Brain Mechanisms Involved in the Perception of Emotional Gait: a combined MEG and Virtual Reality Study

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STATEMENT OF AUTHORSHIP

I, Yu-Tzu Wu, certify that I am the primary author of this thesis. I claim full responsibility for the content and style of the text included herein.

STATEMENT OF ORIGINALITY

This thesis contains no material that has been published elsewhere except where specific references are made. The study presented in **chapter 3** is original material and represents contributions to knowledge in the fields of neural mechanisms involved in visual motion processing and social cognition. Most of the existing knowledge about brain processes involved in emotion perception is derived from research on facial expressions rather than body motions. Furthermore, there exists very limited information on the characteristics of those processes due to the use of neuroimaging tools presenting with limited temporal resolution. In this work, magnetoencephalography (MEG) was used to assess the patterns of brain activation of healthy young adults as they discriminated the emotions conveyed by the gait pattern of human-like virtual pedestrians ambulating in a virtual community environment. It is the first time that such ecological stimuli, reminiscent of daily life, were used and that the temporal characteristics of the brain signals, as described by event-related responses (ERR) were examined and quantified in response to emotional gait. Furthermore, the impact of the gender of the virtual pedestrians on the observer's brain response to emotional gait was examined. The results obtained in this thesis will serve as a basis for comparison to further understand, in the future, the altered emotion recognition performance displayed by patient populations with social cognition deficits.

The data presented in this thesis was collected at the MEG unit of the McConnell Brain Imaging Centre, Montreal Neurological Institute-Hospital. The data was processed at the Feil & Oberfeld Research Centre of the Jewish Rehabilitation Hospital/CISSS-Laval site of the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR), affiliated with McGill University. The study presented in this thesis was approved by the McGill University Health Center Research Ethics Boards (MUHC - REBs).

DEDICATION

I dedicate this thesis to my parents, to whom I owe everything. To my mother, Shu-Chiao Lin, you are a very wonderful woman, and you dedicated all your time to working and taking care of your three children. During the past three years, you sent several packages to me, in which I can feel your love delivering through 10,000 km, and that always reminds me of being strong when I doubt myself. To my father, Tung-Liang Wu, who always respects my decision. You are a warm-hearted person who has taught me how to be empathetic and kind, as always. You are more like my friend, and I feel comfortable sharing my opinion with you. Most important of all, my parent always believes in me, and there are no words that could describe your devotion to me.

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CONTRIBUTION OF AUTHORS

This thesis is presented in a manuscript format and includes one research manuscript, which will be submitted for publication in a peer-reviewed journal. I, Yu-Tzu Tracy Wu, am the main contributor and lead author of all chapters and the manuscript included in this thesis. My contribution extends to the research design, experimental setup, data collection, data analysis, statistical analysis, interpretation of findings, preparation of figures/tables, as well as thesis writing and revisions.

The research project and manuscript presented here were developed under Dr. Anouk Lamontagne and Dr. Sylvain Ballet's supervision. Dr. Lamontagne and Dr. Baillet oriented the selection of the research design, experimental setup, data analysis, statistical analysis, and interpretation of findings, and both of them critically reviewed and provided constructive feedback on this thesis.

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LIST OF ABBREVIATIONS

AMG	Amygdala
dSPM	Dynamic Statistical Parametric Mapping
EBA	Extrastriate Body Area
ERRs	Event-Related Responses
EEG	Electroencephalography
FBA	Fusiform Body Area
FFG	Fusiform Gyrus
GEE	Generalized Estimating Equation
hMT+	Human Middle Temporal Complex
ITG	Inferior Temporal Gyrus
LOTC	Lateral Occipito-Temporal Cortex
LPP	Late Positive Potential
MEG	Magnetoencephalography
Occ	Occipital area
PANAS	Positive and Negative Affect Schedule
PLD	Point Light Display
PMC	Premotor Cortex
pSTS	Posterior Superior Temporal Sulcus
ROIs	Regions of Interest
TPJ	Temporal Parietal Junction
VE	Virtual Environment
VR	Virtual Reality

ABSTRACT

Locomotion, a common and essential activity of daily life, was shown to be modulated not only by the sensorimotor abilities of individuals but also by factors such as emotions and sex/gender. A body of perceptual research indicates that an observer uses information about gait kinematics to decipher the emotions of an individual. There also exists compelling neuroimaging evidence supporting the existence of a brain network specific to the perception of biological motion. Such evidence, however, is largely based on studies that have used two-dimensional point-light displays (PLDs) that are devoid of pictorial information and are not representative of what is experienced in everyday life. In my MSc. project, I thus aimed to investigate the brain signals evoked when perceiving emotions arising from virtual pedestrians' body movements walking in a community environment. The primary objectives were to test for differential activations in brain regions involved in emotion processing from biological motion and to characterize their neural dynamics via event-related responses (ERRs). The secondary objective was to determine whether the gender of the virtual pedestrians affected the brain's response to emotional gait stimuli.

A 275-channel CTF magnetoencephalography (MEG) was used to record the brain activity of 21 healthy young adults (aged from 18-29; men=10; female=11), discriminating the emotions of virtual male or female pedestrians walking in a community environment and displaying different emotional gait patterns (neutral, angry, happy). The ERRs in regions of interest (ROIs) associated with emotion and biological motion processing, including the posterior superior temporal sulcus (pSTS), fusiform body area (FBA), extrastriate body area (EBA), amygdala (AMG), and lateral occipital cortex (Occ), were examined. The processing of brain signals was carried out in Brainstorm, an application dedicated to MEG/EEG data visualization and processing.

Brain signals were found to be characterized by an early positive peak (P1; ~200ms) and a late positive potential (LPP; 400-1500ms), the latter showing three phases, namely an early (400-600ms), a middle (600-1000ms) and a late phase (1000-1500ms). The effects of emotional gait stimuli and gender of the virtual pedestrians on P1 in each ROI were analyzed using generalized estimating equations (GEEs) with two within-subject factors (three emotions, two genders). Similar GEEs were employed for LPP, except that a three within-subject factors model was used

to account for the different phases of the LPP response (three emotions, two genders, and three phases). Due to a lack of significant differences between brain signals observed in the left vs. right brain, responses of both hemispheres were combined in the analyses. Statistical analyses were conducted in SAS 9.4 with an alpha level of significance set to 0.05.

The GEE analyses revealed that P1 amplitude remained unaffected by emotion and gender. LPP amplitude, however, showed a significant emotion x phase interaction in all ROIs, revealing: (i) an emotion-dependent modulation taking place first in pSTS and Occ, followed by AMG, FBA, and EBA, and (ii) generally enhanced brain signals for the angry gait stimuli vs. the happy and/or neutral gait conditions in the middle LPP phase. LPP also showed a gender x phase interaction in pSTS and Occ, revealing that while gender itself did not affect the maximum amplitude of the brain signals, it did affect the time course of the response to emotional gait stimuli. Further qualitative examinations of the brain signal's waveforms between males and females revealed that the brain signals in the presence of a male pedestrian tended to drop sooner compared to their female counterparts, especially for the angry gait condition.

Present results indicate that the nature of the emotional gait stimuli influences the brain's neural activity across all the ROIs that were examined within a time window that is consistent with what is referred to as the LPP (400-1500ms) in the literature. As opposed to P1, which reflects lower-order motion processing and hence did not show any modulation as a function of emotions in the present study, the LPP component has been associated with selective attention to the emotional contents of stimuli. The larger activation generally observed for the angry gait condition is also consistent with the literature on the neural processing of emotions, which reveals that such enhancement is common when observers are exposed to negative or threatening stimuli. In contrast with previous locomotor PLD studies, however, the present study and others that have used human-like agents performing emotional gestures reports an emotion-dependent modulation within the AMG, suggesting that ecologically valid stimuli lead to a stronger modulation, possibly by increasing stimulus saliency and favouring the recall of daily life situations. Our present findings on the temporal course of the brain activation within the LPP phases and across ROIs also suggest that the processing of emotional gait is organized in a hierarchical manner, starting with the visual analyses of body motion information in pSTS and Occ, followed by an analysis of

emotion within the AMG, FBA, and EBA. Lastly, the gender-by-phase interaction observed here in pSTS and Occ is consistent with the role of these areas in face-body integration and perception of gender from biological motion information.

The findings of this study provide evidence that emotional gait, as rendered by stimuli that comprise biological motion and pictorial information, modulate brain activation within areas associated with biological motion and emotion processing and that the temporal characteristics of the brain signals differ depending on whether the emotions are conveyed by a male or a female individual. In addition, findings that are possibly unique to the use of ecological, human-like stimuli were observed, which has implications for the interpretation of findings across studies and for the design of future virtual reality-based applications in research or rehabilitation. Our current findings further generate a basis for comparison to identify defective brain processes associated with social cognition deficits in populations with traumatic brain injury, autism spectrum disorder, and schizophrenia.

ABRÉGÉ

Il a été démontré que la locomotion, une activité courante et essentielle de la vie quotidienne, est modulée non seulement par les capacités sensorimotrices des individus mais aussi par des facteurs tels que les émotions ainsi que le sexe/genre. Un ensemble de recherches sur la perception montrent que les informations sur la cinématique de la marche sont utilisées par un observateur pour interpréter les émotions d'un individu. Il existe également des données probantes en neuro-imagerie soutenant l'existence d'un réseau cérébral spécifique à la perception du mouvement biologique. Cependant, ces évidences sont en grande partie basées sur des études qui ont utilisé des animations par points lumineux bidimensionnelles dépourvues d'informations picturales et qui ne sont pas représentatives de la vie quotidienne. Dans mon projet de maîtrise, j'ai donc cherché à étudier les signaux cérébraux évoqués lors de la perception d'émotions résultant des mouvements du corps de piétons virtuels marchant dans la communauté. Les objectifs principaux étaient de tester les activations différentielles des régions du cerveau impliquées dans le traitement des émotions à partir du mouvement biologique et de caractériser leur dynamique neuronale via les réponses évoquées (‘event-related responses’ ou ‘ERR’). L'objectif secondaire était de déterminer si le genre des piétons virtuels affectait la réponse cérébrale aux stimuli émotionnels de la marche.

Un appareil de magnétoencéphalographie (MEG) CTF à 275 canaux a été utilisé pour enregistrer l'activité cérébrale de 21 jeunes adultes en bonne santé (âgés de 18 à 29 ans ; hommes=10 ; femmes=11) qui distinguaient les émotions de piétons virtuels, hommes ou femmes, marchant dans un environnement communautaire et affichant différents patrons de marche émotionnelle (marche neutre, en colère, heureuse). Les ERRs des régions d'intérêt (RIs) associées au traitement des émotions et du mouvement biologique, y compris le sillon temporal supérieur postérieur (pSTS), l'aire corporelle fusiforme (FBA), l'aire corporelle extrastriée (EBA), l'amygdale (AMG) et le cortex occipital latéral (Occ), ont été examinés. Le traitement des signaux cérébraux a été effectué dans Brainstorm, une application dédiée à la visualisation et au traitement des données MEG/EEG.

Les signaux cérébraux ont été caractérisés par un pic positif précoce (P1 ; ~200ms) et un potentiel positif tardif (PPT ; 400-1500ms), ce dernier présentant trois phases, c’est-à-dire une phase précoce (400-600ms), une phase moyenne (600-1000ms) et une phase tardive (1000-1500ms). Les effets

des stimuli émotionnels de la marche et du genre des piétons virtuels sur P1 dans chaque RI ont été analysés à l'aide d'équations d'estimation généralisées avec deux facteurs intra-sujet (3 émotions, 2 sexes). Des équations d'estimation généralisées similaires ont été utilisées pour le PPT, à l'exception qu'un modèle à trois facteurs intra-sujet a été utilisé pour tenir compte des différentes phases de la réponse du PPT (3 émotions, 2 sexes et 3 phases). En raison de l'absence de différences significatives entre les signaux cérébraux observés entre le cerveau gauche et le cerveau droit, les réponses des deux hémisphères ont été combinées dans les analyses. Les analyses statistiques ont été effectuées à l'aide du logiciel SAS 9.4 avec un niveau alpha de signification fixé à 0,05.

Les analyses statistiques ont révélé que l'amplitude de la P1 n'était pas affectée par l'émotion et le genre. L'amplitude du PPT, cependant, a montré une interaction significative entre l'émotion et la phase dans toutes les RIs, révélant : (i) une modulation dépendante de l'émotion se produisant d'abord dans le pSTS et Occ, suivie par l'AMG, FBA et EBA, et (ii) des signaux cérébraux généralement plus élevés pour les stimuli de marche en colère par rapport aux conditions de marche heureuse et/ou neutre dans la phase médiane du PPT. Le PPT a également montré une interaction entre le genre et la phase dans le pSTS et Occ, révélant que si le genre en lui-même n'a pas affecté l'amplitude maximale des signaux cérébraux, il a affecté le déroulement temporel de la réponse aux stimuli de marche émotionnelle. Un examen visuel des profils d'ondes cérébrales entre les hommes et les femmes a aussi révélé que les signaux cérébraux en présence d'un piéton masculin avaient tendance à chuter plus tôt que ceux de leurs homologues féminins, en particulier pour la condition de marche en colère.

Les résultats actuels indiquent que la nature des stimuli émotionnels de marche influence l'activité neuronale du cerveau dans toutes les RIs qui ont été examinées, dans une fenêtre temporelle qui est cohérente avec ce qui est appelé le PPT (400-1500ms) dans la littérature. Contrairement à P1, qui serait plutôt concerné par le traitement d'information de mouvement d'ordre inférieur et qui n'a donc montré aucune modulation en fonction des émotions dans la présente étude, la composante PPT a été associée à une attention sélective au contenu émotionnel des stimuli. L'activation plus importante généralement observée pour la condition de marche en colère est également cohérente avec la littérature sur le traitement neuronal des émotions qui révèle qu'une telle augmentation est courante lorsque les observateurs sont exposés à des stimuli négatifs ou menaçants. Cependant,

contrairement aux études précédentes ayant utilisé des animations locomotrices par points lumineux, la présente étude ainsi que d'autres qui ont utilisé des agents virtuels représentant des humains effectuant des gestes émotionnels ont trouvé une modulation dépendante de l'émotion dans l'AMG. Ceci suggère que l'utilisation de stimuli écologiquement valides conduit à une modulation plus forte, peut-être en augmentant la saillance des stimuli et en favorisant le rappel de situations de la vie quotidienne. Les résultats actuels sur le déroulement temporel de l'activation cérébrale dans les phases du PPT et à travers les RIs suggèrent également que le traitement d'information en lien avec la marche émotionnelle est organisé de manière hiérarchique, en commençant par les analyses visuelles des informations sur le mouvement du corps dans le pSTS et Occ, suivies par une analyse de l'émotion dans l'AMG, FBA et EBA. Enfin, l'interaction entre le genre et la phase observée dans le STSP et Occ est cohérente avec le rôle de ces zones dans l'intégration visage-corps et la perception du genre à partir des informations de mouvement biologique.

Les résultats de cette étude démontrent que la marche émotionnelle, telle que reflétée par des stimuli comprenant des mouvements biologiques et des informations picturales, module l'activation cérébrale dans les zones associées au traitement d'informations de mouvement biologique et des émotions, et que les caractéristiques temporelles des signaux cérébraux diffèrent selon que les émotions sont communiquées par un homme ou une femme. De plus, des résultats qui sont possiblement uniques à l'utilisation de stimuli écologiques de type 'humain' ont été observés, ce qui a des implications pour l'interprétation des résultats entre les différentes études et la conception de futures applications de réalité virtuelle en recherche ou en réadaptation. Les présents résultats constituent également une base de comparaison pour identifier les processus cérébraux défectueux associés aux déficits sociaux-cognitifs chez les populations souffrant d'un traumatisme cranio-cérébral, de troubles du spectre autistique ou encore de schizophrénie.

THESIS ORGANIZATION AND OVERVIEW

The organization of this manuscript-based thesis adheres to the guidelines for thesis preparation published by McGill Graduate and Postdoctoral Studies. Chapter 1 includes a literature review and rationale of the study. Chapter 2 outlines the objectives and hypotheses of the study. Chapter 3 presents a research manuscript that includes an abstract, introduction, methodology of the experiment, results, and discussion of the findings. Chapter 4 summarizes the findings of the study and discusses the contribution of these findings to rehabilitation and future research. The last chapter of this thesis, Chapter 5, provides references to all studies discussed in the thesis.

CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

Walking is crucial for fulfilling many activities of daily living in the community. Locomotor movements reflect our physical abilities and attributes, and convey social information. For instance, an observer can recognize the social characteristics of a pedestrian, such as identity [1, 2], gender [3-6], and even emotional state [7-11], only from their gait kinematics (e.g., locomotor movements). In the context of pedestrian interactions, the emotions perceived by the observer can, in return, affect their own behaviour, leading to changes in interpersonal space [12, 13], gaze behaviour [14], and even the adoption of defensive movements [15]. Recent studies examining the neural processing of emotional body expressions (e.g., dynamic/static body postures) indicate that emotions modulate brain activity within selective regions such as the posterior superior temporal sulcus (pSTS), the human MT/V5 complex, the extrastriate body area (EBA), the fusiform gyrus (FFG), the temporal parietal junction (TPJ) and the amygdala [16-22]. Furthermore, the few studies that have investigated the impact of emotional gait on the modulation of brain activation have revealed the involvement of additional areas, such as the premotor cortex (PMC) and supplementary motor area (SMA)[23, 24]. However, those few studies either used non-ecological, impoverished stimuli (e.g., point light displays or grey mannequins) and/or have not examined the temporal course of brain activations. This latter aspect is scientifically significant for relating the dynamics of behaviour to those of brain networks and to further understand emotion processing deficits in patient populations affected by, e.g., traumatic brain injury (TBI) or schizophrenia. In this MSc project, I thus examined the brain mechanisms involved in the discrimination of emotions through locomotor movements. I used magnetoencephalography (MEG), a neuroimaging tool with millisecond temporal resolution, to record the brain activity of healthy young observers as they visualized and discriminated the emotions of virtual pedestrians displaying different emotions through their locomotor movements.

1.2 BIOLOGICAL MOTION PERCEPTION

Humans are capable of reading body language based on their observation of the kinematic characteristics of behaviour. This remarkable ability is known as *biological motion perception*.

