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An abstract of
A thesis submitted to the Faculty of Emory College of Arts and Sciences
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Abstract

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Touch interactions are strongly connected to an individual's perception of emotions, movements, and social interactions which are processed through the somatosensory, motor, and visual cortex regions of the brain. Emotions affect our mental health: they influence our perception, alter our physical strength and interfere with our reason. Differences in levels of expression/activation in the somatosensory cortex are connected to the differences in an individual's ability to perceive touch. Moreover, differences in social cognition, neural pathway mechanisms of perceiving touch, movement, and behavior can also directly affect an individual's social touch perception.

Touch interactions have also been shown to play an important role in partnered social dance as it allows them to perceive one another's movements and pressure cues. The purpose of this paper is to discuss the development of a functional task (the Touch task) to be performed in a baseline magnetic resonance imaging (MRI) scan to assess neural areas that correspond to touch while a patient with mild cognitive impairments is thinking of completing a motor goal such as partnered dance. We will conduct fMRI assessments to collect Neural activation information analyzed between completing tasks that include "notice the touch," (T) where a member of the lab will touch the patient's arm down to their hand in rhythmic pattern, "notice the touch, listen, and watch," (TLW) where participants experience the touch of the lab member along with listening to a 15 second clip of tango music while tapping when they hear the music and watching a screen of a man and women tango dancing. The last condition is "listen and watch," (LW) where participants will listen to tango music and watch the couple dance without touch. Each of the conditions last for 15 seconds and is interspersed with 15 second periods of rest.

Results from a group fMRI contrast showed that the TLW condition successfully helped participants think of completing a motor goal and use mental imagery to imagine themselves dancing. Looking at human-human touch interactions in the context of partnered dance helps us understand the neural mechanisms behind touch interactions involving music and visual stimuli for people with MCI. We hope to use the data collected from the baseline fMRI scan and compare it to future fMRI results after participants undergo tango intervention classes to see improvements in motor-cognitive functioning.

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1. Introduction

1.1 Touch Interactions

Touch in the form of e.g., a hug, a handshake, or even a slap, is an important non-verbal communicative tool that helps one express one's emotions and intentions to another (Knapp et al., 2013). Emotions affect our mental health: they influence our perception, alter our physical strength, and interfere with our reasoning (Heraz & Clynes, 2018). Sophisticated neural circuitry interactions allow us to perceive and act upon touch interactions. Perceiving touch is not only important for human-human interactions but essential for human-machine interaction as some machines with emotional intelligence detect responses through passive expressive touches (Heraz et al., 2018). In addition to functional purposes, there is also an affective meaning of touch for social functioning that we see around us on a day-to-day basis. Through understanding touch interactions, for example, through partnered dance, humans gain information about others' affective states, emotions, and motor intentions.

This thesis will first cover the different types of human touch across psychosocial, motor and cognitive spheres, and will provide potential neural bases and known pathways for each. Then we will present the conceptualization of a novel touch task designed to understand more about human-human touch interactions taking place in the context of partnered dancing. We will conclude this introduction by placing the literature within the context of neurodegenerative disease of older adults, specifically, mild cognitive impairment, and/or prodromal Alzheimer's disease (AD).

1.2 Theories about processing emotional body language

Two theories have accounted for the processing of emotional body language-the theory of mind (ToM) and embodied simulation/resonance. ToM states that humans have an innate neural mechanism that helps them infer other's mental states. As a child accumulates experiences, their perspective of the social world is constantly revised which advances their ability to interpret body language. The second theory, which aligns with investigating the activation of brain regions, states that individuals implicitly infer other people's emotional states from social cues through pre-acquired sensory experiences (Gallese & Goldman, 2000). Hence, more studies have started investigating the observation of touch interactions and how it activates brain regions beyond the visual cortex and somatosensory regions (regions involved in the processing of self-experienced touch).

1.3 Types of human touch

Human touch is a complex form of awareness that involves tactile and perceptual awareness. We use a diverse range of movements like tapping, rubbing, squeezing, and pulling as a form of expression, communication, exercise, and function. Touch can be described as active or passive depending on whether the movement is voluntary or uncontrolled. Active movement tends to be directed towards objects and is haptic and controlled. Our hands are primarily used in active touch for engagement and exploration of our surrounding environment. Passive touch characterizes a sensory experience that occurs when the observer does not move, and the stimulation is imposed on the skin of the individual. In this paper, we will be looking into different types of touch but specifically focusing on body-directed passive touch and its effects on brain neural activation in motor and sensory areas.

1.3.1 Importance of touch for psychosocial development

Positive, physical touch promotes healthy physiological development and wellbeing in social mammals, including humans. Many studies have shown that lack of affectionate touch in early life results in negative outcomes in young mammals. For example, rhesus monkeys isolated from touch developed aberrant social skills (Mason & Harlow, 1958). Positive affectionate touch is defined as a part of sensitive, responsive parenting style that improves infants' growth, development, and wellbeing (Feldman, Eidelman, Sirota, & Weller, 2002; Field, 1985). Absence of positive touch and the presence of negative touch, such as spanking and pinching, is linked to aggression, depression, substance use, and violence (Taylor, Manganello, Lee, & Rice, 2010).

Psychosocial touch that occurs during close social interactions, e.g., partnered social dance, activates brain areas such as the right posterior superior temporal sulcus (pSTS) involved in perceiving biological motion and analyzing intentions underlying actions, medial prefrontal cortex (mPFC) involved in attention and memory formation, and dorsal anterior cingulate cortex (dACC) an enigmatic area involved in motor control and cognition (Chauvigne et al., 2018). In addition, interactive tasks of all kinds engage social-cognitive processes and activate areas associated with the mentalizing network, including the pSTS, the mPFC, as well as the temporo-parietal junction (TPJ) involved in information processing and perception. (Decety et al., 2002). The superior parietal lobule is closely linked with the occipital lobe and is involved in aspects of attention, spatial perception, and memory.

1.3.2 Discriminative and affective touch

Discriminative touch subserves the perception of pressure, vibration, slip, and texture, which are critical in providing information about handling objects. Affective touch, the emotional aspect of touch, is functionally distinct from discriminative touch as it captures tactical processing with hedonic or motivational components. Discriminative touch has more “well mapped pathways” as each interaction is more distinguishable. Low-threshold mechanoreceptors (LTMs) transduce information regarding properties of discriminative touch that are innervated by myelinated fibers that enable fast conduction of nerve impulses (McGlone et al., 2014). Myelinated Aβ fibers carry discriminative touch and project to the primary somatosensory cortex. On the contrary, unmyelinated peripheral afferent fibers (also known as C-tactile (CT) afferents) respond to affective touch and project to the posterior insular cortex (Olausson et al., 2002). Hence, receiving pleasant touch results in activation of the posterior insular cortex while stimulation with a piece of wood results in activation of the somatosensory cortex (Francis et al., 1999). Moreover, unmyelinated peripheral afferent fibers lead to oxytocin release that plays a role in intimate social relationships. Active delivery of social touch to another human hand is distinguished from touch of an inanimate object through the release of oxytocin and endogenous opioids (Ebisch et al., 2014a,b).

