait Research 2017

Effect of stroke on the biomechanical determinants of balance during gait at natural and fast speed

Background: There is currently no comprehensive description of the main biomechanical variables involved in balance during gait in persons with hemiparesis despite their high risk of fall. The purpose of the study was to compare the biomechanics of balance during gait between healthy and individuals at the chronic phase post-stroke. **Methods:** Using whole-body 3-D motion analysis and an instrumented treadmill, kinematic and kinetic data were collected during gait at natural and fast speed in healthy young ($N=13$) and older ($N=13$) adults, and in 20 stroke participants. Antero-posterior (AP) and medio-lateral (ML) positions of the global center of pressure (COP), center of mass (COM), and extrapolated COM (XCOM, a combination of COM position and velocity) were calculated relatively to the length and width of the BOS. ANOVAs were used to compare the effect of gait speed and groups on the different variables. **Results:** The COM of the healthy groups was further forward at right/non-paretic heel contact and right and left/paretic midstance compared to stroke participants. It was also more lateral in the stroke groups than in the healthy groups during the right stance phase, particularly at fast speed in the slower stroke group. The XCOM was more backward in the stroke groups than in the healthy groups, and more lateral on the non-paretic side. At fast speed, the COM and XCOM were further forward for each group at each time of the gait cycle, except

at toe-off for COM. In the young and older healthy participants, the COP was closer to the limit of the base of support at heel-contact and toe-off bilaterally, and further forward at mid-stance than in the stroke groups. At fast speed, the COP was further forward at mid-stance and toe-off bilaterally in both groups, with no effect in the ML direction. The AP BOS was always shorter in the stroke groups than in the healthy groups, with no width difference. **Conclusion:** With larger AP displacements of the COP, the COM of the healthy groups moved less and faster, within a longer BOS, than after stroke. However, adaptation of balance biomechanics at faster speed was generally similar between groups, except for the slower stroke group, shifted to the non-paretic side.

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Unpredictable gait perturbation training improves balance and gait abilities more than gait training without perturbations in individuals post-stroke

ESMAEILIMAHANI Vahid, BOUYER Laurent, KAIRY Dahlia, LAMONTAGNE Anouk, DYER Joseph-Omer, DUCLOS Cyril

Balance perturbation training is a promising rehabilitation approach, but limited research is available on its effectiveness for balance post-stroke. The aim of this study was to compare the effects of training with and without unpredictable gait perturbations, on dynamic balance and gait abilities in individuals post-stroke.

Methods: Nineteen stroke individuals were assigned to two groups: perturbation training (PT) and no-perturbation training (nPT) and attended 9 training sessions over 3 weeks using a split-belt treadmill. For PT, perturbations were produced by changing the speed of one of the belts during stance phase every 8 to 16 steps. The intensity of the perturbations increased progressively between sessions according to participants' tolerance. The duration of the training sessions in nPT, i.e. without perturbation, was matched with a PT subject with similar speed. The effects of the training programs on dynamic balance (Mini-BESTest), balance confidence (ABC Scale), gait speed (10-meter walk test (10MWT)), knee extensors' strength (dynamometry), and reintegration into social activities (Reintegration to Normal Living Index (RNLI)) were evaluated and compared using ANOVAs and t-tests.

Results: MiniBESTest (+4.0 (± 5.2) /28 points, $p=.005$), ABC scale (+4.4% (± 6.0), $p=.026$), 10MWT at faster speed (+.17 ($\pm .15$) m/s, $p=.009$), non-paretic knee extensors (+37.2 (± 41.7) Nm, $p=.056$), and RNLI (- 3.4 (± 2.9) /11, $p=.04$) increased

significantly with PT, with no significant changes on 10MWT at comfortable speed (.13 (\pm .19) m/s, p=.065) and maximum strength generation on the paretic side (+32.7 (\pm 41.3) Nm, p=.081). MiniBESTest, gait speed (comfortable and faster), maximum knee extensors strength of paretic side in PT changed significantly in comparison to nPT which did not show any improvement.

Conclusion: Results support the clinical effectiveness of unpredictable gait perturbation training over walking on the treadmill in improving gait and dynamic balance after stroke. Impact on fall risk should be evaluated in a future clinical study.

3- The International congress of Society of Posture and Gait Research 2019

Unpredictable gait perturbation training improves reactive responses, and gait stability functions contrary to gait training without perturbations in stroke individuals

Unpredictable gait perturbation training has been shown to improve post-stroke balance deficits effectively. Dynamic balance control is a complex system, relying on several functions necessary for anticipatory and reactive responses, sensory orientation, and stability during gait. To support the clinical decision of using perturbation training in stroke rehabilitation and to better understand the specific effects of such training, the aim of this study was to compare the effects of training with and without unpredictable gait perturbations on the different functions involved in dynamic balance control, in post-stroke individuals. METHODS: Nineteen stroke individuals were assigned to two groups through covariate adaptive randomization: perturbation training (PT) and noperturbation training (nPT) and attended 9 training

sessions over 3 weeks using a split-belt treadmill. For PT, perturbations were produced by changing the speed of one of the belts during stance phase every 8 to 16 steps. The intensity of the perturbations increased progressively between sessions according to participants' tolerance. The duration of the training sessions in nPT, i.e. without perturbation, was matched with a PT subject walking at similar speed. The effects of the training programs on the different functions of balance control, evaluated using the MiniBESTest, were compared using nonparametric statistics.

RESULTS: Total Mini-BESTest score was different between groups after training ($p=.040$) but not before training ($p=.438$). Unpredictable perturbation training improved the functions involved in anticipatory ($p=.053$) and reactive responses ($p=.027$), and stability during gait ($p=.01$). No significant improvements were found over training in nPT group in any balance function ($p>.33$ for the other functions) except for anticipatory responses ($p\geq.066$). Between-group comparison showed better anticipatory function ($p=.017$) pre-training and better sensory orientation function ($p=.022$) post-training in the PT group than in the nPT group. **CONCLUSION:** Unpredictable gait perturbation resulted in the specific improvement in functions involved in reactive responses and stability during gait. Results are in accordance with the task-specificity principle and support the choice of unpredictable gait perturbation training over walking on the treadmill in post-stroke individuals who have reactive and gait stability deficits.