Specifically, biological motion perception refers to the visual perception of a biological entity engaged in a recognizable activity, such as human walking, and such percept can be recovered even from visually sparse inputs [25]. In 1973, Johansson and colleagues used point-light displays (PLD) to investigate biological motion perception (Fig. 1-a [26]). This technique consists of recording the movements of "light points" placed on an individual's anatomical landmarks while in the dark, as shown in Fig. 1-b. Dittrich et al. (1993) describe three PLD action categories, namely locomotor (e.g., walking, jumping, and leaping, etc.), instrumental (e.g., hammering, lifting, etc.) and social actions (e.g., dancing, greeting, threatening, etc.). Among those three categories, locomotor actions are recognized better and faster than the other actions, probably due to their familiarity with humans [27], and thus represent an ideal approach for investigating biological motion perception.

Biological motion is composed of global and local information [28]. On the one hand, global information conveys a dynamic structure, a vivid impression of a human figure, and higher-order characteristics (e.g., global displacement in space, walking speed, step length, stance/swing phase durations, etc.) [29]. On the other hand, local information refers to the kinematic cues of individual body parts (e.g., angular motion of the head, trunk, arms, and legs) [30]. Several studies suggest that if global information processing is disrupted, for instance, by inverting the orientation of a PLD, certain levels of perception are impaired [27, 31]. For example, Dittrich et al. (1993) showed that the recognition of actions is slower and less accurate when the PLDs are presented upside down [27]. However, despite the disruption of the global configuration, complex actions can still be recognized via the preserved local kinematic cues. Taken together, these observations suggest that biological motion perception emanates from both global and local cues. How these two types of cues are involved in the perception of personal factors such as emotions and gender of the moving individual is discussed in the following section.

1.3 PERCEPTION OF LOCOMOTION

Studies of pedestrian interactions have identified personal or situational factors that influence collision avoidance strategies. Personal factors include those relative to the moving individual perceived by the observer, such as height, gender, emotional state, etc., while situational factors refer to elements such as proximity, orientation, speed, and heading direction [32-34], and both of

the factors can potentially influence pedestrian interactions [34-37]. How one perceives the emotions of gait and how personal factors such as gender and situational factors such as the direction and speed of approach of a pedestrian modulate this percept are central questions to the present thesis.

1.3.1 Perception of emotional gait

Humans are highly social animals; therefore, recognizing others' emotions and responding accordingly are essential for effective social interactions [38]. Emotions can be conveyed in different ways, for instance, via facial expressions and body movements. Body movements become especially important in the context of pedestrian interactions when other individuals are viewed from a distance and/or when facial expressions are unavailable or unclear [10].

The influence of one's emotions on their movements during mobility tasks such as walking has been studied extensively [9, 39-44], including the impact of mood and psychiatric disorders on walking behaviour (for a review, see [45]). Changes in emotional state influence gait speed, with progressively faster speeds from sad to neutral, happy, and angry gait [39, 42, 44, 46]. The effect on walking speed between angry and happy gait is small, which can lead to the misidentification of the emotion if based on gait speed alone [47]. Speed changes are accompanied by changes in body kinematics (joint excursion) and temporal distance factors (step length, cadence). Emotion-specific features independent of walking speed also take place, including changes in sagittal head/trunk orientation, arm movements [48, 49], and lower limb coordination [39], as well as a subjective impression of stomping vs. bouncing for angry vs. happy gait [44].

Studies of locomotor adaptations in the context of pedestrian interaction tasks have revealed that interpersonal space, which is the distance maintained between one and another individual, is modulated by the observer's perception of the emotion displayed by the other individual. For instance, observers rate their preferred interpersonal space as larger and actually implement larger interpersonal distances when interacting with pedestrians demonstrating an angry vs. neutral gait pattern [12, 13]. The inability to recognize emotion from body movements can be challenging and bears significant negative effects on social interactions, leading to difficulties in community participation [50]. In a recent experiment, participants with moderate-to-severe TBI presenting

dysfunctions of social cognition and emotion perception [51] failed to adapt their interpersonal distances when interacting with pedestrians presenting different emotions of gait [52].

1.3.2 Impact of sex and gender

Factors such as the sex and gender of the moving individual also influence the perception of their motion behaviour [53-55]. On the one hand, sex is a multidimensional biological construct that encompasses anatomy, physiology, genes, and hormones, which together affect how we are labelled and treated in the world [56]. On the other hand, gender reflects the behavioural norms applied to males and females in societies, which influence their everyday actions, expectations, and experiences, as well as how people self-determine their own genders [56]. In the context of this thesis, I sought to explore, as a secondary objective, how the observers' perception of emotional gait may be modulated depending on whether this pedestrian is a male or a female. In such a context, which concerns walking as a social behaviour and involves virtual characters, the stimuli (male vs. female pedestrian) can be defined primarily as a gender-related exposure and will be referred to as such in the rest of the thesis. When it comes to the observers, the literature has primarily focussed on identified sex differences in terms of perceptual abilities and brain mechanisms, while sex-based analyses are still lacking, possibly due to inadequate sample size and statistical power so far. The notions of "gender" (stimulus-related) and "sex" (participant-related) are key factors to consider in this project, given their potential influence on the brain's response to the emotional gait stimuli, and, for this reason, they are further discussed in the next paragraphs. Here, only the studies investigating the impact of gender/sex on emotional gait perception are discussed.

Numerous previous studies have shown that the gender of a walking PLD can be identified from structural (body shape) and/or kinematic (movement) cues [3-6]. In terms of kinematic cues, male and female walkers differ primarily in their extent of lateral body sway, with males swinging their shoulders from side to side more than their hips [57]. Moreover, perceived gender can modulate interpersonal interactions, leading individuals to adopt smaller distances when exposed to virtual females vs. males, potentially due to inter-individual attraction and a perceived lesser need for self-protection when interacting with female virtual agents [58]. Interestingly, perceived gender and emotion are interdependent, possibly because of the social stereotypes associated with the male vs.

female gender. For instance, in a study on gender identification, angry throwing motions depicted via PLDs were overwhelmingly judged as performed by men, while sad motion displays were frequently identified as female [59]. Zibrek et al. (2015) extended those findings to locomotion, evaluating the influence of emotion on gender perception. They found that the angry gait was most often rated as "male", regardless of whether the motions were that of a male or a female agent. They also observed that a sad gait was perceived as "less male" compared to other emotions when portrayed by male actors [60].

The sex of the observer also influences how they interpret somebody else's body language [55]. For instance, in a PLD study conducted by Alaerts et al. (2011), female observers displayed faster response times in biological motion recognition and emotion recognition tasks compared to their male counterparts [53]. In a comprehensive review of the literature discussing sex differences in processing emotional stimuli, Kret and de Gelder (2012) also concluded that females tend to better identify most emotions, while males are specifically better at identifying expressions of anger/aggressivity [61].

Interestingly, "gender" (stimulus-related) and "sex" (participant-related) interact and influence the perception of emotions. For example, females better recognize expressions of hostility and anger from the locomotion of male actors, as compared to expressions of i) happiness and ii) angry locomotion behaviour displayed by female actors [62]. While I did not find further evidence of sex-by-gender interaction on the perception of emotional gait in the literature, the findings reported above collectively suggest that sex and gender should be considered as variables of interest in studies of emotional gait.

1.3.3 Situational factors

Situational factors, such as heading direction, orientation, and speed of approach of a pedestrian, are typically considered in studies of pedestrian interactions as they influence the locomotor behaviour of the observer. Examining the effect of the direction of a pedestrian approach on collision avoidance behaviour, both Huber et al. (2014) and Park et al. (2013) reported the adoption of a 'fan-shaped' personal space by observers, characterized by the longest range in the head-on approach, and relatively smaller space in the orthogonal direction [63, 64]. Variations in such

personal space would account for visual processing time [63, 64], as well as the imminent collision risk imposed by a head-on approach [35, 36, 65]. Indeed, in the latter scenario, one cannot simply slow down or speed up to let the other pedestrian pass and must deviate from their initial trajectory to avoid a collision. Furthermore, pedestrians approaching from more central directions are thought to be more socially relevant than pedestrians coming from the side, as the former is interpreted as having an intention of active interaction [66].

Speed also plays an important role in gait pattern observation. Human observers detect speed differences better from structured than from unstructured PLDs [29]. Because the walking speed of an interferer affects collision avoidance strategies [67] and the speed of visual motion stimuli also influences perception [68], emotional gait stimuli used for the present study experiment were selected based on their similar walking speed. Given the influence of heading direction and walking speed, the emotional gait stimuli employed in the present project will consist of virtual pedestrians approaching the observers from different directions, namely from head-on (0°) and diagonally (± 40° right/left), and each condition was controlled with the constant speed.

1.4 NEURAL CORRELATES OF OBSERVING BODY MOVEMENT

There is compelling evidence from brain imaging and lesion-symptom mapping studies for a brain network specific to the perception of biological motion [69-72]. This biological motion brain network comprises visual association areas and brain regions involved in the perception of body parts and movement. Although the study of emotion recognition from human gait is receiving growing attention in perceptual research, there is still limited neuroimaging research on the brain mechanisms involved. Neuroimaging studies based on PLD designs have shown that a set of brain regions is associated with the perception of emotions [20, 73, 74]. Studies so far are indeed restricted to PLDs, and to the best of our knowledge, no ecological stimuli (human-like) approaching everyday life conditions have been used in biological motion neuroimaging studies so far. Whether using richer vs. impoverished biological motion, experimental stimulations would induce different brain activity patterns remains to be determined [74]. Furthermore, my project aimed to fill current knowledge gaps concerning the temporal characteristics of brain activity related to emotion perception from gait patterns. In the following section, we will discuss the state

of current knowledge from neuroimaging studies of emotion recognition from bodily expressions, specifically locomotor movement.

1.4.1 Perception of Emotion from Locomotor Bodily Expressions

1.4.1.1 fMRI

Functional magnetic resonance imaging (fMRI) measures brain activity as local changes in blood flow and blood oxygenation via a compound metric of blood-oxygen-level-dependent (BOLD) signalling. Early fMRI studies have shown activations of the superior temporal polysensory area (STP) in the STS in processing biological motion, and STP is connected to motion-processing regions of the dorsal visual stream and object-processing regions of the ventral visual stream [75, 76]. The STS is associated with the detection of biological motion in purposeful actions [19, 72, 77-80]. For example, Pelphrey et al. (2003) demonstrated that the STS region responds more strongly to biological motion (as conveyed by a walking robot or human) than to meaningless but complex non-biological motion (e.g., a disjointed mechanical figure) [80]. In PLD and full-light displays (FLDs) study contexts, fMRI studies have shown the recruitment of a network of regions comprising hMT/V5+ and TPJ, in addition to posterior superior temporal sulcus (pSTS). For instance, Vaina et al. (2001) reported that the ventral lateral occipital cortex (LOPC) and hMT are activated while participants are tasked to discriminate between biological motion and object motion [69]. Herrington et al. (2007) found a deactivation of the inferior, middle, and superior temporal regions and MT+/V5 in autism spectrum disorder participants, a finding that emphasizes the key role of these regions in the processing of biological motion [81]. Moreover, activation of the fusiform gyrus (FFG), including the fusiform body area (FBA) and extrastriate body area (EBA), is associated with the identification of human-like features [16-18, 20, 22, 23, 82]. Although both FBA and EBA are involved in similar visual processing functions, Taylor et al. (2007) established that FBA responds preferentially to whole-body shapes (or larger segments of the body) and that EBA responds to body parts [83].

Because biological motion is a significant element of social perception, it is pertinent to review which regions are involved in different aspects of the cognitive neuroscience of social perception. In addition to motion-selective areas, the perception of emotions from bodily expressions involves

regions of the "social brain" (e.g., amygdala, AMG). As a general observation, emotion-rich stimuli elicit enhanced brain responses compared to neutral conditions [20, 84-88]. For example, Hadjikhani et al. (2003) observed that the FFG and the AMG showed increased activation in response to bodily expressions of fear [85]. Emotion-related increases in brain activation after the presentation of body expressions have also been observed in the lateral occipitotemporal cortex (LOTC) [88, 89]. However, there have been only few fMRI studies of emotional gait perception. These studies revealed a substantial overlap of the emotion-dependent brain responses with those from PLD and/or FLD studies (e.g., EBA, FBA, pSTS, TPJ, and amygdala) and other regions such as the insula and lateral orbitofrontal cortex (lOFC) [18, 23, 84]. Moreover, activation of the mirror neuron system (MNS), such as the inferior parietal lobule (IPL) and inferior frontal gyrus (IFG), a system characterized by typical selectivity for action execution and observation, has been reported in the perception of emotional gait patterns [84]. The valence of the emotion perceived through biological motion also impacts brain activations, although with contradictory results from the few studies that have investigated this question. Peelen et al. (2007) and Atkinson et al. (2012) both reported enhanced activity in EBA and FBA elicited by both angry and happy body movements compared to neutral stimuli [20, 88]. However, Schneider et al. (2014) reported enhanced cortical hemodynamic responses in the same regions only for negative-emotion gaits (e.g., sad, fearful or angry) and not for positive (e.g., happy) locomotor stimuli [23]. How the valence of the perceived emotional, biological motion affects brain activation, therefore, remains an open question. Considering the confounding effect of walking speed on emotion recognition, Schneider et al. (2014) designed stimuli presenting neutral walks whose speed patterns matched emotional locomotion. They observed brain activation patterns that were specific to the gait pattern's emotional content rather than its speed [23]. In the present study, we considered speed as a confounding factor and, therefore, only employed angry and happy gait patterns, which are two emotional walking expressions with similar speed patterns and stride lengths [90].

1.4.1.2 EEG and MEG

Several dynamical aspects of the brain processes involved in human face and emotion perception have been intensively investigated with electroencephalography (EEG) and MEG. Event-related responses (ERRs) that are time-locked to the stimulus onset or participant responses can be extracted from trial EEG/MEG data and source mapped onto the brain anatomy [91]. The

amplitude and phase of these ERR components are time-specific markers of the strength and dynamics of the underlying neural processes. The majority of ERR studies of affective expression point to relatively late stages of visual processes. Differential ERR effects induced by an emotional vs. neutral condition have been consistently reported for post-perceptual ERR components such as the P300, or the Late Positive Potentials (LPP) captured over centro-parietal scalp regions [92-95]. I discuss in the following paragraphs two distinct temporal stages involved in the processing of motion and emotion.

PLD studies with EEG and MEG have highlighted two main event-related responses [96, 97]. The first component occurs at ~200ms within the extrastriate cortex and is considered to reflecting the visual onset of the moving dot pattern representing a human figure. The second component at ~330ms is detected in the superior temporal sulcus and is associated with the processing of motion patterns. However, the respective timing of those components varies greatly across studies, depending on the nature of the stimulus contents and the experimental design. For example, in a MEG study, Chang et al. (2018) observed the first component at latency and location in line with previous literature, but the latency of the second component varied between 300ms and 600ms, depending on the complexity of the task, such as determining the facing direction of a PLD walker [18]. Regardless, the consensus so far is that the initial ERR component reflects lower-order motion processes thought to be related to configure and attentional processes associated with the encoding of structural cues, whereas the second ERR component may reflect a higher-order perception of biological motion, including emotional valence [98].

Adolphs et al. (2002) divided the temporal signature of the brain systems involved in emotion recognition into three stages: (1) the "Core system" for early perceptual processing of highly salient stimuli (~120ms); (2) the "Extended system" responsible for the detailed perception of emotion (~170ms) and; (3) the "Cognitive system" associated with the conceptual knowledge of emotion stimulus contents (>300ms) [99]. In the cognitive system stage, the effects of emotional contents are expected to occur around the P300 and LPP [92, 100]. The P300 over occipital-parietal areas is involved in attention and memory event storage [94, 95]. The LPP, characterized by a sustained positive deflection (300-600ms) over centro-parietal areas, is involved in the encoding of emotional contents and high/low arousing processes [93, 94, 101-103]. The respective timing

of the P300-then-LPP sequence can be modulated by a variety of cognitive processes, such as attention and working memory load [95].

To the best of my knowledge, however, LPP studies focussed on the perception of facial emotions or affective static pictures and did not address the processing of dynamic, emotional and bodily motions. In fact, there is a knowledge gap concerning the temporal characteristics of emotion perception from dynamic body expressions as a whole. The LPP has been associated with selective attention to the emotional contents of stimuli [104]. Indeed, emotionally evocative stimuli do modulate a broad range of ERRs, from early perceptual processing to components at later stages that are related to higher-order processes, including sustained attention. The LPP is enhanced by negative emotional contents compared to positive/neutral conditions [105-109]. McGhie et al. (2021) further found that the increase in LPP responses correlates positively with increased arousal ratings of fear-inducing stimulation. This suggests that the perception of fear/threat has been during human evolution. However, a segment of the published literature also reports that stimuli with positive valence do enhance the amplitude of the LPP [110, 111]. Whether and how the valence of the emotion perceived through biological motion affects LPP, and other EEG/MEG signal components have been seldom studied so far.

LPP latencies vary considerably between studies depending on stimulus contents (e.g., static vs. dynamic, facial vs. bodily expressions) and experimental design (e.g., one-back, passive viewing, or emotional regulation tasks). The actual duration of the LPP also varies depending on the attentional engagement of the observers and the duration of the stimulus presentation itself. The LPP is commonly further characterized via sub-components of shorter duration (e.g., early, middle, and late-phase sub-components). Some portions of the literature consider that the LPP can serve as an objective indicator of emotional reactivity, complementing other measures used in the clinic or scales used to self-report affective experiences [112, 113].

1.4.2 Gender/sex-related differences

As discussed above in Section 2.1.2.2, “gender” (stimulus-related) and “sex” (participant-related) are key factors we considered in the present project, because they either affect behavioral or brain responses to emotional gait stimuli.

Threatening stimulus contents induce differential brain responses whether the expressions are conveyed by a male or a female agent. Wabnegger et al. (2016) reported hyperactivations of the amygdala in response to looming male faces, which may reflect how they are processed as potential threats [114]. Similarly, Fischer et al. (2004) observed that exposure to angry male faces vs. angry female faces enhances the activation of the visual cortex and the anterior cingulate gyrus [115]. Therefore, we can conclude that threatening male body expressions are interpreted by brain circuits as potentially harmful, including in regions involved in the processing affective signals (AMG), body-related information (EBA, FG, STS, and TPJ), and motor preparation (pre-SMA and PMC). However, how gender also influences emotion perception conveyed by locomotor movements remains to be studied.