Romantic touch between partners engages reward regions of the brain; regions like the ventral striatum and anterior cingulate cortex are boosted by the release of oxytocin (Kreuder et al., 2017). Activation in the somatosensory region varies in amplitude depending on the emotional facial expression of the person (Ravaja et al., 2017). Unpleasant odors can also alter the response of insular and opercular cortices to affective touch (Croy et al., 2016).

When investigating brain activation for affective and discriminative stimuli in the somatosensory regions for infants, twelve-month-old infants showed a significant increase in brain activity for affective touch compared to seven-month-old infants. This suggests that a developmental trajectory occurs during childhood where the posterior insula, pSTS, medial prefrontal cortex, dACC, and somatosensory cortex is already in place during early development

(Bjornsdotter, Gordon, Pelphrey, Olausson, & Kaiser, 2014). Some studies failed to find activation in social brain regions before ten months of age in response to affective touch (Kida & Shinohara, 2013), others were able to find brain activity in response to the same stimuli as early as one month of age (Singh, 2017).

1.3.3 Rhythmic touch

Rhythmic touch can be a type of affective touch that describes systematic stroking and massaging which is related to positive social development. Synchronic interactions are essential for individuals to develop an understanding of self and others' intentions of completing a motor goal. Rhythmic touch has been found to successfully reinforce social behavior like eye contact and face-to-face interactions (Higbee & Pelaez-Nogueras et al., 1996). Rhythmic touch in partnered dance mediates interpersonal synchrony through the passing of mechanical and haptic information. Studies have shown that dancers, compared to non-dancers, have an increased ability to obtain haptic information through rhythmic touch and thus are more likely to stay in sync with their partner (Sofianidis, George et al., 2015). Hence somatosensory information coupling between partners enrolled in rhythmic activity is a critical aspect to tango dance.

The rhythmic qualities of tango dance have been known to be effective at reducing mobility defects associated with aging. Brown et al. (2006) used positron emission tomography (PET) to study the regions of the brain involved in the control of tango movements; increased activity in the basal ganglia was observed when the tango movements were performed to a metered beat in a predictable rhythm.

1.3.4 Self-touch

Self-touch is another type of affective touch which is a conscious or unconscious gesture involving an individual contacting their own body. Humans use more unpredictable touch patterns, less rhythmic patterns, when employing social touch compared to self-touch (Lo, Chu, Penney, & Schirmer, 2021). Such an increase in variability makes social touch more pleasant and salient for both the toucher and the touched person. However, self-touch is predictable, leading to habituation of receptors and sensory attenuation. Sensory attenuation describes the phenomenon where sensory input elicited by self-generated acts is reduced compared to sensory input generated externally. A comparison of CT-targeted self-produced touch with social touch revealed reduced sensory processing in the somatosensory processing, in social cognition, and in self-referential thinking, including posterior and anterior insula (Boehme, Hauser, Gerling, Heilig, Olausson, 2019). Humans need to be able to differentiate between signals they produce themselves and signals that arise from non-self-causes.

Blackemore et al. used an apparatus with a piece of foam to stimulate the palm of the participants' hand and subjects claimed that the stimulation was less pleasant and intense when it was self-produced. The tactile stimulation with the self-controlled apparatus resulted in lower activity in bilateral secondary somatosensory cortex, cerebellum and anterior cingulate (Blakemore, Wolpert, and Frith, 1998). Functional connectivity between the primary and secondary somatosensory cortex contralateral to the ipsilateral cerebellum is related to level of attenuation during self-produced force. The cerebellum predicts the sensation and sends a signal to the somatosensory cortex. Self-scratching and stroking activate the somatosensory cortex and areas of reward circuit which also leads to the deactivation in insula, anterior cingulate, and cerebellum. The insular cortex plays an important role in interoception, the sensing of signals from within the body. One study compared self-induced, and partner induced orgasms and found no difference except regarding variations of prefrontal activity strength.

1.3.5 Pain

Pain has an affective component (e.g., unpleasantness) as well as a sensory discriminative component (e.g., intensity, duration, localization) that are mapped in 2 distinct but overlapping nodes of a complex neural network referred to as the "pain matrix" (Melzack, 1999). The sensory dimension of pain is coded in parietal sensorimotor neural structures, including the somatosensory cortices (Porro et al., 1998). The affective component of the pain experience relies upon neural activity of the anterior cingulate cortex (ACC) and the anterior insula (AI) (Garcia-Larrea & Peyron, 2013). For example, when one knows that they are receiving a painful stimulus through visual cues, emotional experiences stimulate neural activation in ACC and AI. Functional magnetic resonance imaging (fMRI) studies indicate that viewing static pictures of potentially painful situations and imagining feeling the pain activates the parietal operculum and secondary somatosensory cortex (Jackson et al., 2006). This demonstrates that observation of tactile stimuli delivered to other individuals induces activity in the onlookers' somatosensory cortices areas (Keysers et al., 2004); similar activation is found when one experiences pain themselves. While looking at the different types of affective touch, the somatosensory cortex has been shown to play a crucial role in rhythmic touch, self-touch, and pain, encoding incoming sensory information from receptors all over the body.

1.4 Basic Neural mechanisms of touch

Neural activation of touch is dependent on the type of stimuli, visual, auditory, or mental imagery, and the nature of the participant. Mechanoreceptors are sensory receptors found in our skin that convert mechanical pressure into electrical signals that are then sent to the central nervous system for processing. fMRI studies have shown that the primary regions of activation include the somatosensory cortex, motor areas, and visual/auditory cortices.

1.4.1 Somatosensory Cortex

Touch is depicted through activation in various somatosensory regions including the postcentral gyrus (PoCG) that received tactile information from subcortical thalamus. The PoCG is divided into cortical Brodmann Areas (BA) 3a, 3b, 1 and 2 (Brodmann, 1909). BA3 is considered the primary somatosensory cortical area as it receives direct input from the thalamus (Kaas, 1983). BA3 is known for processing “private” touch delivered directly to one’s skin (Keysers and Gazzola, 2009). The primary somatosensory cortex (SI) participates in central processing of both tactile and nociceptive stimuli (Kaas, 1990; Kenshalo Willis, 1991). Areas such as the parietal operculum and insular cortex also process somatosensory information at later stages.

Somatosensory cortical areas receive a wide range of somatosensory inputs from different peripheral receptors and process different kinds of somatic information. However, when specifically looking at touch, the SI contains an essentially spatial representation of the physical body surface. Tactile sensations are localized on a given part of the body due to the organization of the primary somatosensory cortex. SI of each hemisphere contains a complete topographically organized representation of the collateral side of the body. Tactical stimuli administered on a given body part elicits a neural response in a specific portion of SI the homunculus, matching the same body part. The size of individual receptive fields on the skin varies among body parts and therefore among regions of SI. For example, skin regions such as lips and fingers have large SI representations. Skin regions differ in the degree of tactile information they can supply with high tactile acuity regions having a great number of mechanoreceptors. Other skin regions with less mechanoreceptors have smaller SI representation and exhibit lower tactical acuity.

The strength of the relationship between peripheral inputs from the skin and SI representation can be impacted by deafferentation (Buonomano and Merzenich, 1998). Deafferentation happens when the afferent inputs from the body surface cannot reach the matching portions of somatosensory cortices due to nerve resection. The first sign of such reorganization is that deafferented portions of SI start to respond to stimuli presented on adjoining body parts. A reason for this issue could be the existence of synaptic connections between adjacent areas of SI. When portions of SI are no longer able to obtain proper signals from its representation, the signals from lateral representations may then cause neural activity. Forms of deafferentation have also been shown in humans after anesthesia; anesthesia of the right hand improves spatial tactical acuity in the left hand. Depressing the activity of the SI cortex through peripheral anesthesia unmasks normally suppressed responses. When tactile afferents recover, the system reorganizes to its original balance.

Moreover, studies have shown that the primary sensory cortices can be activated in the absence of modality-specific external stimulation. For example, the primary visual (V1), auditory (A1), and somatosensory (SI) cortices can be activated during visual, auditory, tactical mental imagery. Furthermore, visual stimuli that imply sound, touch, or smell can activate primary auditory, somatosensory, and olfactory cortices. The activity patterns tend to be content specific: V1 is activated through visual mental images while the primary auditory cortex is activated through visual stimuli that imply different sounds. Brain regions such as the temporal lobe have a relationship to visual cortex and motion-sensitive regions which is the result of processing affective dimensions in ToM network (Grossman et al., 2000).

It is also hypothesized that the same cortical areas for receiving touch would also be activated when observing social touch interactions. The mere observation of touch is known to induce activation of both the primary and secondary somatosensory cortices (SII) (Blackemore et al., 2005). fMRI results show that touch activates SII, but not, SI, with comparable neural responses when watching a human body being touched as well as touching an object. Hence, SII does not differentiate what object is being touched while there is some differentiation between seeing a human being touched versus an object being touched at the level of SI.

1.4.2 Neural mechanisms of observing human-human touch interactions

Touch plays an important role in affective experiences that can be understood by the pleasant feeling of caress-like stroking touches or hugs. Affective touch activates specific receptors called C-tactile (CT) afferents in the hairy skin. Third person observations of stroking touches have been found to have the same level of activation (Sjoerd et al., 2008). A study conducted to examine gender differences of observing human-human touch depicted that the male participants perceived touch received from a same sex person as less pleasant. Many evidence depicts that tactile stimuli and observed tactile stimuli activates the same core brain networks, namely the somatosensory cortices (Bolognini, Rossetti, Convento, & Vallar, 2013; Keysers et al., 2004; Rizzolatti, Fogassi, & Gallese, 2001; Rossetti, Miniussi, Maravita, & Bolognini, 2012; Schaefer, Heinze, & Rotte, 2005, 2012; Schaefer, Xu, Flor, & Cohen, 2009).

Schaefer et al. (2012) found that the amount of neural activation for observed touch is correlated with levels of perspective taking, the ability to understand how a situation appears to another person, demonstrating that levels of empathy influence the way third party observers are affected by social touch. Peled-Avron et al. (2016), showed that highly empathic participants depicted greater emotional levels when observing human social touch compared to less empathic participants; this demonstrates that observed social touch responses are modulated by levels of empathy.

The right inferior frontal gyrus (rIFG) is part of an observation-execution network implicated in observed touch perception. Low loneliness individuals have slower rIFG reaction times when observing human touch than high-loneliness individuals (Nira et al., 2022).

1.4.3 Neural mechanisms of human-human touch interactions in individuals with disabilities

The different levels of activation in brain regions have been connected to the difference in individuals' ability to perceive touch. Audio-visual stimulation combined with mental imagery more rapidly elicits an elevated physiological response than with mental imagery alone (Hagni et al. 2008). Difference in social cognition, behavior, and neural mechanisms can also directly affect an individual's social touch perception. Touch interactions are affected in developmental abilities. Individuals with Autism Spectrum Disorder (ASD) exhibited impaired nonverbal communication while lacking activation in the somatosensory cortex during touch experiences. Affective touch in people with ASD exhibit reduced activity in response to CT afferents which suggests atypical sensory cortical hyper-reactivity. In contrast, a neurotypical group had affective touch represented in more differentiated areas of somatosensory cortex (Lee Masson, Pillet, Amelynck et al., 2019). Individuals with great need/desire for social touch were found to exhibit stronger emotional response to observed social touch experienced through activation in the postcentral gyrus (Lee Masson et al., 2018). Other groups like older adults with mild cognitive impairments may experience different brain activation in areas devoted to the experience and observation of touch interactions.

Enhanced discriminative tactile acuity (the ability to process discriminative touch) was found in blind individuals and individuals with ASD. This could be due to the greater velocity at which discriminative touch is transmitted through the Aβ fibers and processed through the somatosensory cortex. Blind individuals have also shown to rate touch more pleasant when delivered on the palm than on the forearm showing that the intensity of perceived pleasantness varies across different body parts (Crucianelli, Chancel, & Ehrsson, 2022). The increased pleasantness of the tactile experience directed to the palm can be due to the palm being an active, touch seeking body part that enables and facilitates social interaction (Perini, Olausson, & Morrison, 2015).

CT signals play an important role in affective touch sensations. Alterations in responses to CT-optimal touch have been observed in anorexia nervosa, autism, and fibromyalgia. When examining pain in blind individuals, participants were shown to have lower heat pain thresholds, higher sensitivity to cold pain stimuli, and higher ratings of pain experienced in response to suprathreshold laser stimuli (Slimani et al., 2013).

In our study, we will view the effects on neural activation as our participants with Mild Cognitive Impairments (MCI) watch partnered tango dance from a third person perspective and are told to imagine themselves as the dancers.

1.4.4 Neural mechanisms of motor imagery tasks

Sacco et al investigated the difference in brain activation between participants that performed dance and used motor imagery to recall the steps they had learned. Classical motor imagery tasks involve both motor and visual imagery. Motor learning of new motor skills and motor training for improving learned motor skills require motor attention and can produce changes in cortical motor representations. An fMRI study of the motor imagery of golf players showed the activation of motor and parietal cortices, supplementary motor areas, cerebellum and vermis, and found a correlation between increased number of areas of activation and increased handicap of participants (Ross et al., 2003). Rowe et al. (2002), showed that under attention directed to the action, there is increased activity in the prefrontal cortical regions, the dorsal prefrontal cortex which mediates the effect of attention on premotor cortical activity. Exploring motor learning will help us better understand the subject's conscious attention to movement and visuospatial processing.

Studies have shown that participants observing dance through a third person's perspective activates the right Primary Somatosensory Cortex (S1), right Orbitofrontal cortex (OFC), right Temporal Pole (TP), and Primary Motor Cortex (M1) areas. The pattern of results found for dancers in S1 and M1 suggests that observers' perception of dance actions is enhanced by embodied processes, the use of our own bodily experience and processes to understand our own emotional experience and the experiences of others. The activation in S1 suggests that mirror neurons are "mirroring" the actions and behaviors of others. Patterns of activation in OFC and TP suggests that the observers' perception of dance actions are enhanced by cognitive processes (Jang & Pollick, 2011). The activation in mirror system representations is linked to learned motor skills. Precisely, patterns of finger movements resulted in premotor cortex activation associated with new learning of such patterns (Sakai et al., 2002).