There is now compelling neuroimaging evidence, however, of observer sex-related differences in cortical responses to biological motion perception [116-118]. For instance, enhanced perception of biological motion in adult females is associated with increased fMRI activation of brain regions implicated in emotional/social perception (e.g., AMG, medial temporal gyrus & temporal pole) [116]. Pavlova et al. (2015) reported that female observers exhibit greater early activation of the right parietal, left temporal, and right temporal cortex while discriminating between PLD figures and scrambled motion. They also showed greater later activation of the right frontal and occipital cortices in males, indicating more efficient or faster social decision-making in female participants [117]. We already mentioned that a large portion of neuroimaging research in emotion perception reported sex-related effects on facial expression [119-123], but I anticipate that these effects are relevant to the present study. Aleman and Swart (2008) reported stronger activation of the STS in male vs. female observers in response to faces evoking interpersonal superiority [123]. How salient emotional stimuli are encoded may vary substantially between the sexes, in particular via the differential lateralization of amygdala activity in such context [122].

Furthermore, brain activation patterns are influenced by inter-gender interactions. Kret et al. (2011) used a study design involving female and male actors performing both facial and bodily expressions. They found increased AMG activity in male observers of female faces [124]. Generally, the study of sex differences in the social brain is receiving increased interest. However,

the integration of findings with respect to emotional and bodily expressions is still lacking. Moreover, pro-social disorders such as autism spectrum disorder (ASD), depression, and schizophrenia differ drastically in incidence and severity between males and females. For example, depression is approximately twice as common in females [125]. However, how the neural processes underlying these sex-related differences are involved in social perception remains unclear. Advancing knowledge about the impact of biological sex on the neural perceptual processing of biological motion may provide novel insights into the understanding of gender vulnerability in psychiatric and neurodevelopmental disorders involving social cognition deficits.

1.5 MEG TO INVESTIGATE BRAIN ACTIVITY

Multiple neuroimaging techniques can be used to study brain activation, e.g., EEG, PET, fMRI, or functional near-infrared spectroscopy (fNIRS). Here, we will use MEG, a brain recording modality for investigating and mapping brain millisecond dynamics. MEG is a non-invasive technique distinctive for its high temporal resolution in the millisecond range. MEG spatial resolution is, under favourable circumstances, 2-3 mm for sources located in the cerebral cortex [126]. MEG enables tracking rapid changes in cortical activity in the greatest diversity of tasks and conditions. EEG temporal resolution is similar to MEG's but with lesser spatial localization. Symmetrically, fMRI's temporal resolution is too limited to report the cascade of brain activations in perception and cognitive processes. Although MEG signal strength decreases with the depth of brain sources, recent studies have shown that activity in deeper structures, such as the amygdala, is detectable with MEG [127, 128].

1.6 VIRTUAL REALITY

Although PLD has been an impactful method for studying social and biological motion perception, the emphasis on body kinematics over body structures makes PLDs lack ecological validity. Compared to more abstract displays of biological movement, the FLD method bears greater ecological validity but leads to only slightly improved recognition accuracies of emotional contents [129, 130]. Therefore, the recent use of novel diagram-dynamic agents of biological motion has increased adoption in the field. We used a virtual environment (VE) to create the stimulation material used in the present project. VE refers to a computer-generated scenario of

objects or agents with which observers can interact in real-time [131]. The animate agent (e.g., pedestrians) are created in the VE with a variety of locomotor movements, affecting them with more realistic human-like attributes with a high degree of control in terms of study design. The rich and three-dimensional virtual space provided by VE partly compensates for the limited mobility contingences imposed on the observer during MEG data collection. Previous research has established that the perception of facial and bodily expressions of emotions conveyed by virtual human-like agents is similar to that of human emotions displayed on video [132, 133]. Previous studies [23, 24, 134] have also investigated the perception of emotions conveyed by simple gait patterns of avatars [7] as a uniform, gender-neutral grey mannequin body. Under these conditions, emotional (vs. neutral) gait elicited increased brain responses in regions previously associated with motion processing (e.g., EBA, FBA, pSTS, TPJ, and IFG) and in the AMG and lateral orbitofrontal cortex (lOFC), suggesting that the display of a virtual avatar elicits a broad network of cortical and subcortical structures. However, the realism of the animations used was limited with respect to those of current VE standards and did not enable the study of possible confounding effects of gender on emotion perception. In the present project, we designed three-dimensional human-realistic female and male virtual agents that expressed positive and negative emotional states through their walking locomotion. We applied validated artificial expressions of avatars to study social factors of interest, such as perceived gender rating through gait patterns. We, therefore, sought to examine how the emotion and gender of the virtual agents affected time-resolved brain responses in a group of male and female observers using MEG source imaging.

CHAPTER 2: RESEARCH OBJECTIVES AND HYPOTHESES

2.1 SPECIFIC OBJECTIVES

The primary objective of my research project is:

(1) To test for differential activations in brain regions involved in the processing of emotion from biological motion and to characterize their neural dynamics via event-related responses (ERRs).

The secondary objective is:

(2) To determine the potential effect of the gender of the virtual pedestrians on the modulation of brain activation.

2.2 HYPOTHESES

Based on existing literature involving PLDs or facial emotion recognition experiments, the following hypotheses were postulated:

- **Hypothesis 1:** Gait emotional valence affects late ERR components (e.g., LPP; ~400ms) associated with higher-order processes (e.g., biological motion and emotion perception) while leaving earlier ERR components (e.g., P1 at ~200ms) associated with lower-order visual processes (e.g., luminance) unchanged;

- **Hypothesis 2:** The activation of the amygdala, EBA, FBA, pSTS and lateral Occ is enhanced by emotional gait stimuli, with negative emotions (e.g., anger) evoking larger brain responses compared to positive emotions (e.g., a happy gait);

- **Hypothesis 3:** Male pedestrians evoke enhanced brain activations compared to female pedestrians, especially when moving with an angry gait pattern.

CHAPTER 3: RESEARCH MANUSCRIPT

Perceptual Brain Mechanisms of Emotions Conveyed by the Gait Patterns of Virtual Pedestrians

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3.1 ABSTRACT

INTRODUCTION: Brain processes associated with emotion perception from biological motion have been largely investigated using 2D point-light displays (PLDs), which are devoid of pictorial information and thus not representative of what is experienced in everyday life. In this study, we investigated the brain signals evoked when perceiving emotions arising from the body movements of virtual pedestrians walking in a community environment.

OBJECTIVES: The primary objectives were to test for differential activations in brain regions involved in the processing of emotion from biological motion and to characterize their neural dynamics via event-related responses (ERRs). The secondary objective was to determine whether the gender of the virtual pedestrians affected the brain's response to emotional gait stimuli.

METHODS: Magnetoencephalography (MEG) was used to record the brain activity of 21 healthy young adults discriminating the emotion of virtual male and female pedestrians walking in a community environment and displaying different emotions of gait (neutral, angry, happy). ERR in regions of interest (ROIs) associated with emotion and biological motion processing, including the posterior superior temporal sulcus (pSTS), fusiform body area (FBA), extrastriate body area (EBA), amygdala (AMG), and lateral occipital cortex (Occ), were examined.

RESULTS: Brain signals were characterized by an early positive peak (P1; ~200ms) and a late positive potential component (LPP; 400-1500ms), with the latter being characterized by an early (400-600ms), middle (600-1000ms) and late phase (1000-1500ms). Generalized estimating equations revealed that P1 amplitude remained unaffected by emotion and gender. LPP amplitude, however, showed a significant emotion X phase interaction in all ROIs, revealing i) an emotion-dependent modulation taking place first in pSTS and Occ, followed by AMG, FBA and EBA, and ii) generally enhanced responses for angry vs. happy and/or neutral gait stimuli in the middle LPP phase. LPP also showed a gender x phase interaction in pSTS and Occ, showing that gender affected the time course of the response to emotional gait stimuli.

CONCLUSION: Results provide insights into the spatiotemporal characteristics of brain activity in response to emotional gait. The use of ecological scenarios involving human-like stimuli shows great potential to further the understanding of brain processes under realistic conditions.

Keywords: Biological motion, Emotion, Gender, Locomotion, Neuroimaging, Magnetoencephalography

3.2 INTRODUCTION

Recognizing the emotions of others is essential for effective social interactions [38]. Emotions can be conveyed through different body cues such as facial expressions, postures, and body movements. Body movements are especially useful in the context of locomotion because they can be observed more easily from a distance and would thus contribute to successful locomotor interactions (e.g., interferer avoidance) [8, 9, 129]. The emotional state [9, 129], gender [1, 3, 5, 6] and identity [2] of an individual can all be identified from basic simulations of their locomotor movements using point-light displays (PLD). The identifying information is extracted from local (e.g., knee, hip and lumbopelvic angles) and/or global motion cues (e.g., global displacement or walking speed) [135, 136]. These motion cues are also essential to successful pedestrian interactions, for instance, to register the speed and direction of approach of an individual [137-139].

Several neuroimaging studies, primarily with fMRI, have characterized the brain regions involved in biological motion perception. They comprise the posterior superior temporal sulcus (pSTS), human middle temporal/V5 complex (hMT/V5+), extrastriate body area (EBA), fusiform gyrus (FFG) and the temporal parietal junction (TPJ) [16-23]. These regions are recruited in the allocation of attention and are thought to interact with the brain circuits for motor planning in the premotor cortex (PMC) and supplementary motor areas (SMA) [19, 140]. Recent neuroscience studies have investigated the interaction between emotions, and body postures and movements, which mapped to the fusiform body area (FBA), the inferior temporal gyrus (ITG), EBA, pSTS, TPJ, and the amygdala (AMG) [23, 24, 141, 142]. pSTS is discussed as acting as a major cortical network hub for the perceptual analysis of social cognitive cues, with reciprocal connections with the amygdala, a region involved in the processing of emotion-selective information [79, 143].

Whether and how the valence of the emotion perceived through biological motion affects brain activity has been seldom studied, with contradictory results. There have been observations of a selective increase of amygdala activity in response only to negative (e.g., sad, fearful, or angry) and not positive (e.g. happy) stimuli [23]. Others have reported enhanced amygdala activity for both negative and positive emotional valence of body movements [20, 144].

How these activations unfold over time remains to be fully understood. Electroencephalography (EEG) studies have reported the time courses of brain activations in PLD tasks, highlighting two major event-related responses (ERRs) [96, 97]: a first component peak about 200ms in the extrastriate cortex after the onset of the moving dot pattern of a human figure; a second component peak at about 330ms in the posterior superior temporal sulcus region associated with the visual analysis of motion patterns. However, the latency of this latter component varies from 300 to 600ms across studies, depending on the nature of the moving stimuli and requirements of the motion discrimination task, e.g., identifying the facing direction of a PLD walker [18].

Adolphs et al. (2002) proposed three successive stages in the brain processes of emotion recognition: 1) the "Core system" for the early perceptual processing of highly salient stimuli, with a latency of about 120ms; 2) the "Extended system" responsible for the detailed perception of emotion reaction (~170ms); and (3) the "Cognitive system" associated with the conceptual knowledge of emotion signalled by the stimulation (>300ms) [99]. Within the cognitive system stage, the P300 and the late positive potential (LPP) are two widely studied even-related responses. The P300 over occipital-parietal areas is conceived as a marker of attention and working memory storage [94, 95]. The LPP is characterized by a sustained positive deflection (300-600ms) over centro-parietal areas, related to the encoding of emotional and high/low arousing processing in the perception of facial emotions and affective static pictures [93, 94, 101-103]. Whether and how these brain signal markers are associated with the brain processing of dynamic, emotional, and bodily motions is unknown and was the main objective of the present study. We, therefore, sought to advance the understanding of neurophysiological characteristics of emotion perception from dynamic body expressions.

Because PLDs emphasize body kinematics over body structures, they lack ecological validity. Virtual reality (VR) allows the creation of more realistic human-like agents with a high degree of control over the simulated body motion behaviour. The perception of facial and bodily expressions of emotions by VR human-like agents is similar to that of human emotions captured on video [132, 133]. Furthermore, the perception of the expressed emotion is more accurate when a whole-body expression is presented as a full-light display (e.g., a video clip) compared to PLDs [129].

Few studies have investigated brain activations when observing the emotional gait of a human-like agent [23, 24, 134]. They showed, with fMRI and functional near-infrared spectroscopy (fNIRs), an emotion-dependent modulation of brain activation in regions previously identified in PLD and full-light display tasks (e.g., EBA, FBA, pSTS, TPJ, IFG, and AMG). They also reported effects in the insula and lateral orbitofrontal cortex (lOFC), which suggests that the display of a virtual human-like agent may recruit a broader set of cortical and subcortical areas. These studies used the same set of animations created by Roether et al. (2009) [7], which feature a uniform, gender-neutral grey mannequin body, although the animations were created from motion captures of male and female actors. The realism of these animations is therefore limited with respect to current VR standards, and they may bear possible confounding effects of gender on emotion perception. Indeed, growing evidence shows that the gender information conveyed by biological motions and stimuli modulates the perception of emotions [3, 53, 60]. One neuroimaging study explored the difference between processing female and male bodily expressions and showed that male vs. female threatening expressions elicited differential activations within the EBA, FBA, pSTS, and PMC [124]. We, therefore, sought to elucidate whether gender and emotional gait stimuli induce interacting brain activations.

Here we designed three-dimensional human-realistic female and male virtual agents that expressed positive and negative emotional states through their locomotion. We sought to examine how the emotion and gender of the virtual agent affected time-resolved brain activations in a group of male and female observers using magnetoencephalography (MEG) source imaging. Our primary objectives were to test for differential activations in brain regions involved in the processing of emotion from biological motion and to characterize their neural dynamics via event-related responses (ERRs) while perceiving emotion from locomotor movements performed by male or female virtual pedestrians. Our secondary objective was to determine whether the gender of the virtual pedestrians affected those brain responses. We hypothesized that: i) gait emotional valence affects late ERR components (e.g., LPP), not the earlier ERR components (e.g., P1 at ~200ms); ii) the activation of the amygdala, EBA, FBA, pSTS, and lateral Occ is enhanced by emotional gait stimuli, with negative emotions (e.g., anger) evoking larger brain responses compared to positive

emotions (e.g., a joyful gait); iii) male pedestrians evoke enhanced brain activations compared to female pedestrians, especially when moving with an angry gait because it is typically perceived as more threatening [54, 124, 145].

3.3 METHODS

3.3.1 Participants

Twenty-one healthy young adults (10 males and 11 females) aged 18-29 years (24.82 ± 2.90 years [mean ± 1SD]) participated in this study. In order to be included, participants had to be right-handed (as per the Edinburgh Handedness Inventory) [146] and present normal or corrected-to-normal vision (EDTRS ≥ 20) [147]. Those with a current or past neurological or psychiatric disorder were excluded, as well as those with an implanted device interfering with MEG acquisition. The experiment was approved by the research ethics committee of the McGill University Health Centre (MUHC), and all participants gave their written informed consent prior to entering the study.

3.3.2 Stimulus Presentation

The stimuli consisted of short movie clips displaying three emotional gait patterns (angry, happy, neutral) performed by a female and a male virtual pedestrian (Fig. 2-a). They were shown walking in a Montreal subway station, walking toward the observer's vantage point, from either the top middle (0°), right, or left (±40°) of the scene. The gait initiation phase was invisible to participants as the walking virtual pedestrians became visible after large sliding doors in the virtual environment (VE) were opened. The pedestrians disappeared when reaching the midline of the door frame. A centrally located crosshair (0°) was overlaid on the VE for participants to fixate on during each trial. Emotional gait animations were captured from one male and one female actor portraying whole-body expressions of the different emotions of interest while walking on a self-paced treadmill (walking velocities ~1.6 m/s). Their full body kinematics were recorded at 120Hz using a 6-camera Vicon motion capture system (Vicon Motion Systems Ltd, Oxford, UK) and 40 passive reflective markers positioned on specific body landmarks, as per the Plug-In-Gait model from Vicon™. Pegasus Advanced™ was used to animate a male and a female virtual pedestrian with the recorded movements. Two validated animations depicting pedestrians performing at least

four continuous gait cycles, with an emotion discrimination accuracy of ≥ 80 %, were selected for each emotional gait condition and used in this experiment (see Appendix I). Having two animations per condition rather than a single animation enabled variability from trial to trial, akin to real-life experiences, while minimizing the risk of identifying the emotion based on other unrelated information (e.g., posture position). The 3-dimension (3D) VE was projected using a 3D PROPixx (VPixx Technologies) projector on a rear-projection screen (50cm height x 80cm length) located in the MEG room, in front of the participants, at a viewing distance of 50 cm (Fig. 2-b). The field of view of the VE animations was 50cm in height by 80cm in width, with a resolution of 1920x1080 pixels and a refresh rate of 60 Hz. The 3D real-time rendering of the VE was programmed and controlled in Unity 3D® and required participants to wear cardboard-made passive 3D glasses.

3.3.3 Task

Each MEG session lasted approximately 2.5 hours, including preparation and data collection. MEG data collection itself lasted about one hour. First, participants were introduced to the general procedure and task instructions. They were requested to fill out the Positive and Negative Affect Schedule (PANAS) questionnaire to evaluate their mental state [148]. Subsequently, a minimum of twenty practice trials were conducted before MEG data collection until participants reached a minimum of 80% accuracy on the emotion discrimination task and felt comfortable with the task and set-up. Participants were then assessed while seated under the MEG helmet, holding a small response box consisting of five keys providing their responses during the discrimination task. The response box was held with both hands resting on their lap, which reduced MEG signal contamination induced by arm muscle tension (Fig. 2-c). As shown in Fig. 3, each stimulus depicting a virtual walking pedestrian lasted 4000ms, followed by a response prompt screen. If no response was provided by the participant within 2000ms, a new trial was initiated. Trials were separated by an inter-stimulus interval (ISI) of variable duration between 750 and 1350ms, during which a static subway scene with closed doors was presented. Five blocks of male and five blocks of female virtual pedestrian animations comprising 48 trials each were presented in random order across participants. Within each block, the presentation order of emotions and directions of approach was also randomized. A total of 480 trials were collected, with 80 trials for each of the six emotion/gender combinations. Participants were instructed to fixate a crosshair at the center of

the display at all times and to report the perceived emotion of the pedestrian's gait when prompted by the response screen and using the response box. The response screen provided a 3-alternative response choice, identified with text (happy, neutral, angry) and arrows pointing up, left, or right. The response choices were associated with the three middle keys of the response box. The position of response options on the response screen was fixed within a given block but was randomly arranged between blocks to maintain participant's alertness. Each block lasted 5mins, and participants were invited to rest for 2mins every two blocks. Upon completing MEG data collection, the participant responded to a short feedback questionnaire about their perception of the VE [149].