The observer's motor expertise level is known to cause variation in brain responses. For example, an expert ballet dancer is shown to have greater activity in mirror areas, including the premotor, parietal cortices, and somatosensory cortex, while watching ballet moves. This suggests that action observation activates mirror areas to the extent that the observed action is represented in the subject's personal motor repertoire; similar activation patterns would be found if the subject had acquired the motor skills to perform such actions. There was no indication that perceptual processing, the process of selecting, organizing, and interpreting information, occurs with observing dance movements as no activation in the inferotemporal and occipital cortices were found (Gautheir et al., 2000). Activity in the middle temporal areas reflected semantic categorization of the dance moves by experts but not by non-experts (Vandenberghe et al., 1996).

The motor expertise effect showed two distinct activations, one dorsal and one ventral, within the premotor cortex. Dorsal premotor activation was found bilaterally while ventral premotor activation was found in the left hemisphere. The parietal cortex showed two distinct activations- the intraparietal sulcus showed bilateral activity and the superior parietal lobule showed right hemisphere activity. Primate studies suggest that movements of each body part are coded in independent, parallel parieto-frontal circuits that represent different motor related effectors; this causes direct somatotopic matching between visual stimuli of body parts and corresponding movements (Buccino et al., 2001).

In a study investigating changes in lateral occipitotemporal cortex (LOTC) during action processing following motor learning of novel choreography in professional ballet dancers, it was found that the area was activated most while viewing dance compared to visualization and movement. Significant increases in activation were observed over time in left lateral occipital complex only during visualization of the unlearned dance, and all subregions were activated bilaterally during the viewing task after 34 weeks of performance, suggesting learning induced plasticity (Nota, Levkov, Bar, & DeSouza, 2016).

Our participants from our partnered dance study will undergo our touch task protocol to help us further understand the effects of observing tango dance versus participating in tango dance on neural activation.

1.5 Partnered Dance Study

Movement requires balance, spatial attention, and timing that is all calculated in the brain’s sensorimotor system. The posterior parietal cortex translates visual information into motor command and sends the signals to motion-planning areas in the premotor cortex and supplementary motor areas. These instructions then get sent to the primary motor cortex which then generates neural impulses that travel to the spinal cord and make muscle contract (Brown & Parsons, 2008).

Dance is a type of sport that is known to promote well-being in healthy people; it involves complex body movements that are synchronized to music and involves the culturally mediated body, emotion, and mind. Dance therapy is a new therapeutic approach for improving balance, mobility, and walking. Older adults who regularly dance have a more stable gait pattern, better balance and faster reaction time than older adults who do not dance. Dance is also a therapeutic tool that addresses both psychological and physical impairments in a variety of neurological conditions including stroke, multiple sclerosis, spinal cord index, and Huntington’s disease.

Argentine tango has been used and investigated in adults with neurologic conditions to improve gait and balance. The effects of Argentine tango on movement control in Parkinson’s disease were compared with those of American ballroom dance (Hackney and Earhart, 2009). Both dance groups improved more than the control group. The tango group improved as much or more than those in the waltz/foxtrot group on several measures. A PET study demonstrated increased activity in the basal ganglia when tango movements were performed to a mastered and predictable beat (Brown et al., 2006).

The partnered dance study focuses on incorporating motor and cognitive training to create an ideal intervention to target cardiovascular (CV), social, and motor-cognitive domains important to patients with mild cognitive disorders. Partnered rhythmic rehabilitation (PRR) is a form of CV exercise that may target vascular dysfunction specifically in Alzheimer's disease patients (AD). Participants will engage in partnering exercises on how to interpret motor goals through touch, exercises to develop understanding of temporal relationships of movement to music, novel step introduction, connecting previously learned and novel step elements. Classes include practicing previously learned steps, a 20-minute standing warm-up, and partnering and rhythmic enhancement exercises. Tango dance steps are used as the main dance movements in the study where participants alternate between leading and following roles. Intervention sessions from the partnered dance study are then compared to the walk intervention sessions which receive equivalent dose, volume, frequency, intensity, and duration of exercise to PRR. During the PRR interventions, the instructors will follow a codified syllabus with 24 distinct lessons while the WALK interventions will consist of walk groups that follow AHA guidelines for walking groups. Both classes will include a warm-up, and 55–60-minute PRR and WALK session.

1.6 Basic neural mechanisms of partnered tango dance

Partnered tango dance is a cognitive motor dual task that allows participants to engage in cognitive and motor tasks simultaneously. Motor-cognitive integration involves vestibular, visual, and somatosensory systems crucial for balance, and executive function, visuospatial, and attentional/working memory (WM) domains important for mobility performance. Dual motor cognitive tasks are shown to activate the right-fronto-parietal network and the cerebellum. A larger and more bilateral frontoparietal network is recruited with a short-term memory task in addition to a motor task.

Gait velocity defines a person’s basic ability to walk. In older adults, gait velocity in dual task conditions was associated with functional connectivity in sensorimotor, fronto-parietal areas, supplementary motor and prefrontal regions.

After training they found increases in the SMA (supplementary motor area) and the premotor area - bilateral. Increases were found in the M1 (primary motor area) and the S1 (primary somatosensory area), inferior parietal lobule, superior temporal gyrus, decreased activation was found in the R hemisphere in lingual gyrus, fusiform gyrus, anterior and posterior cerebellum. These findings suggest some reorganization of the locomotor neural areas post-training (5 one –hour classes over one week, in basic tango steps).

Imagery after tango dancing elicits expansion of motor areas of the brain (Sacco et al., 2006). Sacco et al report they found activation at baseline (before taking tango dancing) in primary motor area (leg foot), premotor area, supplementary motor area, prefrontal cortex, insula, cingulate gyrus, primary somatosensory areas, paracentral lobule, inferior parietal lobule, precuneus and cerebellum.

When conducting a PET scan on participants performing tango dance, activation in the cerebellum and parietal lobe was found as it contributes to spatial perception and orientation in humans and mammals. The cerebellum serves as a conductor monitoring information across various brain regions to assist in orchestrating actions by receiving a broad array of sensory inputs from the auditory, visual, and somatosensory cortical systems, and it contains sensorimotor representation for the entire body. Synchronized conditions of movement with music showed that the medial geniculate nucleus (MGN) lit up. In the absence of music with movement, the anterior vermis showed less activation than with music (Brown & Parsons, 2008).