3.3.4 MEG data acquisition

MEG data were acquired at the McConnell Brain Imaging Centre (BIC), Montreal, Canada, using a 275-channel whole-head system (CTF/VMS, Port Coquitlam, British Columbia, Canada). Data were recorded with a sampling frequency of 2400Hz. Prior to MEG data collection, each participant's scalp, eyebrows, and nose were digitized with approximately 200 points using a 3D digitizer system (Isotracker, Polhemus) to co-register functional MEG data with the default anatomy (MNI ICBM152 [150]) provided in Brainstorm. The participant's head position inside the MEG sensor helmet was determined with three localization coils fixated at the nasion and left/right preauricular sites (fiducial points). Horizontal and vertical electrooculograms (EOG) and an electrocardiogram (ECG) were acquired with bipolar montages to capture eye movements, blinks and heartbeats, respectively, for subsequent MEG artifact detection and removal.

3.4 DATA ANALYSIS

3.4.1 Behavioral data

Behavioural performances were quantified in terms of the proportion of correct responses in the emotion discrimination task (%), regardless of the approaching direction of the pedestrians. The emotion discrimination accuracy scores (N=21) were analyzed with a generalized estimating equation (GEE) model comprising two within-subject factors: the virtual pedestrian's emotion (angry, happy, and neutral) and gender (female and male). Statistics of post-hoc comparisons were corrected using Bonferroni correction. The short feedback questionnaire (SFQ) and PANAS scores were summarized with descriptive statistics (mean ± 1SD).

3.4.2 MEG data preprocessing

MEG data preprocessing and analysis were conducted using Brainstorm [151]. The data were resampled at 256Hz and notch filtered at the power frequency of 60 Hz with its first three harmonics to reduce power line contamination. The power spectrum density (Welch's method) of all MEG sensor traces over the entire recordings was estimated to evaluate noise levels. A bandpass filter was subsequently applied at 0.1-30Hz to remove high-frequency components. Artifacts related to eye movements and cardiac activity were automatically detected and attenuated using Signal Space Projections (SSP). Independent components analysis (ICA) of the MEG sensor time series was performed, resulting in 20 components obtained with the extended infomax algorithm implemented in Brainstorm. Topographical maps of possible artifactual components related to eye movements and blinks were visualized and manually selected/eliminated. MEG data were then segmented into epochs ranging from −500 to 4000ms relative to stimulus onset (0ms; door opening). Baseline correction was performed on individual trial waveforms using a reference period from -500 to 0ms. Only correct trials in terms of emotional discrimination were considered for further analysis.

3.4.3 MEG source estimation

Source maps were obtained from the event-related trial average data for each participant and condition. Head models were obtained using the overlapping-sphere approach. The MEG source maps were constrained to 15,000 vertices distributed over the cortical surface. Prior to each MEG session, instrumental and environmental noise in the empty MEG room were captured with a 2-min recording and summarized via a noise covariance matrix subsequently used in the source mapping procedure. We used Brainstorm's dynamic statistical parametric mapping (dSPM) estimator of cortical current density with default parameters (depth weighing order set to 0.5 and maximal amount 10) [152]. The dSPM source maps are standardized by the equivalent of the MEG signal-to-noise ratio (SNR) at each cortical location. Spatial smoothing of the resulting source maps in each participant and each task condition was applied, with a full width at half maximum (FWHM) parameter of 3 mm. Five bilateral regions of interest (ROIs) were selected according to previous studies of biological motion perception and emotion processing and included the amygdala (AMG), fusiform gyrus (FBA), extrastriate body area (EBA), lateral occipital cortex (Occ), and the posterior superior temporal sulcus (pSTS). [16, 17, 24]. The Montreal Neurological

Institute (MNI) coordinates [x, y, z] of each ROI location were AMG (L [-32.9, -18.5, -12.5] / R [33, -21.7, -15.2]), FBA (L [-38.4, -26.6, -30.9]/ R [35.5, -36.2, -27.9]), EBA (L [-53.5, -74.4, 1.3] / R [58.7, -66.2, 8.8]), pSTS (L [-66, -52.8. 21.1] / R [70.7, -30.1, 10.3]), and lateral Occ (L [-39.4, -82.0, 7.9] / R [37.5, -91.6, 6.4]). The surface area of each ROI comprised between 60 and 120 vertices, corresponding to 7-16 cm^2.

For each task condition, a time series estimated currently at each cortical source within each ROI was extracted and used for the subsequent ERR analysis. We also derived contrast maps between cortical source maps in the emotional vs neutral pedestrian (angry vs neutral and happy vs neutral) by computing the difference between rectified cortical maps for each subject before averaging across participants.

3.4.4 Event-related response (ERR) analysis

We computed the mean response from each ROI from the dSPM maps, resulting in 10-time series [5 ROIs (e.g., AMG, EBA, FBA, Occ, and pSTS) per hemisphere]. A z-score transformation was applied to the resulting ROI traces with respect to their respective pre-stimulus mean and standard deviation. We considered two ERR components of interest, P1 and LPP, and estimated the latency of their respective peaks from the grand average ROI waveforms across participants and conditions. The P1 component was defined as the maximum positive peak after stimulus onset, with ROI-specific latencies: AMG, FBA, and EBA: 200-250ms, lateral Occ: 250-300ms, and pSTS: 250-350ms. For LPP, and in line with previous studies [109, 153, 154], we used a time interval between 400ms and 1500ms after stimulus onset. The time windows of the LPP strongly vary between studies. In order to enhance the comparability with similar studies [103, 109, 154] and to account for the time course of the observed brain responses in our experiment, we divided the LPP interval of interest further into three time windows. The LPP was quantified around its peak amplitude as well as during sustained activity, which includes early (400-600ms), middle (600-1000ms), and late LPP (1000-1500ms). The mean amplitude of source signals were derived across each LPP time window.

3.5 STATISTICAL ANALYSIS

MEG data were analyzed by means of generalized estimating equations (GEE). We first verified with univariate analyses that there were no hemispheric differences in P1 or LPP brain activation. We, therefore, pooled source data from the homologous ROIs in both hemispheres for all subsequent analyses. P1 was analyzed separately for each ROI with a GEE model comprising the emotion and gender of the virtual pedestrian as within-subject factors. For LPP, GEEs with three within-subject factors, i.e., emotion, gender, and phase (early, middle, and late), were used. Effects were deemed statistically significant at $p<0.05$, corrected for multiple comparisons with Bonferroni corrections. The GEE statistical analysis was conducted using SAS 9.4. Statistical differences in cortical contrast maps were assessed using two-sample paired parametric t-tests with Brainstorm, with a $p<0.05$ significance level and a false discovery rate (FDR) correction.

3.6 RESULTS

3.6.1 Behavioral data analysis

As shown in Fig. 4, participants correctly identified the emotions associated with gait with at least 80% accuracy across conditions. Although differences in response accuracy across conditions were small (3 - 12%), the GEE analysis revealed a significant main effect of emotion ($\chi2(2, 126)=16.38$, $p=0.0003$) and gender ($\chi2(2, 126)=4.26$, $p=0.039$). Post-hoc comparisons further revealed significantly higher accuracy of response for the angry vs. neutral and happy gait (Δ =3.86 to 11.9%, $p<0.0001$), as well as for the female vs. male pedestrian ($\Delta=0.0304$, $p=0.021$). No participant showed a strong positive or negative effect on the day of testing, with the mean ($\pm$ 1SD) positive and negative affect values of 31.1 $\pm$ 7.1 and -17.0 $\pm$ 5.3, respectively, on the PANAS (max=50). The mean SFQ score was 3.68 $\pm$ 0.61 out of 5 (range: 3.0 – 4.0), indicating a moderate sense of presence in the virtual environment.

3.6.2 MEG source analysis

The activity in brain regions of interest was first evaluated using t-tests (as implemented in *Brainstorm*), which allowed identifying significant levels of activation in response to emotional gait conditions with respect to the neutral condition. As illustrated in the contrast maps in Fig. 5, key regions involved in emotion processing and/or biological motion perception (e.g., AMG, FBA,

EBA, pSTS, and Occ.) showed significantly enhanced activation and confirmed the selection of ROIs for the present experiment. Furthermore, ERR traces retrieved from the five selected ROIs with their respective pre-stimulus mean and standard error of the mean (SEM) are shown in Fig. 6. The two evoked components, P1 and LPP, were observed at latencies of ~200ms and ~400ms, respectively. Since univariate analyses showed no significant difference between the left vs. right brain hemisphere for P1 (χ^2 (1, 252) < 1.13, p = 0.288) and LPP (χ^2 (1, 252) < 1.13, p = 0.257), data from the two hemispheres were combined in subsequent analyses.

GEE analyses revealed that the amplitude of P1 remained unaffected by emotion (χ2 (2,252) < 2.38, p > 0.305) and gender (χ2 (1,252) < 0.44, p > 0.508) and showed no statistically significant emotion x gender interactions (χ2 (2,252) < 1.90, p > 0.387) across the five ROIs. As observed in Fig. 7, however, the mean LPP amplitude for the five ROIs showed substantial variations across emotional gait conditions and time intervals. Results from the GEE model, which included emotion, gender, and phase as factors, are further summarized in Table 1.

The first key finding is that, while there was no significant main effect of the emotional gait on LPP amplitude in any of the five ROIs, the LPP amplitudes showed a significant emotion x phase interaction in all those ROIs. Post-hoc comparisons, further detailed in Fig. 6, revealed that in AMG and FBA, angry pedestrians evoked significantly larger LPP responses in comparison to the happy and/or neutral pedestrians in the middle (p=0.0003 –0.0091) and late LPP phases (p=0.0031 – 0.0120), but not in the early LPP phase (p=0.0749 - 0.6850). In EBA, a larger response was elicited by the happy pedestrian in comparison to both the neutral and angry pedestrians in the late LPP phase (p=0.0139 – 0.0324). Overall, larger responses during the middle phase of EBA were observed compared to its later phase. In pSTS and Occ, the angry pedestrian elicited significantly larger LPP responses compared to the happy pedestrian but not the neutral pedestrian (p=0.0521 – 0.2956) in both the early (p=0.0002 - 0.0065) and middle LPP phases (p= 0.0092 – 0.0214). In the late LPP phase, a significantly weaker response for the angry vs. happy pedestrian was instead observed due to a dramatic decrease in signal amplitude (p=0.0341 – 0.0498).

For clarity, the effects of gender, while considered in the same GEE model as emotion and phase, are presented separately in Fig. 7 b. No significant main effect of gender only or gender x emotion

interactions on LPP amplitude was observed in any of the ROIs (p=0.0823 – 0.0740). Significant gender x phase interactions, however, emerged for pSTS and Occ specifically (p=0.0033 – 0.0293). In those two ROIs, the interactions were caused by subtle variations in the way the signal amplitude varied across LPP phases for the male vs. female pedestrian conditions. Indeed, while either or both the male and female pedestrians elicited larger signal responses in the middle vs. early LPP phase (p<0.0001 – 0.0453), only the male pedestrian condition showed larger signal amplitudes in the middle vs. late LPP phase (p=0.0101 – 0.0190). In Occ, however, a larger response was also evoked in the late LPP by the female pedestrian compared to the male pedestrian (p = 0.0104).

3.7 DISCUSSION

We used MEG to investigate the spatiotemporal dynamics of brain activity when healthy young observers are exposed to emotional gait stimuli portrayed by virtual male and female pedestrians in a virtual community environment. This ecological paradigm revealed the effects of the emotional gait stimuli across the ROIs examined (AMG, FBA, EBA, pSTS, Occ). We found changes in amplitude and/or timing of the ERR's late positive potential time window (LPP; 400–1000ms), as defined in the literature. We also found that the gender of the virtual agents also impacted ERR measures.

Our primary objective was to characterize the brain signal changes involved in emotion perception from locomotor movements. As hypothesized, the richly textured ecological simulations used yielded a modulation of brain activation in response to emotional gait in ROIs related to visual processing (e.g., lateral Occ.), motion and form analysis (e.g., pSTS, EBA, and FBA) and processing of social cues (e.g., AMG).

This pattern of modulation is overall consistent with earlier studies that used simplified/impoverished stimuli such as PLDs and FLDs, where effects of the emotional movement were also detected in brain areas related to body representation (i.e., EBA, FBA, and pSTS) [20, 73, 144]. A noteworthy difference with previous PLD studies, however, is that we observed an emotion-dependent activation in the AMG. Enhanced AMG activation was previously observed in response to biological vs. random motion (e.g., object or scramble motion) in PLD

studies [155, 156]. However, we are not aware of modulations of AMG activation in response to emotional gait stimuli induced by PLD stimuli. We explain this apparent discrepancy by the extent of ecological validity of the stimulus employed [74]. Here, larger AMG activations were elicited by the human-like virtual agents displaying an angry gait. Similarly, a previous fMRI study conducted by Goldberg et al. (2015) also observed AMG activations in response to negative emotional gait stimuli displayed by faceless mannequins, which, while not as realistic as those employed in the present study, had enhanced ecological validity compared to PLDs [24].

We also observed modulations of FBA and EBA activation in response to a happy gait. We are currently not aware of PLD or FLD studies showing the influence of a happy gait on brain activation. Schneider et al. (2014) used presentations of faceless virtual agents with fNIRS to examine such responses [23]. They reported no significant difference in brain activation in areas EBA, FBA, pSTS, and the temporoparietal junction (TPJ) between happy vs. neutral gait conditions. We noted that two studies on emotional body movements in other tasks, however, did report enhanced FBA and EBA activations in response to happy stimuli [20, 144], as in our present study. Another locomotor study by Schneider et al. (2014) further reported that the rates of correct responses in the happy (74%) and neutral (60%) gait stimulus conditions were lower than those from our present data (87.3% and 91.7%, respectively). We interpret this difference as indicative of potential ambiguity in emotion recognition on behalf of participants, which might have reduced differential effects in brain activations between the two emotional gait conditions in previous studies. From the two studies mentioned above, which reported enhanced FBA and EBA activations during happy body movements not related to locomotion, the tone that used PLDs reported high emotion recognition rates (above 80%) [20], and the that used FLDs reported significant differences in subjective rating between emotional and neutral gaits [144]. This suggests that the salience of the stimulus used is a crucial component of the paradigm. We used realistic virtual agents (e.g., presenting human-like body structures, physical appearances, and displacements in space) embedded in a realistic environment (subway station), which participants were able to relate to, reminiscing their own real-life experiences. To conclude, the ecological validity of the trial presentation material and stimulus appears to influence brain responses to emotionally charged gait movements. These aspects need to be taken into consideration in study designs and the interpretation of findings in the field.

We also identified the temporal characteristics of brain responses to emotional stimuli. We are aware of previous reports from facial emotion experiments [157], but we believe our contribution to the study of responses to emotional gaits and emotional body movements fills a knowledge gap in the field. Previous studies used neuroimaging tools with slower temporal resolution (e.g., fMRI or fNIRS), which may have limited their sensitivity to dynamical stimuli. We observed two main ERR components, P1 (~200ms) and LPP (~400ms-1500ms). We verified our hypothesis that the presence of an emotional (non-neutral) gait stimulus did not modulate the P1 amplitude. Previous efforts did not report changes in P1 amplitude in response to PLD walkers vs. scrambled motion [96, 97]. This absence of effect was discussed as the P1 component being related to early visual (e.g., luminance) or lower-order motion processes (e.g., from basic structure cues or selective spatial attention) [158]. This would explain why we did not observe emotion-dependent amplitude changes of the P1. We did find a second component (LPP) that is considerably delayed compared to what is reported in the literature (~300ms) on biological motion perception [96, 97]. A previous MEG study examined brain responses in an identification task of the facing direction of PLD walkers and reported a second component between 300ms and 600ms post-stimulus onset [18]. We argue that the latency of this second component may depend on task complexity: more complex tasks, e.g., involving the encoding of social cues, may induce delayed and longer processing durations. In fact, the time window of the second component reported in our study, which ranged from 400 to 1500ms, is consistent with that of LPP, which is typically associated with selective attention to the emotional contents of stimuli [104]. Our analyses determined how the amplitude of this second (LPP) component unfolds over time between emotional gait conditions.

We found an interaction between emotion and the early, middle, and late phases of this LPP component across ROIs, which suggests that the dynamics of the LPP are modulated by the emotion presented. Previous studies have shown that the emotional content (e.g., affective pictures [110, 159, 160], faces [93, 161], and hand gestures [162]) robustly potentiates the LPP, an observation that we replicated here using emotional gait stimuli. Looking more closely at the different phases of the LPP, our results indicated that in the early phase, pSTS and Occ elicited larger responses to angry vs. happy gaits. We note that the pSTS has been linked preferentially to

motion and social processing [19, 69, 163-166]. Schneider et al. (2014) also found that the STS showed enhanced activation in response to negative vs. neutral stimulations [23]. During the middle LPP phase, the effect of angry gait in Occ and pSTS persisted, and we found a subsequent enhancement of brain activation within AMG, FBA, but not EBA, for the angry vs. happy and/or neutral gait. We, therefore, conclude that the processing of bodily-conveyed emotions is organized in a hierarchical manner, as described by Sokolov et al. (2018) [167]. Visual information is processed in pSTS and Occ, then transferred to the AMG, FBA, and EBA for subsequent analysis of emotional contents [73, 168, 169] via known anatomical connections [170-172]. We did not find an effect of selectivity for the angry gait condition in the middle LPP phase in EBA. We speculate that this region may be dominantly involved in the processing of body shapes and movements during action observation [173] over the processing of emotions. In the late phase of the LPP, we found an enhanced neural response for angry vs. neutral gaits exclusively in the AMG. Such enhanced and persistent AMG activation in response to negative stimuli is consistent with earlier work showing that AMG is principally involved in the processing of stimuli related to threats and danger [174-177]. Interestingly, our study's happy gait condition also induced larger activations in the late stage of LPP in regions that included FBA and EBA, compared to neutral gait stimuli. The reasons for this late enhancement of LPP in the happy condition are still unclear. Although the rates of emotion recognition were high in our study, we focussed our analyses on trials with correct responses only. This late LPP effect may have been caused by the recognition uncertainty for happy vs. neutral stimuli [24, 178, 179]. Such uncertainty would imply longer decision-making processing time and hence delayed responses. It may therefore explain the prolonged late LPP phase for the happy condition, as opposed to the angry condition, for instance, as this latter might have been easier to detect.

Our secondary objective was to determine whether the gender of virtual pedestrians affected the brain's response to emotional gait stimuli. We expected larger brain activity in response to male vs. female pedestrians, with the angry male condition eliciting larger activations in all task conditions. Our results, however, revealed no differences in the emotion-dependent modulation of LPP amplitude when viewing male vs. female pedestrians in any of the tested ROIs. This observation differs from an fMRI study conducted by Kret et al. (2011), which found significantly higher activation in EBA and STS when viewing threatening male vs female actions [180]. In that

study, however, the angry actions included overly aggressive movements where actors 'showed their fists', and others 'stamped their feet and made resolute hand gestures'. This presentation material may have produced a stronger feeling of threat in observers compared to the angry gait pattern used in our study. Our results did reveal an interaction between gender and phase in pSTS and Occ across all emotional gait conditions. Both areas are thought to be involved, respectively, in face-body integration [181] and perception of gender information from biological motion [182].

We argue that the gender x phase interaction primarily results from differences in how brain activation unfolds over time between male and female stimuli rather than actual differences in activation amplitude between male vs. female stimuli. For instance, the amplitude of activity in Occ was similar between male and female stimuli in the early and middle LPP but was lower for male vs. female pedestrians in the late LPP phase. Our analysis of this waveform in Fig 6 further shows that while the maximal activation in Occ is similar between male and female stimuli, the signal amplitude drops rapidly in the late LPP phase for male pedestrians, especially in the angry gait condition. Although not statistically significant, we found a similar pattern of rapid decrease of brain signal amplitude in other ROIs as well, especially for the angry male condition. This effect may be caused by the participants disengaging from the task earlier when presented with an angry male pedestrian vs. their female counterpart and other emotional conditions because this specific stimulus/condition pairing is processed faster. While we cannot ascertain this hypothesis as the experimental design did not allow for reaction time measurement, and while our response accuracies were subtly but significantly higher for the female pedestrian, as reported in the literature [60], others have observed shorter reaction times when identifying facial emotions of anger in male versus female actors [183]. Other studies have also shown that selective attention can modulate the ERR response because of disengagement from a task, causing a decrease in the ERR amplitude [184-186]. Taken together, our results suggest subtle differential effects in the time course of the brain signals in response to emotional gait movements of male vs. female pedestrians rather than actual differences in the maximal amplitude of brain activations.

3.8 LIMITATIONS

The intensity of the emotion was not controlled in this study: we, therefore, cannot exclude that some emotions may have been expressed with more intensity than others. However, we tested that

all emotions were recognized by all participants, with a minimum of 80% accuracy. We also included only correct trials in our analyses. In addition, the stimuli did not enable the dissociation between the impact of gait patterns (kinematics) and the physical appearance (face or body shape) of the virtual pedestrian for assessing the effect of gender. Further research could replicate this study and employ a neutral gender virtual agent as an additional control condition. Lastly, the inclusion of right-handed participants only, as well as the limited range of emotions studied and the binary classification of sex and gender considered, may limit the generalization of the reported findings. Other emotions, such as sadness or fear, could be explored to expand further our understanding of neural processes involved across a broader spectrum of emotions.

3.9 CONCLUSION

We aimed to advance the understanding of spatiotemporal characteristics of brain activity in response to emotional gait using MEG. We used a scenario presentation context with virtual pedestrians, which improved the ecological validity and familiarity of the task. The findings of this study provide evidence that emotional gait, as rendered by stimuli that comprise biological motion and pictorial information, modulate brain activation within areas associated with biological motion, form, and emotion processing and that the temporal characteristics of the brain signals differ depending on whether the emotions are conveyed by a male or a female individual. In addition, findings that are possibly unique to the use of ecological, human-like stimuli were observed, which has implications for the interpretation of findings across studies and for the design of future virtual reality-based applications in research or in rehabilitation. Current findings further generate a basis for comparison to identify defective brain processes associated with social cognition deficits in populations with traumatic brain injury, autism spectrum disorder, and schizophrenia [81, 187, 188]

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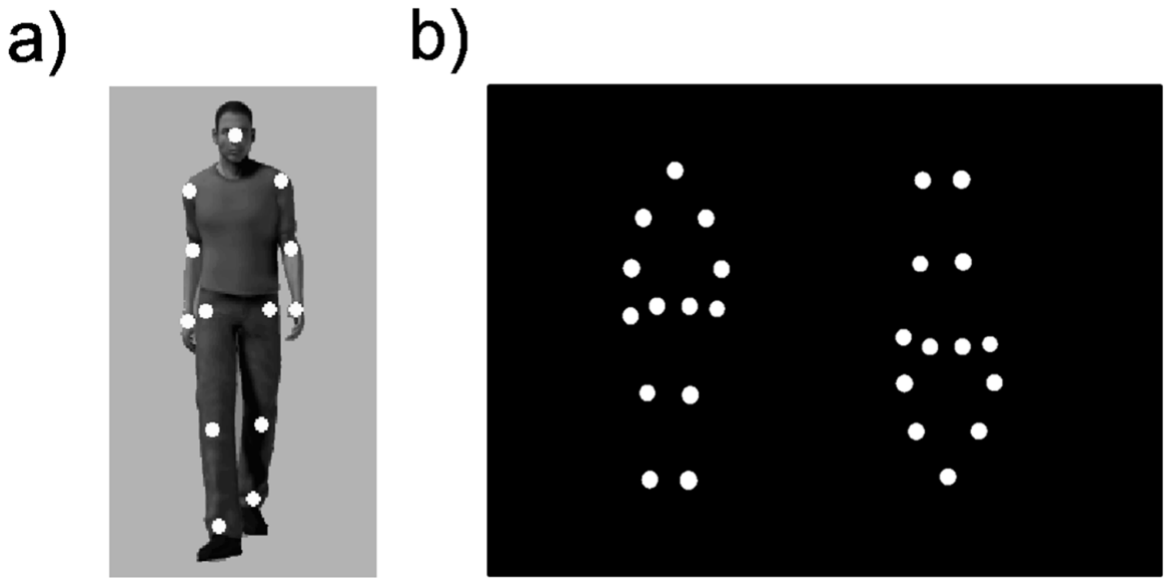
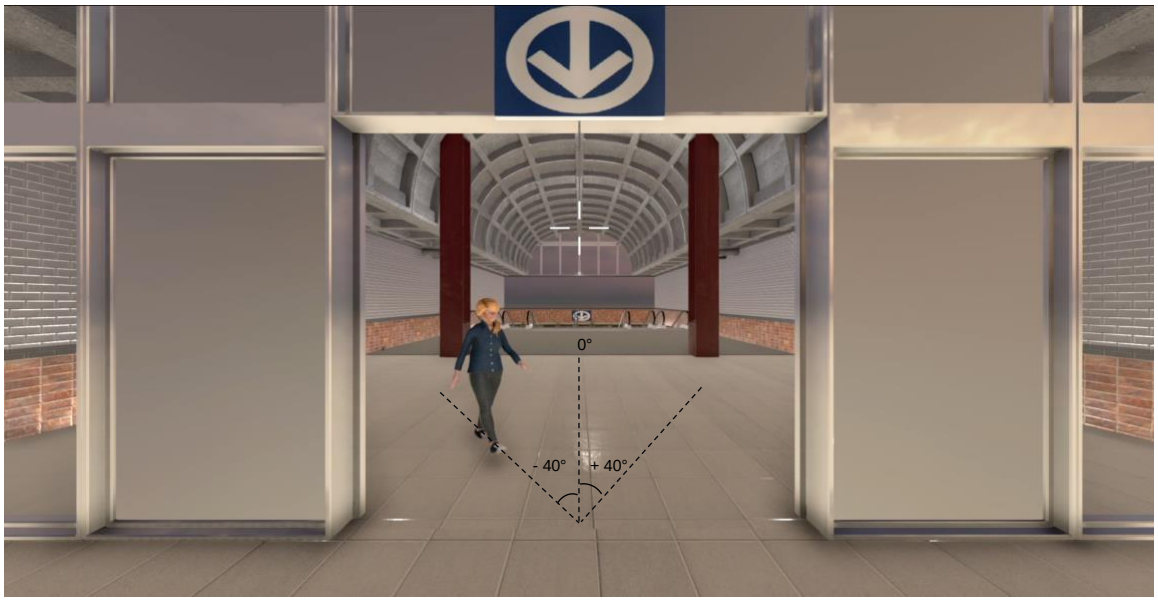


Figure 1. (a) The schematic depiction of the concept of the point-light display. The bodily motion of a human walker is represented as a constellation of moving white dots attached to each joint. (b) An example of the stimulus displayed in the darkness, as used in biological motion perception experiments.

a.



b.

c.

Figure 2. (a) Example of the virtual environment with a metro station background and an approaching virtual pedestrian walking with an emotional gait. The black dotted lines indicate the three possible pedestrian trajectories. (b) The experimental setup, including the rear-projection display and the MEG instrument. (c) One participant with electrodermal sensors measuring heartbeats and eye movements, as well as 3D glasses. They were instructed to hold the response box with both hands to avoid MEG signal contamination induced by muscle tension.

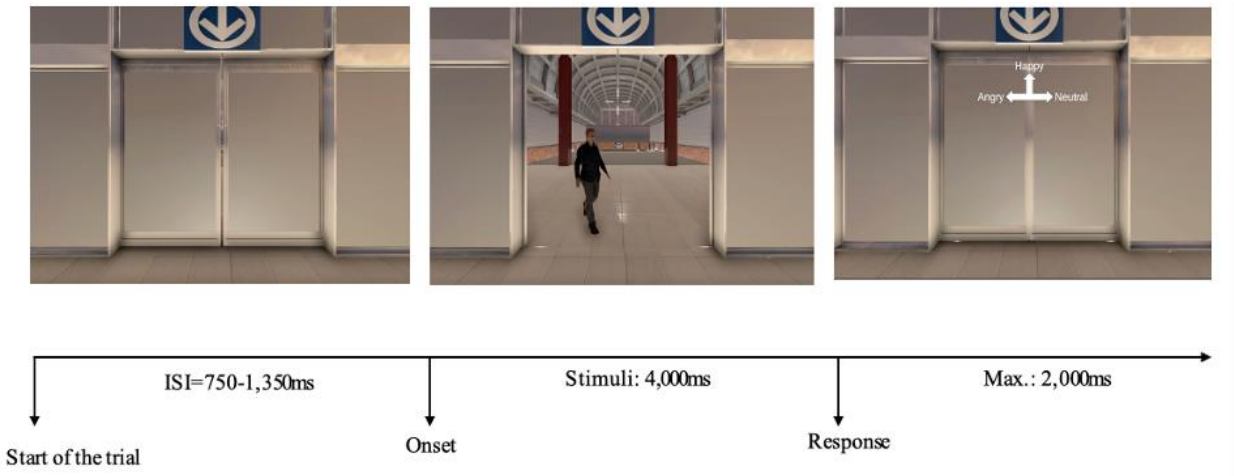


Figure 3. The paradigm used in the present study. Timeline of an experimental trial with an example of a male pedestrian approaching and displaying a gait pattern. At the end of the trial, the panel with three alternative options popped up to request participants to provide responses.

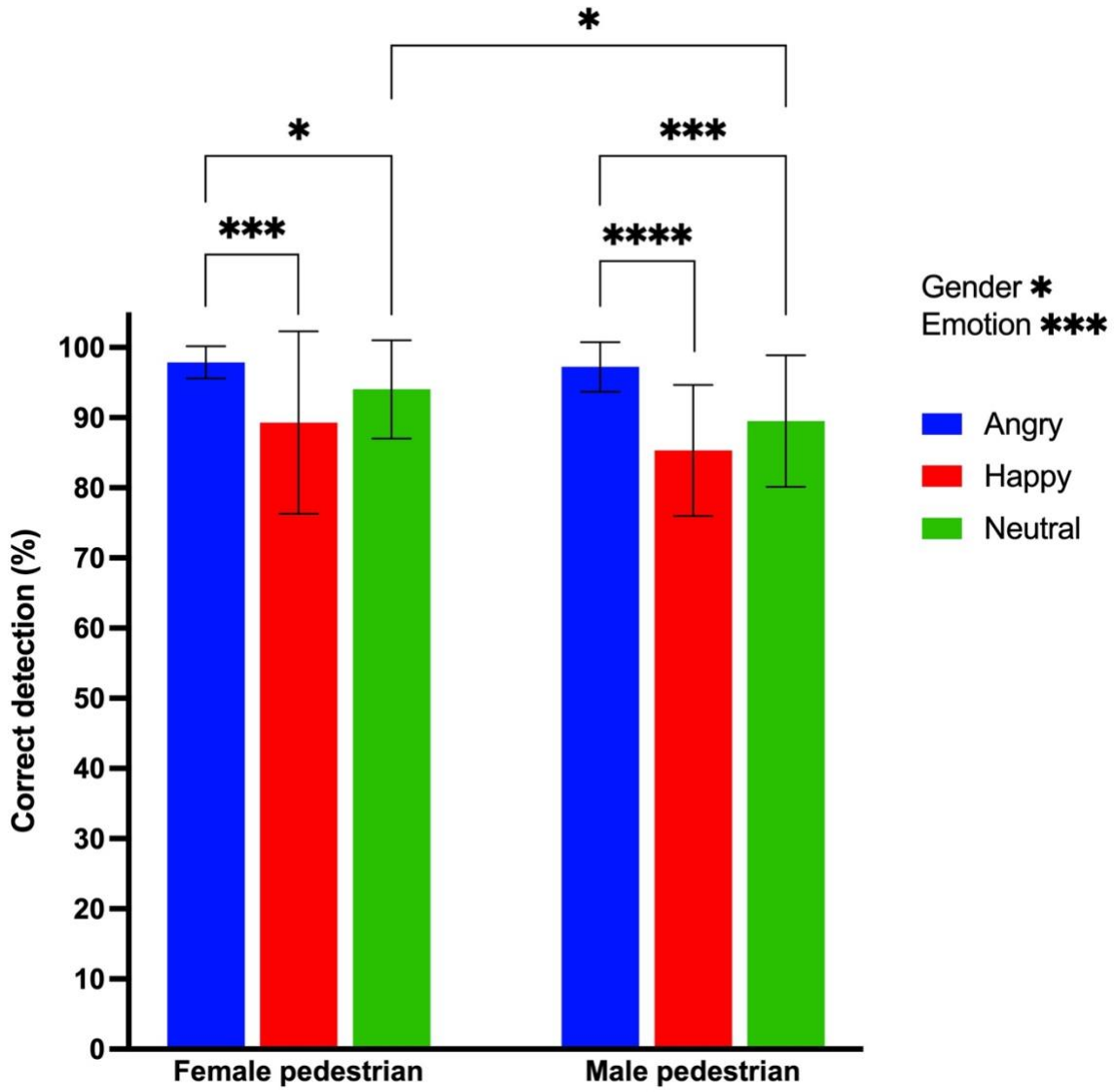


Figure 4. Mean (± 1SD) rate of correct responses in the emotion identification task for each emotional gait condition (blue: angry; red: happy; green: neutral) for the female (left column) and male virtual pedestrian (right column). Statistically significant main and interaction effects are indicated, as applicable. Likewise, post-hoc comparisons that were statically significant are also illustrated (* $p<0.05$. ** $p<0.01$. *** $p<0.001$. **** $p<0.0001$).

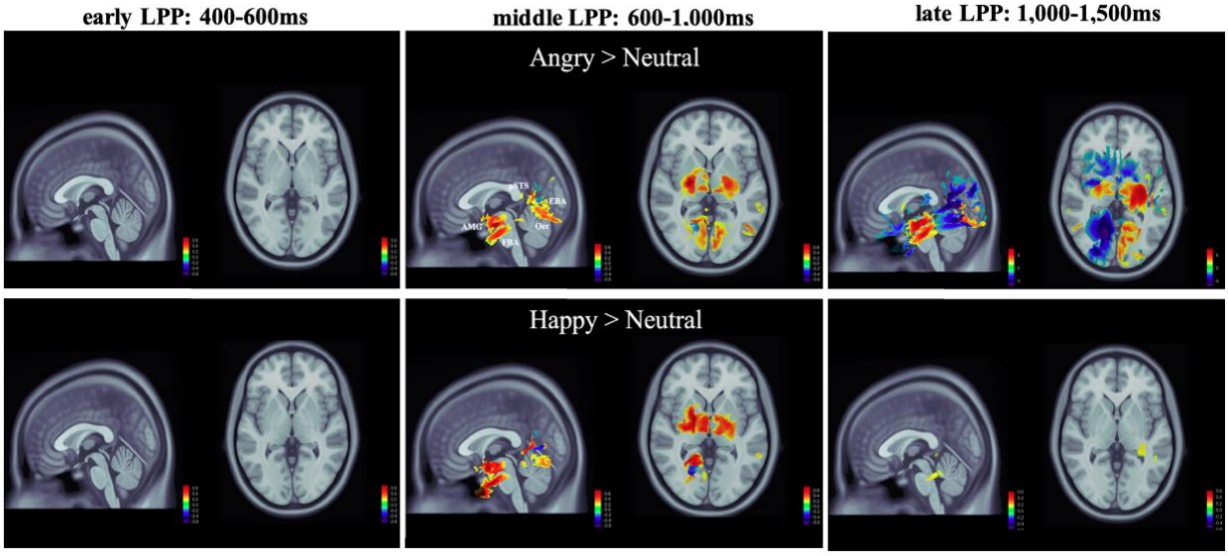


Figure 5. Contrasts of emotional (upper: angry vs neutral; bottom: happy vs neutral) gait patterns showed stronger and more widespread emotion-specific activation (left: medial view; right: superior view), and the ROIs were indicated in the activation areas. The colour bars on the right indicate the grading of the z-score. Note that the scale of angry vs neutral (top-right) was modified to match the values. The obtained results were averaged across the time interval of early LPP (400-600ms), middle LPP (600-1,000ms), and late LPP (1,000-1,500ms), respectively.