The visual motion area MT+/V5 of the brain has been shown to be significantly active when exploring the neural basis for touch interactions in partnered tango dance (Chauvigne et al., 2018). MT+ develops motion-specific responses to nonvisual input, suggesting that cross-modal plasticity can be influenced by the normal functional specialization of a cortical region. V5 has historically been described as an area for the perception of visual motion. However, studies have shown that this complex responds not only to visual motion but to tactile motion as well, such as that which occurs when the skin surface is passively stroked (Beauchamp et al., 2007, Blake et al., 2004, Hagen et al., 2002, van Kemenade et al., 2014, Wacker et al., 1991). Hence, this led to the suggestion that MT+/V5 might be a supramodal area for the perception of touch.

1.7 Basic neural mechanisms of partnered tango dance in older adults with cognitive impairments

Mild cognitive impairment (MCI) refers to the transitional state between the cognitive changes of normal aging and very early dementia (Petersen, R., & Negash, S., 2008). During this state, an individual may exhibit great memory loss and other cognitive deficits that are more likely to progress to dementia more rapidly.

A driver of this inquiry is knowing more about the neurophysiological mechanisms of human-human touch interactions, e.g., in the context of partnered dance, a potentially impactful therapy to enhance function in older adults with mild cognitive impairment (MCI). Studying MCI provides insight into how aging, and dementia affect regions of the brain; it can also provide context into how effective therapy treatments can prevent the worsening of neurodegenerative diseases. We are interested in improving health care and rehabilitative therapies for older adults with MCI. To do this, and improve therapies that show promise, e.g., partnered dance, we need to better understand the neural mechanisms underlying intentional touch interactions involving music, and visual stimuli for people with MCI. Because of this goal, we designed a touch task that would incorporate elements of visual, sound, and touch stimuli- we created an immersive video scenario involving participants watching a couple dance (a man and a woman in leading and following roles) from the shoulders down. Participants could identify with either partner during the dancing. Traditional "standards"' of Argentine tango were played to which the partners were dancing. The participant would feel a touch (a squeeze on the forearm/hand area) while lying in the scanner, to serve as a proxy for the embrace in tango.

By going through this immersive experience, we are interested in which brain areas are activated during the task for these different conditions: Touch, Listen, and Watch, Listen and Watch or just Touch. Through looking at neural activation patterns, we hope to find that participants are successfully able to perceive themselves dancing through observation and with the help of the administered conditions.

2. Methods

2.1 Participants

For this study, older adults with MCI were recruited from the Atlanta area. The participants have impaired cognitive and motor skills, making them ideal candidates for the Partnered Dance Study. Before beginning the intervention, eligibility criteria were met through a screening visit. The participants were randomized to 90-minute PRR, an intervention that targets cardiovascular, social, and motor-cognitive domains, or the control WALK group. Randomization for participants was calculated based on sex (Male vs. non-Male) and age (under age 65 vs. 65 years or older). Therefore, younger males were allocated to a separate randomization list while older females were allocated according to a separate randomization list, and so on. Each list was created with 40 entries in total, totaling to 160 entries. 32 individuals after randomization were initially chosen to participate in the touch task protocol and undergo a baseline fMRI scan (Table 1). We present here only data from these baseline scans. Results from the randomized clinical trial are forthcoming. Further, we only present data from 11 participants in the Results section at this time. Future analyses and dissemination of results are planned.

Inclusion criteria were: diagnosis of MCI using the AD neuroimaging initiative (ADNI) criteria, age ≥ 50, Ability to walk 10 or more feet with or without an assistive device, and not having been hospitalized within the last 60 days.

Exclusion criteria were: diagnosis of Parkinson's disease or other neurodegenerative disease besides prodromal Alzheimer's disease, significant musculoskeletal, cognitive, or neurological impairments, acute medical illness requiring hospitalization, uncontrolled congestive heart failure, inability to perform MRI (e.g. metal implants or cardiac pacemakers, claustrophobia), and confounding neurologic conditions (e.g. seizure disorders, head injury with loss of consciousness > 30 minutes).

The demographics of the participants along with data collected from cognitive assessments and health questionnaires is shown in Table 1.

2.2 Screening Related Measurements

Before undergoing the baseline fMRI assessment, participants were asked to complete a screening cognitive assessment to measure memory loss, possible dementia, and functional abilities. In addition, participants were asked to complete an informed consent form, health questionnaire, and MRI history/screening form.

Our focus was to collect data on cognitive assessments that measured executive functioning, visuospatial working memory, verbal learning, and short-term visual memory. The MOCA test was primarily used to measure the participants' global functioning based on a 30-point scale that assesses various domains (Hackney, 2021). Participant scores must be between 18-25 at screening. Brooks Spatial Task was used to evaluate the participants' spatial working memory while Boston Naming task (BNT) was used to evaluate verbal learning and memory. The Reverse Corsi Blocks assessment was used to assess short-term visuospatial memory. Executive functioning was measured through the Tower of London test (TOL). Scores from the Short Form health survey-12 (SF-12) including Physical (PCS) and Mental Composite (MCS) scores were used to investigate social and physical functioning (Table 1).

A single informed consent form (combined consent/HIPAA) was obtained from each participant. The consent form describes the purpose of the study, the procedure to be followed, and the risks and benefits of participation. A copy was given to each participant and was documented in the participant's study record and medical record per Emory University policy.

The Emory University institutional review board reviewed and approved this protocol. All participants provided informed consent before participating. All participants provided written informed consent prior to participation in the MRI scanner.

Table 1. Demographics Characteristics of Baseline Scan

	Total Sample n(%) or mean ± SD n=32
Age (y)	73.4 (7.6)
Gender	
Male	14(43.8%)
Female	18 (56.3%)
Education	
Some college/associate degree	12 (37.5%)
Bachelor's degree (BA/BS)	11 (34.4%)
Master's degree	6 (18.8%)
Doctoral degree	2 (6.30%)
Race	
White/Caucasian	18(56.3%)
Black/African American	11(34.4%)
Multiracial	1(3.10%)
Hispanic or Latino	1(3.10%)
Other	1(3.10%)
Housing	
House/Apt/Condo	29(90.6%)
Senior Housing	3(9.40%)
Transportation	
Driving own vehicle	27(84.4%)
Friends/Family Drive	4(12.5%)
Public transportation	1(3.10%)
Marital Status	
Single	3(9.41%)
Relationship	21(65.6%)
Separated/Divorced	6(18.8%)
Widowed	2(6.30%)
Veteran	
Yes	4(12.5%)
No	28(87.5%)

Occupational status	
Work part-time	3 (9.4%)
Homemaker	1(3.1%)
Retired	28(87.5%)
Number of comorbidities	4.09±1.96
Composite physical function index (/24)	22.4±2.3
QOL AD scores (/52)	40.6±5.29
Number of prescription medications	N=24
Number of falls in past year	0.810±1.47
BDI-II score	5.74±4.86
SF12-MCS (Mental Component Summary)	45.6±5.30
SF12-PCS (Physical Component Summary)	54.0±7.71
Verbal learning and memory Boston Naming task (BNT) (total correct)	14.5±0.72
Spatial learning Brooks Spatial Task (percent correct/100 points)	60.97±26.5
Executive functioning Tower of London test (TOL) (scaled total achievement score)	10.7±4.45
Short-term visual memory Reverse Corsi Block test (product score)	23.8±11.97
Montreal Cognitive Assessment (MOCA)	
Visuospatial/Executive function	3.81±0.87
Attention/working memory	5.45±0.93
Verbal memory	2.74±2.03
Orientation	5.55±0.77
Naming	2.77±0.43
Abstraction	1.71±0.64
Delayed	2.74±2.03
Total score (/30)	24.4±3.66