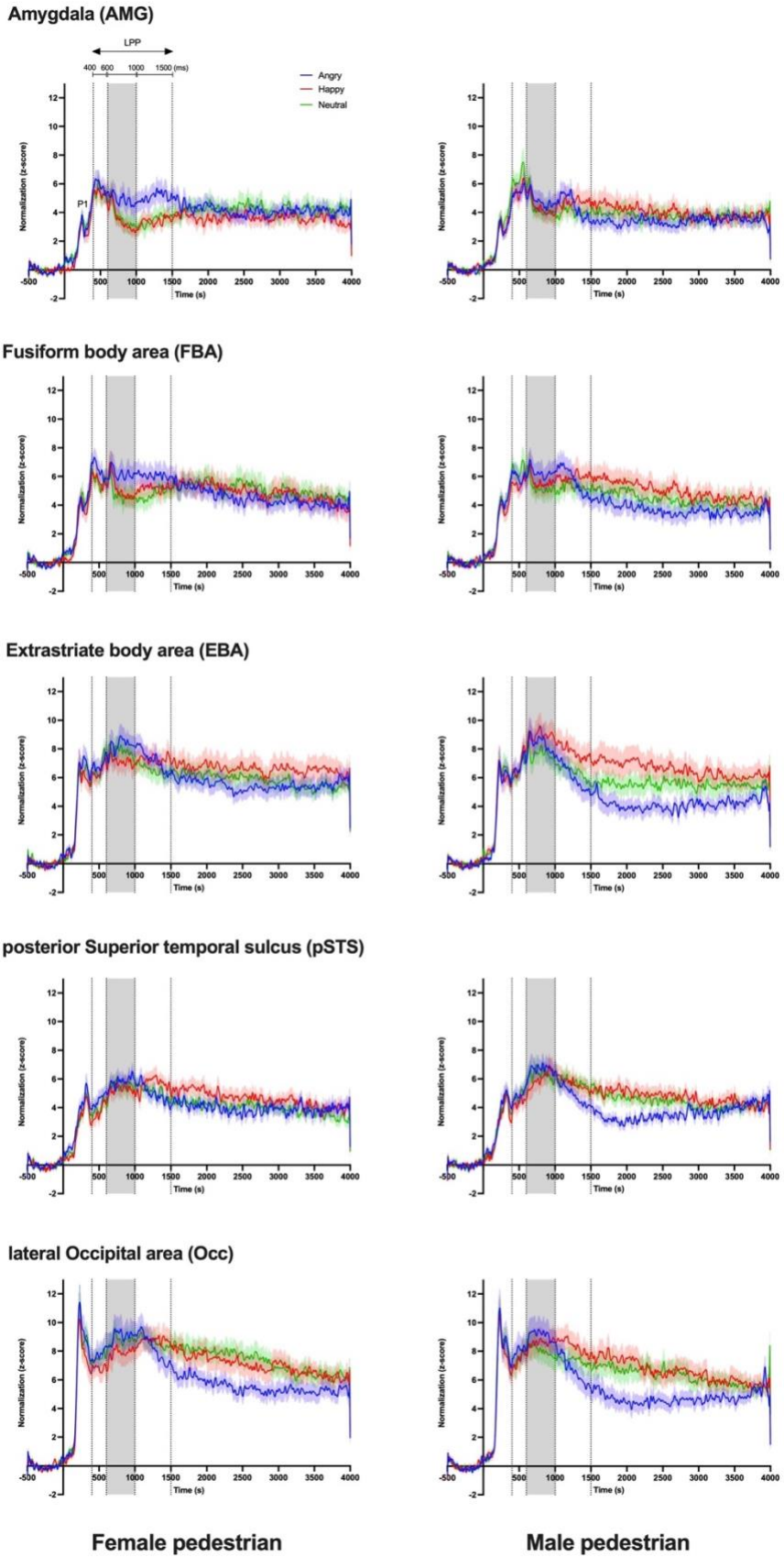


Figure 6. Each trace represents the grand-average waveform with SEM for each emotional gait condition of the female and male pedestrians. The different colours illustrate the different emotions, i.e., angry (blue), happy (red), and neutral (green). The three separate time intervals of the entire LPP component are marked with vertical lines representing the early (400-600ms), middle (600-1000ms), and late LPP (1000-1500ms) phases.

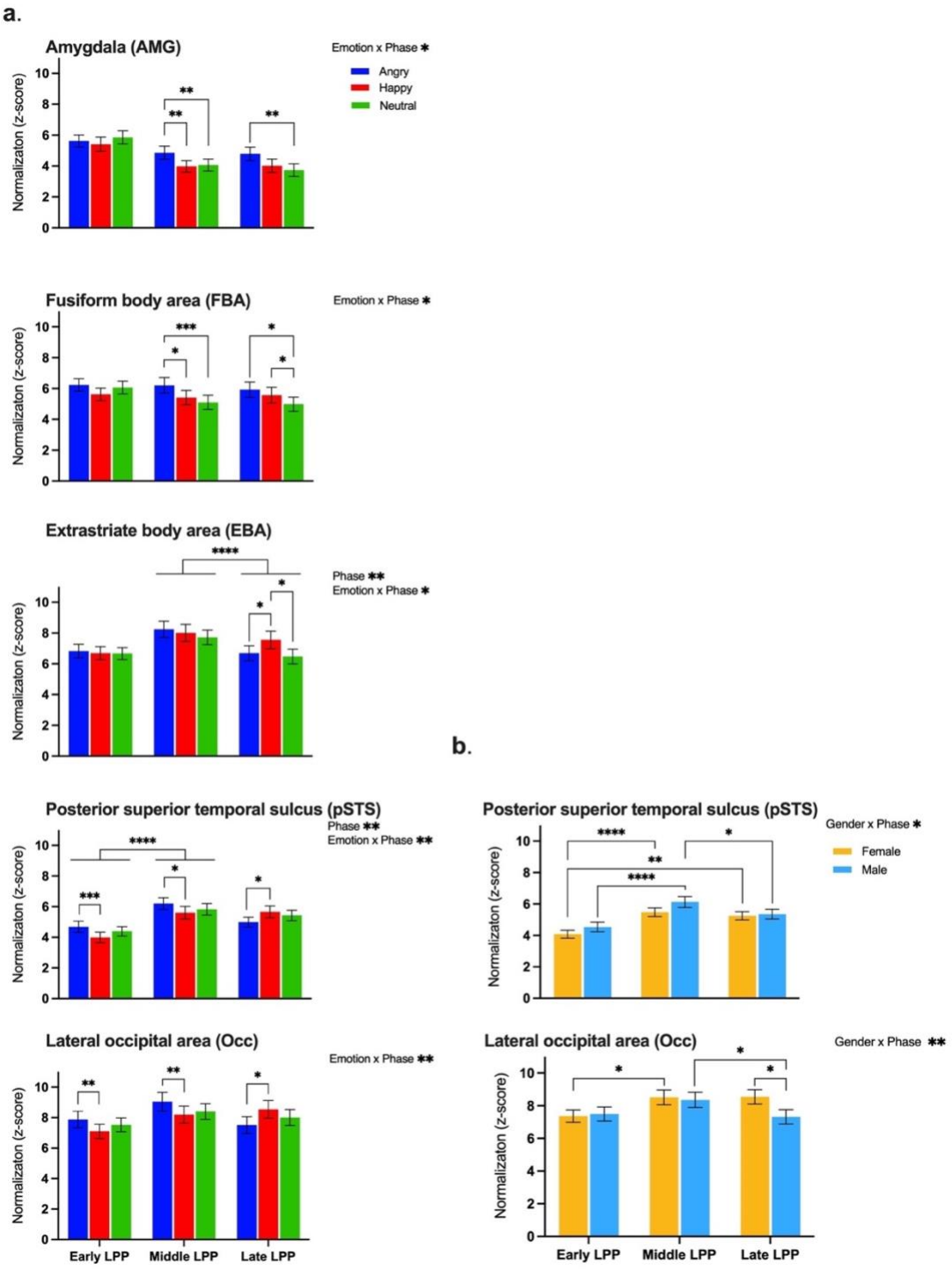


Figure 7. (a) Mean LPP amplitude ± SEM for three separate time windows over 5 ROIs (e.g., AMG, FBA, EBA, pSTS, Occ) with significant emotion x phase interactions. (Blue: angry; Red: happy; Green: neutral). (b) Mean LPP amplitude of pSTS and Occ with the significant gender x phase interactions (Orange: Female pedestrian; Light blue: Male pedestrian). The symbol indicates * $p<0.05$. ** $p<0.01$. *** $p<0.001$. **** $p<0.0001$.

	Main effect						***Two-factor interaction***											
	df, Chi-square, Pr. > ChiSq.																	
	Emotion			**Gender**			**Phase**			**Emotion x Phase**			**Emotion x Gender**			**Phase x Gender**		
AMG	2	3.94	0.1392	1	0.76	0.3822	2	4.99	0.0825	4	10.39	0.0344*	2	3.02	0.2205	2	0.60	0.7399
FBA	2	5.77	0.0559	1	0.01	0.9254	2	0.67	0.7162	4	12.00	0.0173*	2	1.51	0.4695	2	1.88	0.3911
EBA	2	1.30	0.5219	1	0.82	0.3638	2	10.51	0.0052**	4	10.94	0.0272*	2	2.92	0.2326	2	4.99	0.0823
pSTS	2	1.19	0.5511	1	1.52	0.2170	2	11.90	0.0026**	4	14.16	0.0068**	2	1.61	0.4475	2	7.06	0.0293*
Occ	2	1.17	0.5569	1	0.92	0.3379	2	4.24	0.1200	4	14.28	0.0065**	2	2.99	0.2243	2	11.44	0.0033**

Table 1. This table summarizes the significance of the main and interaction effect on LPP amplitudes in each ROI (AMG, FBA, EBA, pSTS, Occ.). Statistically significant results are indicated with star symbols, when applicable: *p<0.05, **p<0.01, ***p<0.001.

CHAPTER 4: GENERAL DISCUSSION

In this study, we investigated the healthy brain mechanisms involved in the perception of emotional gait. This chapter discusses the knowledge gaps addressed by this thesis work and the implications of findings for future studies.

4.1 SUMMARY OF FINDINGS

Locomotion, a common and essential activity of daily life, is modulated not only by the sensorimotor abilities of individuals but also by factors such as emotions and sex/gender. The purpose of this MSc thesis was to investigate the spatiotemporal dynamics of brain activity when healthy young observers are exposed to emotional gait stimuli. To achieve this goal, we designed a MEG experiment to record the brain activity of healthy young participants as they discriminated emotional gait stimuli portrayed by human-like, male, and female virtual pedestrians walking in a virtual community environment.

Confirming the first hypothesis, results revealed that the nature of the emotional gait stimuli influenced the neural activity across the ROIs examined, as indicated by a modulation in the amplitude and/or latency of the ERRs in a time window consistent with the LPP (400-1500ms) in the literature on emotion processing. To our knowledge, however, this is the first time that modulation of the LPP component was observed in response to emotional gait stimuli specifically. This late modulation may apparently contrast with what was previously reported in the very few PLD studies that have examined the temporal characteristics of the brain response to biological motion cues, and which have reported modulations in an earlier time window (e.g., ~300ms). However, these previous studies employed impoverished stimuli (PLD consisting of moving dots) and simpler tasks (e.g., detecting biological motion), whereas the stimuli (biological motion and pictorial information) and task (deciphering emotions) used in the present MSc project were more complex and naturalistic. Furthermore, the enhanced and robust potentiation of LPP observed in the present project is consistent with the role of this component which, based on studies of facial emotions or affective static pictures [102, 103, 108, 154, 159], has been associated with the processing of higher-order visual information. Conversely, in contrast with LPP, we found that the

amplitude of P1 is unaffected by emotion (and gender), which suggests that the P1 component is associated with early visual or lower-order motion processes.

The ecological stimulations, as stipulated in hypothesis 2, yielded a modulation of brain activation in response to emotional gait in ROIs related to visual processing (e.g., Occ.), motion and form analysis (e.g., pSTS, EBA, and FBA) and processing of social cues (e.g., AMG). In contrast to previous PLD studies on emotional gait, the present study and others using human-like agents performing emotional gestures did report a modulation in the AMG. This suggests that ecologically valid stimuli lead to a stronger modulation of activity in AMG, possibly by increasing stimulus saliency and favouring the recall of daily life situations. Our results may reflect our daily life experiences, although subtle differences do exist in terms of the perceptual [132] and behavioural responses of individuals [13, 65] in virtual vs. physical environments.

Analyses of LPP responses further revealed an interaction between emotion and phase across all ROIs, suggesting that the time course of this activation differs with the emotion presented. Considering the temporal course of activations across the different ROIs, our results further suggest a hierarchical organization, starting with the visual information first processed in pSTS and Occ, then transferred to AMG, FBA, and EBA for subsequent analysis of human action and emotion [73, 168, 169]. We found that the valence of emotional gait (positive vs. negative) also affects LPP responses. Indeed, we observed enhanced responses for angry vs. happy and/or neutral gait stimuli in the middle LPP phase in the ROIs examined. The observation of an enhanced AMG activation in response to negative stimuli is consistent with earlier work, which shows that AMG is principally involved in processing stimuli related to threats and danger [174-177]. Interestingly, the happy gait was also found to induce larger activations in the late stage of LPP in regions that included FBA and EBA, compared to neutral gait stimuli. This late enhancement of LPP for the happy condition could be caused by the often-reported recognition uncertainty for happy vs. neutral stimuli in the literature [24, 178, 179], which would imply longer decision-making processing time and hence delayed responses for participants.

To address the last and third hypotheses, the effects of the virtual pedestrians' gender on brain activation were examined. Our results revealed no differences in the emotion-dependent

modulation of LPP amplitude when viewing male vs. female pedestrians in any ROIs. They showed, however, the presence of an unexpected interaction between gender and phase in pSTS and Occ. Areas pSTS and Occ are thought to be involved, respectively, in face-body integration [181] and perception of gender information from biological motion [182], which may explain the differential variations in the brain signals in those areas when exposed to male vs. female stimuli. This gender x phase interaction, however, appears to result primarily from differences in how brain activation unfolds over time between male and female stimuli rather than actual differences in activation amplitude between the two stimuli. Interestingly, the activation in Occ was found to be significantly lower for male vs. female pedestrians in the late LPP phase, the former showing a rapid drop of the signal that was especially visible for the angry gait condition. While not coming out as statistically significant, a similar pattern of a rapid drop of the brain signal was observed in other ROIs as well. This rapid drop may be caused by the participants disengaging from the task earlier when presented with an angry male pedestrian vs. a female pedestrian and/or other emotional gait conditions because the angry male condition would be recognized faster. This hypothesis would be consistent with a behavioural study that reported a faster reaction time when judging angry facial expressions in male vs female actors [183].

4.2 SIGNIFICANCE AND FUTURE DIRECTION

Results collected from the present study deepen our understanding of the brain processes involved in emotion perception from locomotor movements and the modulatory role of gender information in these processes. The few past studies that have explored the modulation of brain responses to emotional gait stimuli mainly focussed on the spatial aspect of the brain response, leaving temporal characteristics largely unexplored. In this MSc project, the MEG measurement allowed following the rapid changes in cortical activity, providing insights into ongoing brain signal processing. In fact, the study conducted as part of this MSc project was the first to quantify ERRs and uncover an emotion-dependent modulation of LPP in response to emotional gait. Such findings may be fundamental in encouraging future studies to examine the functionality of LPP as a neural marker for emotional reactivity in the context of interpersonal interactions. The nature of the stimuli used in this study (3D, human-like agents) also yielded common as well as different results from those reported in previous studies that have employed impoverished stimuli such as PLDs. This aspect

of ecological validity needs to be taken into consideration in the design of future studies and the interpretation of findings across studies in the field.

This project can be further expanded to explore the potential influence of the sex of the observers on the brain's response to the emotional gait stimuli, with the recruitment of a larger sample size allowing for adequate statistical power. Amongst others, clarifying the impact of sex on neural circuits underpinning biological motion or emotion processing may provide novel insights into the understanding of gender vulnerability in some psychiatric and neurodevelopmental disorders involving social cognition deficits. Disorders related to social functioning, including autism, depression, and schizophrenia, differ drastically in incidence and severity between males and females[189]. The information collected in the study will also serve as a basis for comparison to identify defective brain processes involved in social cognition deficits in populations such as individuals with traumatic brain injuries, autism spectrum disorder, and schizophrenia.

CHAPTER 5: REFERENCES

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APPENDIX

Appendix I – Emotion discrimination accuracy

The accuracy of each video clip (~ 4 seconds); only the video clip with the highest accuracy above 80% was selected for the experiment. A published psychophysiological study has shown that humans can recognize several factors, such as the identity, sex, or emotion, of PLD walkers solely by their gait with 70–80% accuracy or even above. Considering the fact of less difficulty for emotion recognition from a virtual avatar than ambiguous PLD, we decided to set our cut-off of 80% to ensure the validation of emotional gait.

Participant = 22 (Female = 9; Male = 13)

Gender	Emotion	Video I	Video II
Female	Angry	87.30%	92.06%
	Happy	82.54%	80.51%
	Neutral	92.06%	98.42%
Male	Angry	89.34%	84.84%
	Happy	86.36%	83.33%
	Neutral	95.45%	92.42%

Appendix II – English consent form

INFORMATION AND CONSENT FORM

Healthy young adults

Research Study Title:	Perceptual brain mechanisms of emotions conveyed by the gait pattern of virtual pedestrians
Protocol number:	2021-7393
Researcher responsible for the research study:	Dr. Anouk Lamontagne, PT, PhD, School of Physical and Occupational Therapy, McGill University Tel: (450) 588-9550, ext.: 531; Email: anouk.lamontagne@mcgill.ca Yu-Tzu (Tracy) Wu, MSc student, School of Physical and Occupational Therapy, McGill University Tel: (438) 530-7456 Email: yu-tzu.wu2@mail.mcgill.ca
Co-Researcher(s)/sites:	Dr. Sylvain Baillet, PhD, McConnell Brain Imaging Center, Montreal Neurological Institute (MNI) Tel: (514) 398-5469 Email: sylvain.baillet@mcgill.ca Dr. Shashank Ghai, PhD, Jewish Rehabilitation Hospital, Laval Tel: (450) 688-9550 ext. 626 Email: shashank.ghai@mail.mcgill.ca Dr. Eva Kehayia, PhD, Jewish Rehabilitation Hospital, Laval Tel: (450) 688-9550 ext. 634 Email: eva.kehayia@mcgill.ca
Sponsor:	Supported by the National Sciences and Engineering Research Council (RGPIN 04471-2016)

INTRODUCTION

We are inviting you to participate in this research study because you are a healthy young adult, and we aim to examine healthy patterns of brain activation involved in emotion recognition. However, before you accept to take part in this study and sign this information and consent form, please take the time to read, understand and carefully examine the following information. You may also want to discuss this study with your family doctor, a family member, or a close friend.