Table 1. Values are presented as Mean±SD for continuous variables, and n (%) for categorical variables.
QOL-AD = Quality of Life AD scores range from 13-52 points. Higher scores indicate better quality of life.
BDI-II= Beck Depression Inventory II scale. Higher scores indicate worse depression.
SF-12 = short form 12, PCS= physical composite scale, and MCS= mental composite scale. Average score is 50 points. Higher scores indicate better quality of life.
For Corsi blocks, the product score is the product of the span and the trials.
TOL= scaled total achievement score

In the images that we include here for MRI scans, the following 11 participants' data were included:

PRR001, PRR003, PRR004, PRR005, PRR007, PRR008, PRR014, PRR017, PRR022, PRR027, PRR030.

2.3 Administered fMRI assessment

Participants were asked to lie in the MRI scanner. The task protocol was then described for them enough times such that they understand what was required of them before going into the tube. Participants engaged in a touch task with an MRI compatible bear claw in the right hand. Participants were exposed to three different conditions, in between rest conditions. The three conditions were “touch” (T), “touch, listen, and watch” (TLW), and “listen and watch” (LW). There were twenty-four, 15 second blocks of “touch”, twenty-four 15 second blocks of “touch, listen, and watch”, and twenty-four 15 second blocks of “listen and watch” across 4 runs (meaning there will be 6 blocks of conditions in each run). Throughout the 1st 3 seconds of each block, a voice cue indicated whether the participants would experience a “touch”, “listen and watch” or “touch, listen or watch” trial. Block order was randomized in each functional run and 15 second rest blocks were imposed after every block of condition (Figure 1). (TR= 7.24 s, TE = 32ms, 72 slices with 10% gap, FOV= 208 mm, flip angle 52°, voxel size $2 \times 2 \times 2$ mm^3).

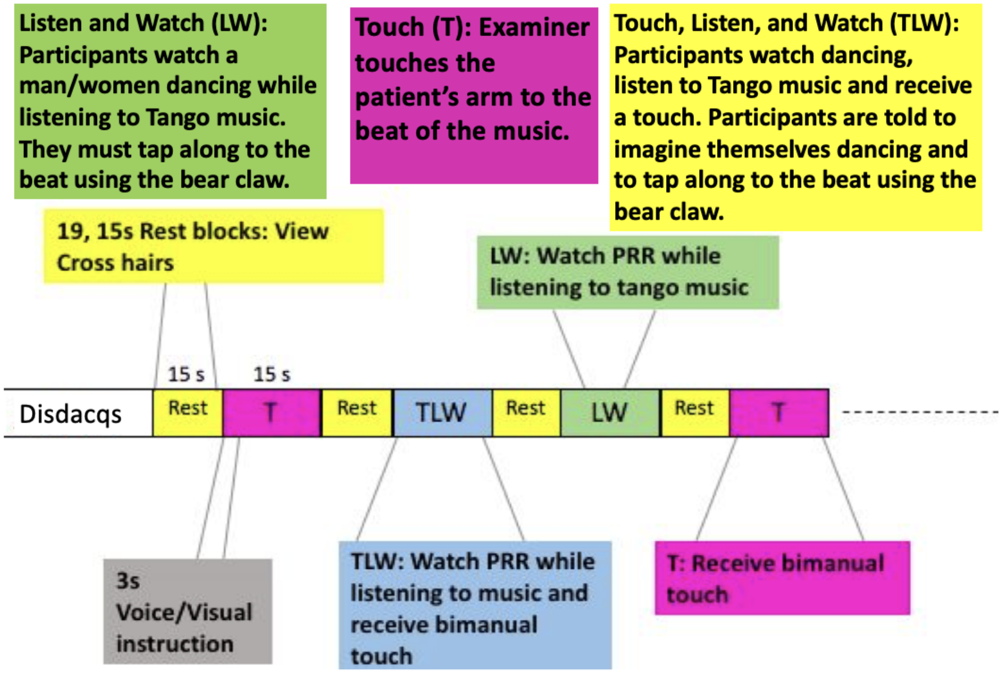


Figure 1. Blocks of conditions (T vs. LW vs. TLW) administered between rest conditions.

Figure 1 Illustrates the blocks of the three different conditions (T vs. TLW vs. LW) with periods of rests administered between blocks. There are 24, 15 second blocks of "touch", 24, 15 second blocks of "touch, listen and watch", and 24, 15 second blocks of "listen and watch", across 4 runs. Block order was randomized in each functional run. Throughout the 1st 3 seconds of each block, a voice cue indicates whether the participant will experience a "touch", "listen and watch", or "touch, listen or watch" trial. With 12 second rest blocks imposed between each run; the sequence order is counterbalanced across participants.

2.3.1 Touch Task Protocol Conditions

Lying supine, participants engaged in a touch task with an MRI compatible bear claw in the right hand. Participants were exposed to three conditions, interleaved with rest conditions. In one condition, they saw a screen depicting, "notice the touch". In another condition, they saw a screen depicting the words, "notice the touch, listen, and watch". In a third condition, they read the screen depicting the words, “listen and watch”. During conditions that referenced “touch”, participants felt an examiner touching their forearm close to their hand. In conditions that reference “listen”, participants heard commercial recordings of Argentine tango music performed by the composer, Florindo Sassone. The songs were “Yira, Yira”, “Marejada”, “Maipo”, and “Lagrimas”. Each song was used once in a run with 15 second clips taken from the songs. Participants tapped the claw when they heard the music. During the conditions that references “watch”, participants saw a screen with a couple, a man and a woman, performing simple tango-like steps. The man and the woman were viewed from the shoulders down; they were clasping forearms during all dance sequences. Participants were instructed, “When you see people dancing on the screen, imagine that you are the man/woman in this video”. They were also instructed to “tap your finger along with the beat while you imagine that you are dancing”. During the rest condition, participants were instructed to “rest” and focus on the crosshair image that appeared on the screen (Figure 2).

A research assistant held the left forearm of the participants during all touch conditions (“Touch” and “Touch, Listen and Watch”). There was no touch during rest periods or during “Listen and Watch” conditions.

Participants were also told before the scan to use the Celaris claw to tap along to the beat with their right hand. At the end of the assessment, participants were asked to fill out a task performance sheet which asked them what they were focusing most on: touch, listening or watching the video, whether they were successful in imagining themselves as the man or woman dancing in the video, whether the touch made the experience feel more real, like they were dancing, and probed for any other comments.