We invite you to speak to the researcher responsible for this study (Anouk Lamontagne) or other research team members (Tracy Wu, Sylvain Baillet, Shashank Ghai, Eva Kehayia) and ask them any questions you may have about this study. Please also ask a member of the research team about any parts of this consent form you do not understand.

BACKGROUND

The ability to read body language is essential for humans to produce appropriate social interactions with others. People can identify the actions and intentions of others by observing their body movements and make a social judgement related to their emotional state or gender. Such principles also apply to daily living activities such as community walking, where we detect the emotions and intent of others through walking movements and react accordingly. To date, we have very little information on the brain regions involved in the perception of emotions conveyed by the walking pattern of individuals. Establishing the healthy patterns of brain activation involved will serve as a basis to understand deficits in emotion perception and social interactions presented by clinical populations (e.g. population with traumatic brain injury and autism spectrum disorder).

PURPOSE OF THE RESEARCH STUDY

The purpose of this study is to characterize the brain signals of healthy young adults as they detect the emotion of male and female virtual pedestrians expressing different emotional states through their walking movements. The primary objective is to understand the brain connection between regions responsible for motion and emotion processing. Additionally, the secondary objective is to examine the impact of the other factors (e.g., gender/sex, direction of approach of pedestrian) on brain activation involved in motion and emotion processing.

For this research study, we will recruit 24 right-handed participants (12 men, 12 women) aged between 18 and 29 years.

DESCRIPTION OF THE RESEARCH PROCEDURES

This research study will take place at the Magnetoencephalography (MEG) unit, McConnell Brain Imaging Centre, Montreal Neurological Institute-Hospital.

1. Duration and number of visits

Your participation in this research study will include a single visit which will last approximately 2 hours, including the clinical assessment (30 min), preparation time (30 min) and MEG testing (60 min).

2. Overview of study participation

This study employs a repeated measure, experimental study design. Your participation involves one **emotion discrimination task** with a total of 480 trials. During the session, you will be instructed to observe male/female pedestrians walking and discriminate their emotional states. Meanwhile, your brain activation will be measured by a neuroimaging instrument called magnetoencephalography (MEG). MEG measures the magnetic fields generated by the tiny electrical currents that flow in your brain without injecting any compound in your body, without administering external energy or radiation. Because MEG is very sensitive, you must be in an electromagnetically shielded chamber, which filters waves generated by electronic devices, to ensure the quality of the data. You will be evaluated while seated in the MEG chair in front of a translucent screen and wear 3D glasses to view the virtual display projected on the screen. Throughout the testing, English or French instructions will be provided. You will also be provided with a keyboard to indicate your responses (i.e., which emotion you perceived). The researcher will remind you not to move your head during the test because head movements degrade the data quality, and you will be invited to rest between blocks.

3. Study Procedures

Your involvement in this research study comprises of the following steps and procedures:

DESCRIPTION OF STUDY PROCEDURES		
Procedure		**Description**
Initial Clinical Assessment (20 min)	Eligibility screening	Your age and health condition will be reviewed in order to ensure your eligibility to the study. For the same purpose, handedness and visual acuity will be assessed.
	Sex & gender interview	You will be requested to report your biological sex to the researcher. An optional gender self-identification question will also be asked. Responses will be kept confidential.
	Emotional state assessment	Your emotional state will be assessed using a brief self-report questionnaire - Positive and Negative Affect Schedule (PANAS).
Preparation (30 min)	Habituation trials	Practice trials of the emotion discrimination task will be provided outside the scanner room. You will be instructed to practice until reaching 80% of correct responses on the task, with a minimum of 20 practice trials and a maximum of 60 trials.
	Clothes change	Because MEG is very sensitive, you will be asked to change to a hospital gown to ensure your clothes or particles on their fabric do not alter data quality. You will be able to change in a dedicated, private locker room right outside the MEG suite.
	Electrodes attachment	The researcher will tape a few electrodes on your torso (for monitoring heartbeats) and on your forehead and cheeks (for monitoring eye movements). This is to control for possible, normal, magnetic artifacts generated by eye movements and heartbeats. The researcher will also tape additional electrode-like sensors on your head to monitor your head position inside the MEG instrument. Finally, the researcher will use a pencil-like device to acquire the shape of your head in three dimensions.
MEG Measurement (1 hour)	Pre-operation	You will be asked to perform the test while seated on the MEG chair. The researcher will modulate a suitable seat position for you. The MEG helmet will cover only the top, back and sides of your head. At all times, you will be able to communicate with the MEG operator who will be sitting immediately outside the MEG room. The MEG operator will also be able to see you through a monitor screen. A verbal confirmation process will be followed through a microphone in the MEG room to ensure that you understand the instructions.
	Habituation trials	Before the actual data collection, you will practice a minimum of 5 trials until you feel comfortable with the task.
	Resting-state recording	The resting-state brain activity will be recorded at the very beginning of the experiment and the end. During the recording, you will be instructed to stay as stable as possible and look at the crosshair displayed on the screen for 6 mins.
	Emotion discrimination task	You will be instructed to fixate your gaze on the crosshair. Each visual simulation will last approximately 4 seconds. The simulations consist of virtual male or female pedestrians approaching from different directions

		and displaying different emotional states through their walking pattern. After the simulation ends, you will be given 2 seconds to provide your answer among multiple choices (happy, angry and neutral) by pressing the desired arrow key on a keyboard. Overall, you will conduct a total of 480 trials. The data collection in the MEG scanner will last approximately 1 hour. You will be invited to rest for 1 min between blocks of 96 trials (5 breaks). You can, however, take a break as often as needed during the experiment. If you do not feel comfortable at any moment during the test, please speak up, wave your hands or simply stand-up and walk out of the room: you will be able to open the MEG room door from the inside.
Final Clinical Assessment (10 min)	Electrodes removal	The attached electrodes will be removed and cleaned using a sanitizer.
	VR experience questionnaire	After the experiment, you will be requested to report your sense of presence in the virtual environment using a short feedback questionnaire (SFQ).

BENEFITS ASSOCIATED WITH THE RESEARCH STUDY

There is no direct benefit to you for participating in this research. However, we hope that the study results will contribute to the advancement of scientific knowledge on the brain processes involved in emotion recognition from body movements. Results will also be used as a basis for comparison to contrast with those obtained in population with social cognition deficits.

RISKS ASSOCIATED WITH THE RESEARCH STUDY

A possible risk associated with this study is a breach of confidentiality or use of your personal information by a third party. To limit this risk, we will take steps to protect your confidentiality described in the Confidentiality section below.

You may find the clinical evaluation (questionnaires, interview) upsetting or distressing. You can refuse to respond to any of the questions and/or choose to stop participating in the study altogether at any time. You do not have to give any reason for refusing to answer a question or for stopping to participate. If you feel uncomfortable at any time, do not hesitate to tell the researcher(s) who will stop the interview or the experiment.

Your participation in the emotion discrimination experiment, as well as the MEG assessment, involves minimal risks. According to the latest knowledge, there is no known health risk associated with the magnetic field emitted by the MEG scanner as you do not have any contraindications (e.g., presence of any non-removable metal device, such as a cochlear implant, a pacemaker, or a neurostimulator containing electrical circuitry, generating magnetic signal).

To prevent the risks of COVID19 infection, data collection will follow the sanitary guidelines of the Ministère de la Santé et des Services Sociaux and McGill University. A member of the research team will greet you at the door of the neuro and walk with you to the MEG unit. A designated, single toilet bathroom will be provided so that you can change before testing. Other than you, only one member of the research team and the MEG operator will be present in the testing environment. The researcher and MEG operator will disinfect their hands and wear personal protective equipment at all times (e.g., gloves, eye goggles, facemasks). As participant, you will also wear a facemask, which you will be requested to remove only once seated in the MEG chair and ready for data collection. All surfaces will be disinfected before and after the experiment. A distance of 2 meters between you and other persons present in the environment will be maintained at all times, with the exception of when the electrodes are being apposed to your skin.

We do not foresee any other risks associated with this study.

INCONVENIENCES LINKED TO STUDY PROCEDURES

Virtual environments: Certain individuals may experience cybersickness (e.g. nausea, headaches, dizziness) when

exposed to virtual reality simulations. People who are motion sick in everyday life are more prone to cybersickness. Such symptoms, while unpleasant, have no long-term consequences. If you were to experience cybersickness, please ask the researcher to take a pause until it resorbs. If it does not resorb, you may opt to stop the experiment at any time.
You may also experience fatigue due to many trials and the duration of the test, but this will also be temporary. If you become tired during the session, you will be able to rest before continuing.
MEG testing: During the imaging measurement, you may experience discomfort or dizziness because you will be in a confined environment during the tests. If this happens, you can always communicate with the researcher and request a break/interruption of your participation.
These are the only foreseeable inconveniences that may result from study participation.

VOLUNTARY PARTICIPATION AND THE RIGHT TO WITHDRAW
Your participation in this study is voluntary. Therefore, you may refuse to participate. You may also withdraw from the *ongoing* project at any time, without giving any reason, by informing a member of the study team. In accepting to participate in this study, you will not relinquish any of your rights, and you will not relieve the researchers nor their sponsors or the institutions involved from any of their legal or professional obligations. You will be informed in a timely manner if any information becomes available that may impact your willingness to continue participating in this study.
The researcher or the Research Ethics Board may put an end to your participation without your consent. This may happen if new findings or information indicate that participation is no longer in your interest, if you do not follow study instructions, or if there are administrative reasons to terminate the project.
If you withdraw or are withdrawn from the study, you may also request that the data already collected about you be removed from the study. If you request that your data be removed and the information already collected about you can be identified as yours, it will be destroyed. If the data has been anonymized or was always anonymous (i.e. does not contain any information that can be used to identify you), the data will continue to be used in the analysis of the study.

CONFIDENTIALITY
During your participation in this study, the researcher and his/her team will collect and record information about you. They will only collect information necessary for the study.
The following information will be collected: information from your interview, questionnaires, including your identity, gender identification, past and present health conditions, as well as the results of the tests, exams, and procedures that you will undergo during this research project. Your research file could also contain other information, such as your name, sex, date of birth and ethnic origin.
All the information collected during the research project will remain confidential to the extent provided by law. You will only be identified by a code number. The key to the code linking your name to your study participant number will be kept by the researcher.
It is possible that the experiment will be recorded with video and that photographs will be taken. We will only use these with your permission for educational and/or scientific purposes. It is, however, not necessary to consent to this section in order to participate in the current project. If you refuse to consent, the recordings and photographs concerning you will be destroyed at the end of the project to respect your confidentiality.
The study data will be stored for 10 years by the researcher responsible for this study. The data can also be stored in a database called Open MEG Archive (OMEGA) if you accept and sign the database consent form provided by the investigators. All the information collected for the registry will remain strictly confidential to the extent prescribed by law. The data may be published or shared during scientific meetings; however, precautions will be taken to ensure that it will not be possible to identify you.

INCIDENTAL FINDINGS
The images and data collected are not routinely examined for abnormalities. In the course of this study, if we uncover evidence of a significant incidental finding, we will communicate with you and to a health professional of your choice.

FUNDING OF THE RESEARCH PROJECT

The researcher and the institution have received funding from National Sciences and Engineering Research Council (RGPIN 04471-2016) to conduct this research project.

CONFLICT OF INTERESTS
The researchers have no conflict of interest to declare.

COMPENSATION
You will receive an amount up to a maximum of $60 to cover your travel and parking costs after the evaluation, upon presentation of receipts.

SHARING STUDY RESULTS
At the end of the study, you may have access to the results if desired. Results from this study will be presented at conferences and published in journals.

SHOULD YOU SUFFER ANY HARM
Should you suffer harm of any kind following any procedure related to the research study, you will receive the appropriate care and services required by your state of health.
By agreeing to participate in this research project, you are not waiving any of your legal rights nor discharging the researcher, the sponsor, or the institution, of their civil and professional responsibilities.

CONTACT INFORMATION
If you have questions or if you have a problem, you think may be related to your participation in this research study, or if you would like to withdraw, you may communicate with the researcher or with someone on the research team at the following number:

Yu-Tzu (Tracy) Wu (yu-tzu.wu2@mail.mcgill.ca), MSc student, McGill University, at the following phone number: (438)-530-7456.

Dr. Anouk Lamontagne (anouk.lamontagne@mcgill.ca), Ph.D. at the following phone number: (450)-688-9550 extension 531.

Dr. Sylvain Baillet (sylvain.baillet@mcgill.ca), Ph.D. at the the following phone number: (514)-398-5469

For any question concerning your rights as a research participant taking part in this study, or if you have comments, or wish to file a complaint, you may communicate with:

The coordinator of the McGill University Health Center Research Ethic Board, Ms. Linda Zegarelli, at the following phone number: (514) 398-1046 or by email at the following address: reb.neuro@mcgill.ca

The Patient Ombudsman of the McGill University Health Center, Ms. Stéphanie Urbain at the following phone number: (514) 934-1934 ext. 22223 or by email at the following address: ombudsman@muhc.mcgill.ca

OVERVIEW OF ETHICAL ASPECTS OF THE RESEARCH

The McGill University Health Centre Research Ethics Board reviewed this research and is responsible for its ethics oversight.

Research Study Title:	Perceptual brain mechanisms of emotions conveyed by the gait pattern of virtual pedestrians

SIGNATURES

Signature of the participant

I have reviewed the information and consent form. Both the research study and the information and consent form were explained to me. My questions were answered, and I was given sufficient time to make a decision. After reflection, I consent to participate in this research study in accordance with the conditions stated above.

1) I accept that my participation in the study be:
   Photography only ☐
   Video-recorded ☐
   Neither ☐

2) I authorize a member of the research study to contact me to check the transcript of what I said.
   Yes ☐ No ☐

3) I wish to receive a copy of the study results by email.
   Yes ☐ No ☐ If yes, please provide contact information: _____

4) I authorize a member of the research study to contact me in the future to ask if I am interested in participating in other research.
   Yes ☐ No ☐ If yes, please provide contact information: _____

Name of participant Signature Date

Signature of the person obtaining consent

I have explained the research study and the terms of this information and consent form to the research participant, and I answered all his/her questions.

Name of the person obtaining consent Signature Date

Commitment of the principal researcher

I certify that this information and consent form were explained to the research participant, and that the questions the participant had were answered.

I undertake, together with the research team, to respect what was agreed upon in the information and consent form, and to give a signed and dated copy of this form to the research participant.

Name of the principal researcher Signature Date

Appendix III– French consent form

FORMULAIRE D'INFORMATION ET DE CONSENTEMENT

Jeunes adultes en bonne santé

Titre du projet de recherche:	Mécanismes perceptuo-cognitifs des émotions transmises par le patron de marche de piétons virtuels.
Numéro de protocole:	2021-7393
Chercheur responsable du projet de recherche:	Dr. Anouk Lamontagne, PT, PhD, École de physiothérapie et d'ergothérapie, Université McGill Tél: (450) 588-9550, ext.: 531; Courriel: anouk.lamontagne@mcgill.ca Yu-Tzu (Tracy) Wu, MSc étudiante, École de physiothérapie et d'ergothérapie, Université McGill Tél: (438) 530-7456 Courriel: yu-tzu.wu2@mail.mcgill.ca
Co-chercheur(s)/sites:	Dr. Sylvain Baillet, PhD, Centre d'Imagerie Cérébrale McConnell, L'Institut-hôpital Neurologique de Montréal Tél: (514) 398-5469 Courriel: sylvain.baillet@mcgill.ca Dr. Shashank Ghai, PhD, Hôpital juif de réadaptation, Laval Tél: (450) 688-9550 ext. 626 Courriel: shashank.ghai@mail.mcgill.ca Dr. Eva Kehayia, PhD, Hôpital juif de réadaptation, Laval Tél: (450) 688-9550 ext. 634 Courriel: eva.kehayia@mcgill.ca
Commanditaire:	Projet subventionné par le Conseil de recherches en sciences naturelles et en génie du Canada (RGPIN 04471-2016)

INTRODUCTION

Nous vous invitons à participer à ce projet de recherche parce que vous êtes un jeune adulte en bonne santé et que notre objectif est d'examiner les patrons d'activation cérébrale sains impliqués dans la reconnaissance des émotions. Avant d'accepter de participer à ce projet et de signer ce formulaire d'information et de consentement, veuillez prendre le temps de lire, de comprendre et de considérer attentivement les renseignements qui suivent.

Nous vous invitons à discuter avec le chercheur responsable de cette étude (Anouk Lamontagne) ou à un autre membre de l'équipe de recherche (Tracy Wu, Sylvain Baillet, Shashank Ghai, Eva Kehayia) afin de leur poser toutes les questions que vous pourriez avoir sur cette étude. Veuillez également demander à un membre de l'équipe de recherche de vous expliquer les sections de ce formulaire de consentement que vous ne comprenez pas.

RENSEIGNEMENTS GÉNÉRAUX

La capacité à lire le langage corporel des autres est essentielle afin que les personnes aient des interactions sociales appropriées. Les personnes peuvent identifier les actions et les intentions des autres en observant leurs mouvements corporels et porter un jugement social lié à leurs émotions ou à leur sexe. Ces principes s'appliquent également aux activités de la vie quotidienne, comme la marche en communauté, où nous détectons les émotions et les intentions des autres via leurs mouvements de marche et réagissons en conséquence. À ce jour, nous disposons de très peu d'informations sur les régions du cerveau impliquées dans la perception des émotions véhiculées par le patron de marche. Déterminer le profil d'activation cérébrale impliqué chez des personnes saines servira de base pour comprendre les déficits au niveau de de la perception des émotions et des interactions sociales chez des populations cliniques (comme par exemple, les personnes ayant subi un traumatisme crânien ou celles ayant un trouble du spectre de l'autisme).

BUT DE L'ÉTUDE

Le but de cette étude est de caractériser les signaux du cerveau de jeunes adultes en bonne santé lorsqu'ils détectent les émotions de piétons virtuels masculins et féminins exprimant différents états émotionnels par leurs mouvements de marche. L'objectif principal est de comprendre la connexion cérébrale entre les régions responsables du traitement des mouvements et des émotions. De plus, l'objectif secondaires est d'examiner l'impact d'autres facteurs (par exemple le genre/sexe, la direction d'approche du piéton) sur l'activation cérébrale impliquées dans le traitement des émotions et du mouvement.

Pour cette étude, nous recruterons 24 participants droitiers (12 hommes, 12 femmes) âgés entre 18 et 29 ans.

OBJECTIFS DU PROJET DE RECHERCHE

Cette étude aura lieu à l'unité de magnétoencéphalographie (MEG) située au Centre d'imagerie cérébral McConnell de l'Institut-hôpital neurologique de Montréal.