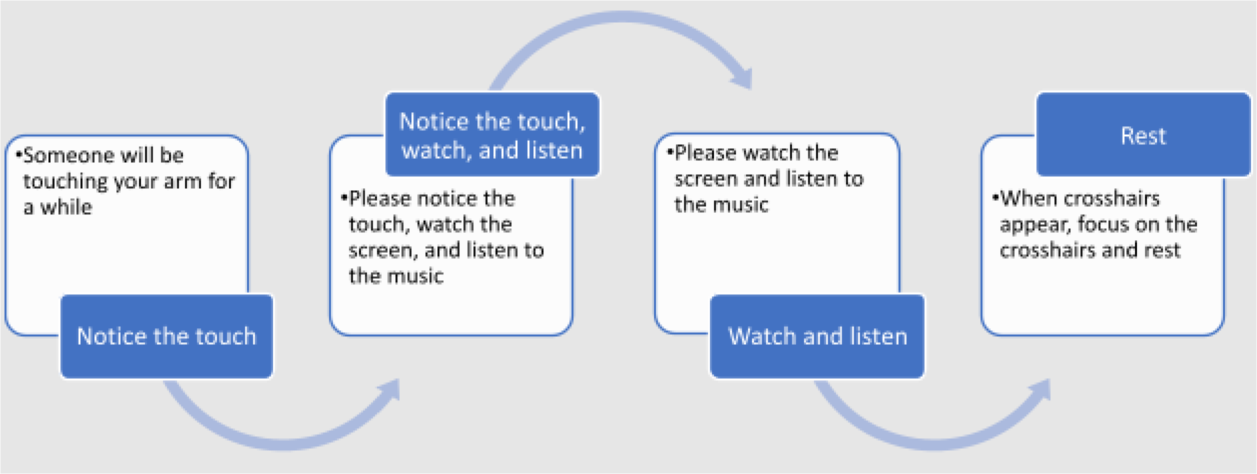


Figure 2. Instructions administered during each condition (T vs. TLW vs. LW) and rest.

Figure 2 Instructions participants saw or heard during each condition (T vs. TLW vs. LW) and rest blocks. During watch conditions, they were further asked to imagine themselves as the dancers and tap along to the beat.

2.4 Anatomical Data Processing

The T1-weighted (T1w) image was corrected for intensity non-uniformity (INU) with `N4BiasFieldCorrection`, distributed with ANTs 2.3.3, and used as T1w-reference throughout the workflow. The T1w-reference was then skull-stripped with a *Nipype* implementation of the `antsBrainExtraction.sh` workflow (from ANTs), using OASIS30ANTs as target template. Brain tissue segmentation of cerebrospinal fluid (CSF), white-matter (WM) and gray-matter (GM) was performed on the brain-extracted T1w using `fast` [FSL 6.0.5.1:57b01774, RRID:SCR_002823, @fsl_fast]. Brain surfaces were reconstructed using `recon-all` [FreeSurfer 7.2.0, RRID:SCR_001847, @fs_reconall], and the brain mask estimated previously was refined with a custom variation of the method to reconcile ANTs-derived and FreeSurfer-derived segmentations of the cortical gray-matter of Mindboggle [RRID:SCR_002438, @mindboggle]. Volume-based spatial normalization to two standard spaces (MNI152NLin2009cAsym, MNI152NLin6Asym) was performed through nonlinear registration with `antsRegistration`

(ANTs 2.3.3), using brain-extracted versions of both T1w reference and the T1w template. The following templates were selected for spatial normalization: *ICBM 152 Nonlinear Asymmetrical template version 2009c* [@mni152nlin2009casym, RRID:SCR_008796; TemplateFlow ID: MNI152NLin2009cAsym], *FSL's MNI ICBM 152 non-linear 6th Generation Asymmetric Average Brain Stereotaxic Registration Model* [@mni152nlin6asym, RRID:SCR_002823; TemplateFlow ID: MNI152NLin6Asym].

2.5 Task fMRI Preprocessing

For each of the 4 BOLD runs found per subject (across all tasks and sessions), the following preprocessing was performed. First, a reference volume and its skull-stripped version were generated using a custom methodology of fMRIPrep. Head-motion parameters with respect to the BOLD reference (transformation matrices, and six corresponding rotation and translation parameters) are estimated before any spatiotemporal filtering using `mcflirt` [FSL 6.0.5.1:57b01774, @mcflirt]. BOLD runs were slice-time corrected to 0.312s (0.5 of slice acquisition range 0s-0.625s) using `3dTshift` from AFNI [@afni, RRID:SCR_005927]. The BOLD time-series (including slice-timing correction when applied) were resampled onto their original, native space by applying the transforms to correct for head-motion. These resampled BOLD time-series will be referred to as *preprocessed BOLD in original space*, or just *preprocessed BOLD*. The BOLD reference was then co-registered to the T1w reference using `bbregister` (FreeSurfer) which implements boundary-based registration [@bbr]. Co-registration was configured with six degrees of freedom. Several confounding time-series were calculated based on the *preprocessed BOLD*: framewise displacement (FD), DVARS and three region-wise global signals. FD was computed using two formulations following Power (absolute sum of relative motions, @power_fd_dvars) and Jenkinson (relative root mean square displacement between affines, @mcflirt). FD and DVARS are calculated for each functional run, both using their implementations in *Nipype* [following the definitions by @power_fd_dvars]. The three global signals are extracted within the CSF, the WM, and the whole-brain masks. Additionally, a set of physiological regressors were extracted to allow for component-based noise correction [*CompCor*, @compcor]. Principal components are estimated after high-pass filtering the *preprocessed BOLD* time-series (using a discrete cosine filter with 128s cut-off) for the two *CompCor* variants: temporal (tCompCor) and anatomical (aCompCor). tCompCor components are then calculated from the top 2% variable voxels within the brain mask. For aCompCor, three probabilistic masks (CSF, WM and combined CSF+WM) are generated in anatomical space. The implementation differs from that of Behzadi et al. in that instead of eroding the masks by 2 pixels on BOLD space, a mask of pixels that likely contain a volume fraction of GM is subtracted from the aCompCor masks. This mask is obtained by dilating a GM mask extracted from the FreeSurfer's *aseg* segmentation, and it ensures components are not extracted from voxels containing a minimal fraction of GM. Finally, these masks are resampled into BOLD space and binarized by thresholding at 0.99 (as in the original implementation). Components are also calculated separately within the WM and CSF masks. For each CompCor decomposition, the *k* components with the largest singular values are retained, such that the retained components' time series are sufficient to explain 50 percent of variance across the nuisance mask (CSF, WM, combined, or temporal). The remaining components are dropped from consideration. The head-motion estimates calculated in the correction step were also placed within the corresponding confounds file. The confound time series derived from head motion estimates and global signals were expanded with the inclusion of temporal derivatives and quadratic terms for each [@confounds_satterthwaite_2013]. Frames that exceeded a threshold of