Durée et nombre de visites

Votre participation à ce projet de recherche comprend une seule visite qui dure environ 2 heures, incluant l'évaluation clinique (30 minutes), le temps de préparation (30 minutes) et les tests MEG (60 minutes).

Aperçu de la participation à l'étude

Cette étude utilise un devis expérimental à mesure répétées. Votre participation implique une **tâche de discrimination des émotions** qui se déroule sur 480 essais. Au cours de la session, vous serez invités à observer des piétons hommes ou femmes en train de marcher et à reconnaître leur état émotionnel. Pendant ce temps, l'activation de votre cerveau sera mesurée par un instrument de neuro-imagerie appelé magnétoencéphalographie (MEG). La MEG mesure le courant magnétique généré par de minuscules courants électriques qui circulent dans votre cerveau, sans devoir injecter de composante dans votre corps et sans administrer d'énergie externe ou de radiation. La MEG est très sensible et par conséquence vous devrez être dans une chambre à blindage électromagnétique qui filtre les ondes générées par les appareils électroniques afin d'assurer la qualité des données. Durant l'évaluation, vous serez assis sur la chaise MEG devant un écran translucide et vous porterez des lunettes 3D pour voir l'affichage virtuel projeté sur l'écran. Tout au long du test, des instructions en anglais ou en français vous seront fournies. On vous donnera également un clavier pour indiquer vos réponses (c'est-à-dire l'émotion que vous aurez perçue). Le chercheur vous rappellera de ne pas bouger la tête durant le test car les mouvements de la tête

dégradent la qualité des données. Vous serez invités à vous reposer entre les blocs de test.

Procédures d'étude
Votre implication dans cette étude comprend les étapes et procédures suivantes:

DESCRIPTION DES PROCÉDURES DE L'ÉTUDE		
Procédure		Description
Évaluation clinique initiale (20 min)	Dépistage d'éligibilité	Votre âge et votre état de santé seront examinés afin de vérifier votre éligibilité à cette étude. Pour les mêmes raisons, votre dominance manuelle et votre acuité visuelle seront évaluées.
	Entrevue sur le sexe & genre	Il vous demandera de mentionner votre sexe biologique au chercheur. Une question facultative quant à votre identité sexuelle (votre genre) vous sera aussi posée. Vos réponses demeureront confidentielles.
	Évaluation de l'état émotionnel	Votre état émotionnel sera évalué à l'aide d'un court questionnaire d'auto-évaluation – l'Échelle d'affects positifs et d'affects négatifs (« Positive Affect and Negative Affect Schedule », PANAS)
Préparation (30 min)	Essais de pratique	Des essais de pratique de la tâche de discrimination des émotions seront faits à l'extérieur de la salle de MEG. Vous serez invité à pratiquer la tâche jusqu'à ce que vous atteigniez un taux de succès de 80%, avec un minimum de 20 essais de pratique et un maximum de 60 essais.
	Changements de vêtements	Puisque la MEG est très sensible, on vous demandera de mettre une blouse d'hôpital pour nous assurer que vos vêtements ou que des particules sur le tissu n'altèrent pas la qualité des données. Vous pourrez vous changer dans un vestiaire privé à proximité de la salle de MEG.
	Installation des électrodes	Le chercheur positionnera quelques électrodes sur votre torse (pour mesurer vos battements cardiaques) de même que votre front et les joues (pour le suivi des mouvements des yeux). Ceci a pour but de dépister des artéfacts normaux possibles générés par des mouvements des yeux et des battements de cœur. Le chercheur positionnera également des électrodes supplémentaires qui sont des capteurs permettant de suivre la position de votre tête à l'intérieur du MEG. Enfin, le chercheur utilisera un dispositif de type crayon magnétique pour mesurer la forme de votre tête en 3 dimensions.
Mesures MEG (1 heure)	Pré-opération	On vous demandera d'effectuer le test en position assise sur la chaise MEG. Le chercheur ajustera la position de l'assise pour qu'elle soit adaptée à vous. Le casque MEG ne couvrira que le haut, l'arrière et les côtés de votre tête. À tout moment, vous pourrez communiquer avec l'opérateur de la MEG qui sera assis immédiatement à l'extérieur de la salle MEG. L'opérateur pourra également vous voir à travers une caméra. Ensuite, un processus de confirmation verbal sera établi à l'aide d'un microphone dans la salle MEG pour s'assurer que vous compreniez les instructions.
	Essais de pratique	Avant la collecte des données, vous pratiquerez la tâche pendant un minimum de 5 essais ou jusqu'à ce que vous vous sentiez confortable avec la tâche.

	Enregistrement de l'état de repos	L'activité de votre cerveau au repos sera enregistrée au tout début ainsi qu'à la fin de la session. Pendant l'enregistrement, vous serez invité à rester immobile autant qu'il vous est possible et à regarder un repère visuel affiché à l'écran pendant 6 minutes.
	Tâche de discrimination des émotions	On vous demandera de fixer votre regard sur un repère visuel. Chacune des simulations durera environ 4 secondes. Les simulations comprennent des piétons virtuels, hommes ou femmes, qui approchent de différentes directions en affichant différents états émotionnels via leur patron de marche. Une fois la simulation terminée, vous disposerez de 2 secondes pour fournir votre réponse parmi plusieurs choix d'émotion (heureux, en colère et neutre) en appuyant sur la touche désirée sur un clavier. Au total, vous effectuerez 480 essais. La collecte de données dans la salle MEG durera environ 1 heure. Vous serez invités à vous reposer pendant 1 minute entre des blocs de 96 essais (5 pauses). Vous pouvez cependant faire une pause aussi souvent que nécessaire au cours de la tâche. Si vous ne vous sentez pas à l'aise durant le test, à tout moment vous pourrez parler, agiter vos mains ou simplement vous lever et sortir de la pièce. Vous pourrez ouvrir la porte de la salle MEG de l'intérieur.
Évaluation clinique finale (10 min)	Enlèvement des électrodes	Les électrodes qui vous ont été installées seront retirées et nettoyées à l'aide d'un désinfectant.
	Questionnaire de votre expérience avec la réalité virtuelle	À la fin de la session, on vous demandera d'indiquer votre impression de présence dans l'environnement virtuel à l'aide d'un court questionnaire, le « Short feedback Questionnaire -SFQ ».

AVANTAGES ASSOCIÉS AU PROJET DE RECHERCHE

Vous ne retirerez pas de bénéfices de votre participation à ce projet de recherche. Nous espérons que les résultats obtenus contribueront à l'avancement des connaissances scientifiques sur les processus cérébraux impliqués dans la reconnaissance des émotions à partir des mouvements corporels. Les résultats seront également utilisés comme une base de comparaison pour comprendre les résultats observés auprès de populations présentant des déficits de cognition sociale.

RISQUES ASSOCIÉS AU PROJET DE RECHERCHE

Un risque possible associé avec cette étude est une violation de la confidentialité ou l'utilisation de vos informations personnelles par un tiers. Pour limiter ce risque, nous prendrons les mesures nécessaires pour protéger votre confidentialité, décrites dans la section Confidentialité ci-dessous.

Il est possible que vous trouviez l'évaluation clinique (questionnaire, entrevue) dérangeante ou angoissante. Vous pouvez refuser de répondre à l'une des questions et/ou choisir de cesser de participer à l'étude à tout moment. Vous n'avez pas à donner de raison pour refuser de répondre à une question ou pour arrêter votre participation. Si vous vous sentez mal à l'aise à n'importe quel moment, n'hésitez pas à le dire au(x) chercheur(s) qui arrêteront l'entrevue ou la session.

Votre participation au test de discrimination émotionnelle, ainsi qu'à l'évaluation MEG, comporte des risques minimes. Selon les dernières connaissances, il n'y a aucun risque pour la santé connu associé au champ magnétique émis par le MEG compte tenu que vous n'avez aucune contre-indication (par exemple, la présence d'un appareil métallique non amovible, tel qu'un implant cochléaire, un stimulateur cardiaque, ou un neurostimulateur contenant des circuits électriques et générant un signal magnétique).

Afin de prévenir les risques d'infection à la COVID-19, la collecte des données se fera selon les directives sanitaires

du ministère de la Santé et des Services sociaux et de l'Université McGill. Un membre de l'équipe de recherche vous accueillera à la porte du Neuro et vous accompagnera jusqu'à l'unité MEG. Une salle de bain désignée avec des toilettes uniques sera à votre disposition afin que vous puissiez vous changer avant le test. À part vous, un seul membre de l'équipe de recherche ainsi que l'opérateur MEG seront présents dans l'environnement lors du test. Le chercheur et l'opérateur MEG désinfecteront leurs mains et porteront en tout temps un équipement de protection individuelle (i.e. gants, lunette de protection, masque). En tant que participant, vous devrez également porter un masque que vous devrez retirer une fois assis dans le fauteuil MEG et prêt pour la collecte de données. Toutes les surfaces seront désinfectées avant et après la session. Une distance de 2 mètres entre vous et les autres personnes présentes dans l'environnent sera maintenue en tout temps, sauf lorsque les électrodes sont apposées sur votre peau.
Nous ne prévoyons aucun autre risque associé à cette étude.

INCONVÉNIENTS ASSOCIÉS AU PROJET DE RECHERCHE
Environnements virtuels: Certaines personnes peuvent ressentir un cybermalaise (e.g. nausées, maux de tête, vertiges) lorsqu'elles sont exposées à des simulations de réalité virtuelle. Les personnes atteintes du mal des transports au quotidien sont plus sujettes à ce cybermalaise. De tels symptômes, bien que désagréables, n'ont pas de conséquences à long terme. Si vous ressentez ce malaise, veuillez demander au chercheur de faire une pause jusqu'à ce qu'il se résorbe. S'il ne se résorbe pas, vous pouvez choisir d'arrêter la session à tout moment.
Vous pouvez également ressentir de la fatigue en raison du grand nombre d'essais et de la durée du test, mais ce sera également temporaire. Si vous vous sentez fatigué pendant la séance, vous pourrez vous reposer avant de continuer
Tests MEG: Pendant la mesure d'imagerie, vous pouvez ressentir un certain inconfort ou des vertiges car vous serez dans un environnement confiné pendant les tests. Si cela se produit, vous pouvez communiquer à tout moment avec le chercheur et demander une pause / interruption de votre participation.
Ce sont les seuls inconvénients prévisibles pouvant résulter de votre participation à cette étude.

PARTICIPATION VOLONTAIRE ET DROIT DE RETRAIT
Votre participation à ce projet de recherche est volontaire. Vous êtes donc libre de refuser d'y participer. Vous pouvez également vous retirer de ce projet à n'importe quel moment, sans avoir à donner de raisons, en informant l'équipe de recherche. En acceptant de participer à cette étude, vous ne renoncerez à aucun de vos droits, et vous ne dégagerez ni les chercheurs ni leurs partenaires ou les institutions impliquées d'aucune de leurs obligations légales ou professionnelles. Vous serez informé en temps opportun si des informations pouvant avoir un impact sur votre volonté de continuer à participer à cette étude deviennent disponibles.
Le comité d'éthique de la recherche peut mettre fin à votre participation, sans votre consentement. Cela peut se produire si de nouvelles découvertes ou informations indiquent que votre participation au projet n'est plus dans votre intérêt, si vous ne respectez pas les consignes du projet de recherche ou encore s'il existe des raisons administratives d'abandonner le projet.
Si vous vous retirez du projet ou êtes retiré du projet, vous pouvez demander que les données déjà collectées à votre sujet soient supprimées de l'étude. Si vous demandez que vos données soient supprimées, les informations déjà collectées à votre sujet qui peuvent être identifiées comme les vôtres seront également détruites. Si les données ont été anonymisées ou ont toujours été anonymes (c'est-à-dire qu'elles ne contiennent aucune information pouvant être utilisée pour vous identifier), ces données continueront d'être utilisées dans l'analyse de l'étude.

CONFIDENTIALITÉ
Pendant votre participation à cette étude, le chercheur et son équipe collecteront et enregistreront des informations vous concernant. Ils ne recueilleront que les informations nécessaires à l'étude.
Les informations suivantes seront recueillies: les informations issues de votre entretien, les questionnaires, y compris votre identité, votre identification sexuelle, vos conditions de santé passées et présentes, ainsi que les résultats des tests, examens et procédures que vous allez subir au cours de ce projet de recherche. Votre dossier de recherche pourrait également contenir d'autres informations, telles que votre nom, votre sexe, votre date de naissance et votre origine ethnique.
Toutes les informations recueillies au cours du projet de recherche resteront confidentielles dans la mesure prévue

par la loi. Vous ne serez identifié que par un numéro de code. La clé du code reliant votre nom à votre numéro de participant à l'étude sera conservée par le chercheur.
Il est possible que l'expérience soit filmée et que des photographies soient prises. Nous ne les utiliserons qu'avec votre permission à des fins éducatives et/ou scientifiques. Il n'est cependant pas nécessaire de consentir à cette section pour participer au projet. Si vous ne consentez pas, les enregistrements et photographies vous concernant seront détruits à la fin du projet afin de respecter votre confidentialité.
Ces données de recherches seront conservées pendant 10 ans pas le chercheur responsable de cette étude. Les données peuvent également être conservées dans une base de données appelée l'Archive MEG Ouverte (OMEGA) si vous acceptez et signez le formulaire de consentement de la base de données fourni par les chercheurs. Toutes les informations recueillies pour le registre resteront strictement confidentielles dans la mesure prescrite par la loi. Les données de recherche pourront être publiées ou faire l'objet de présentations scientifiques, mais il ne sera pas possible de vous identifier.

Découvertes fortuites
Les images et données recueillies ne sont pas systématiquement examinées pour des anomalies. Au cours de cette étude, si nous effectuons une découverte fortuite importante, nous communiquerons avec vous et avec un professionnel de la santé de votre choix.

FINANCEMENT DU PROJET DE RECHERCHE
Le chercheur principal et l'institution ont reçu un financement du Conseil de recherches en sciences naturelles et en génie du Canada (RGPIN 04471-2016) pour effectuer ce projet de recherche.

CONFLIT D'INTÉRÊTS
Les chercheurs n'ont aucun conflit d'intérêts à déclarer.

COMPENSATION
Vous recevrez un montant allant jusqu'à un maximum de 60 $ pour couvrir vos frais de déplacement et de stationnement après l'évaluation, sur présentation des reçus.

PARTAGE DES RÉSULTATS DE L'ÉTUDE
À la fin de l'étude, vous pouvez avoir accès aux résultats si vous le souhaitez. Les résultats de cette étude seront présentés lors de conférences et publiés dans des revues.

EN CAS DE PRÉJUDICE
Si vous deviez subir quelque préjudice que ce soit par suite de toute procédure reliée à ce projet de recherche, vous recevrez tous les soins et services requis par votre état de santé.
En acceptant de participer à ce projet de recherche, vous ne renoncez à aucun de vos droits et vous ne libérez pas le médecin responsable de ce projet de recherche, le commanditaire et l'établissement de leur responsabilité civile et professionnelle.

IDENTIFICATION DES PERSONNES-RESSOURCES
Si vous avez des questions ou éprouvez des problèmes en lien avec le projet de recherche, ou si vous souhaitez vous en retirer, vous pouvez communiquer avec le médecin responsable ou avec une personne de l'équipe de recherche au numéro suivant :

Yu-Tzu (Tracy) Wu (yu-tzu.wu2@mail.mcgill.ca), MSc étudiante, Université McGill, au numéro de téléphone suivant : (438) 530-7456.

Dr. Anouk Lamontagne (anouk.lamontagne@mcgill.ca), Ph.D. au numéro de téléphone suivant : (450) 688-9550 extension 531.

Dr. Sylvain Baillet (sylvain.baillet@mcgill.ca), Ph.D. au numéro de téléphone suivant : (514) 398-546

Pour toute question concernant vos droits en tant que participant à ce projet de recherche ou si vous avez des plaintes ou des commentaires à formuler, vous pouvez communiquer avec :

Le coordinateur du Comité d'éthique de la recherche (CER) du Centre universitaire de santé McGill (CUSM), Ms Linda Zegarelli, au numéro : (514) 398-1046, ou à l'adresse courriel suivante: reb.neuro@mcgill.ca

Le Commissaire local aux plaintes et à la qualité des services du Centre Universitaire de santé McGill, Ms Stéphanie Urbain au numéro : (514) 934-1934 ext. 22223, ou à l'adresse courriel suivante: ombudsman@muhc.mcgill.ca

SURVEILLANCE DES ASPECTS ÉTHIQUES DU PROJET DE RECHERCHE

Le comité d'éthique de la recherche du Centre Universitaire de santé McGill a approuvé le projet et en assurera le suivi.

Titre du projet de recherche :	Mécanismes perceptuo-cognitifs des émotions transmises par le patron de marche de piétons virtuels.

SIGNATURE

Signature du participant

J'ai pris connaissance du formulaire d'information et de consentement. On m'a expliqué le projet de recherche et le présent formulaire d'information et de consentement. On a répondu à mes questions et on m'a laissé le temps voulu pour prendre une décision. Après réflexion, je consens à participer à ce projet de recherche aux conditions qui y sont énoncées.

5) J'accepte que ma participation à cette étude soit:
   - Photographiée seulement ☐
   - Enregistrée par vidéo ☐
   - Aucun ☐

6) J'autorise un membre de l'étude de recherche à me contacter pour vérifier la transcription de ce que j'ai dit :
   Oui ☐ Non ☐

7) Je souhaite recevoir une copie des résultats de l'étude par courriel.
   Oui ☐ Non ☐ Si oui, veuillez fournir vos coordonnées: _____

8) J'autorise un membre de l'étude à me contacter à l'avenir pour me demander si je suis intéressé(e) à participer à d'autres recherches.
   Oui ☐ Non ☐ Si oui, veuillez fournir vos coordonnées: _____

Nom du participant Signature Date

Signature de la personne qui obtient le consentement

J'ai expliqué au participant le projet de recherche et le présent formulaire d'information et de consentement et j'ai répondu aux questions qu'il m'a posées.

Nom de la personne qui obtient le consentement Signature Date

Engagement du chercheur responsable

Je certifie qu'on a expliqué au participant le présent formulaire d'information et de consentement, que l'on a répondu aux questions qu'il avait.

Je m'engage, avec l'équipe de recherche, à respecter ce qui a été convenu au formulaire d'information et de consentement et à en remettre une copie signée et datée au participant.

_____

Nom du chercheur responsable Signature Date