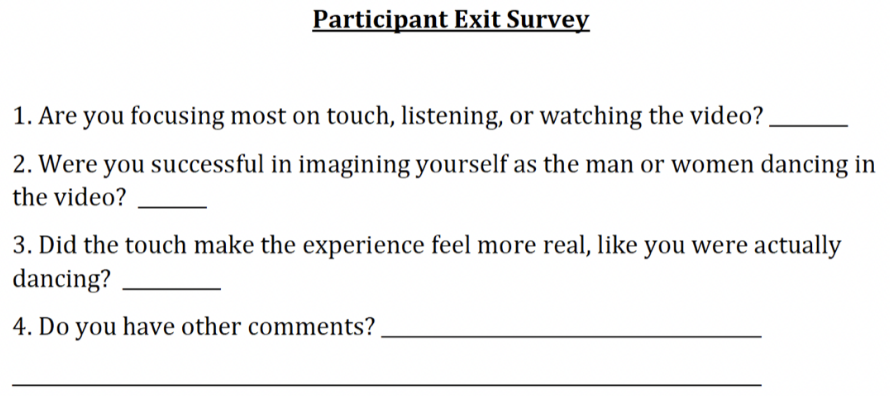
0.5 mm FD or 1.5 standardized DVARS were annotated as motion outliers. Additional nuisance timeseries are calculated by means of principal components analysis of the signal found within a thin band (*crown*) of voxels around the edge of the brain, as proposed by [@patriat_improved_2017]. Automatic removal of motion artifacts using independent component analysis [ICA-AROMA, @aroma] was performed on the *preprocessed BOLD on MNI space*time-series after removal of non-steady state volumes and spatial smoothing with an isotropic, Gaussian kernel of 6mm FWHM (full-width half-maximum). Corresponding "non-aggressively" denoised runs were produced after such Smoothing. Additionally, the "aggressive" noise-regressors were collected and placed in the corresponding confounds file. All resamplings can be performed with *a single interpolation step* by composing all the pertinent transformations (i.e., head-motion transform matrices, susceptibility distortion correction when available, and co-registrations to anatomical and output spaces). Gridded (volumetric) resamplings were performed using `antsApplyTransforms` (ANTs), configured with Lanczos interpolation to minimize the smoothing effects of other kernels [@lanczos].

2.6 Task fMRI GLM

BOLD estimation and statistical analysis of the fMRI data was performed using SPM12. Statistical analysis within each participant used a linear convolution GLM with a regressor used for each of the 3 conditions as well as one for each of the 4 runs. Four different contrasts were performed and the estimates from these were used for the group comparisons. For statistical analysis across participants, a mass univariate General Linear Model (GLM) was used. T-Tests were then performed comparing conditions with one another to determine which condition exhibited a greater BOLD response than the other condition (s) in every voxel in the brain.

2.7 fMRI Task Performance Exit Survey

The Participant Exit Survey was conducted after the fMRI assessment. The survey asked participants if they were more focused on touch, listening, or watching the video, whether they successfully were able to imagine themself as the man or woman dancing in the video, if the touch made the experience feel more real and if they felt as if they were dancing, and if they had any additional comments they would like to add. The responses from the survey helped us determine if the partner touch task is a valid way of determining the neural areas activated during touch, listening, and watching partnered human-human interactions while dancing (Figure 3). Some of the participants' responses to the exit survey are shown in table 2. Results show that participants focused the most on watching the video during "watch" conditions. Results also depict that the touch made the experience more real, like they were actually dancing.



Participant Exit Survey

1. Are you focusing most on touch, listening, or watching the video? _______

2. Were you successful in imagining yourself as the man or women dancing in the video? ______

3. Did the touch make the experience feel more real, like you were actually dancing? ________

4. Do you have other comments? ________________________________
____

Figure 3. Participant Exit Survey Questionnaire

Figure 3 depicts the Exit Survey that took place at the end of the fMRI assessment to evaluate the participants' performance during the Partner Touch Task assessment. The Exit Survey is used to determine if the MRI imaging accurately reflects neural activation of tango dance components.

Table 2. fMRI task performance Exit Survey results for all 32 participants

Participants	Are you focusing mostly on touch, listening, or watching the video?	Were you successful in imagining yourself as the man or woman dancing in the video?	Did the touch make the experience feel more real, like you were actually dancing?
PRR001	Touch	Yes	No
PRR003	Listen	Yes	Yes
PRR004	Watch	Yes	Yes
PRR005	Watch	Yes	Yes
PRR007	Watch	Yes	Yes
PRR008	Listen	No	Yes
PRR014	Watch	Yes	No
PRR009	Touch	Yes	Yes
PRR010	Listen	Yes	Yes
PRR011	Watch	Yes	Yes
PRR012	Watch	Yes	Yes
PRR013	Listen	Yes	Yes
PRR014	Touch	Yes	No
PRR017	Watch	No	Yes
PRR018	Watch	Yes	Yes
PRR021	Listen	Yes	Yes
PRR022	Touch	No	Yes
PRR023	Watch	Yes	Yes
PRR024	Watch	Yes	No
PRR027	Listen	Yes	Yes
PRR029	Touch	Yes	No
PRR030	Watch	No	Yes
PRR031	Watch	Yes	No
PRR032	Touch	Yes	Yes
PRR033	Watch	Yes	Yes

Table 2. depicts participant self-report responses after undergoing the fMRI touch task assessment. Most participants were focused on watching the video, were successfully able to imagine themselves dancing, and said that the touch experience made it feel like they were dancing.

3. Results

3.1 Participant Cognitive Assessments

The 32 participants who were scanned were 14 men and 18 women, who had at least some college education. They were more than 35% non-white, most of them lived independently in a house or apartment, drove their own vehicle, were in a relationship, and were retired. They had 4 comorbidities on average, and their Composite Physical Function index shows that they had good functional status physically. Their average MOCA score of 24 indicates some mild cognitive impairment. Out of the 32 participants that underwent the fMRI scan, 11 participants' data is included in this thesis because the data were prepared and analyzed at the time of completion. Table 3 depicts the demographics of the 11 participants whose data were used for fMRI analysis. These 11 participants (3 White, 2 male individuals) had MoCA scores at baseline assessment of range [19-29], and age range 56-86 years], and they had at least 14 years of education. Their QOL (SF-12 scores) indicate they had moderate to good physical and mental quality of life.

Table 3. Demographics for participants that went through fMRI analysis

	Age (y)	Race	Years of education	Gender	MOCA score	SF12-PCS	SF12-SFS
PRR001	78	White	16	Male	24	44.1	45.2
PRR003	56	Black	16	Female	25	61.5	45.3
PRR004	70	Black	16	Female	25	55.8	40.0
PRR005	71	Black	18	Female	28	56.4	47.4
PRR007	75	Black	14	Female	29	61.5	45.3

PRR008	78	Black	14	Male	23	37.8	46.3
PRR014	86	Black	18	Female	26	58.5	43.1
PRR017	74	Black	18	Female	19	61.8	47.7
PRR022	76	White	14	Female	28	58.8	51.2
PRR027	81	Black	14	Female	24	40.1	56.6
PRR030	72	White	16	Female	20	46.7	51.0

Table 3. Characteristics and Demographics of 11 participants whose data are presented. Short Form health survey-12 (SF-12) includes Physical (PCS) and Mental Composite (MCS) scores, which indicate physical and mental quality of life that is self-reported.

3.2 BOLD differences between T, LW, and TLW conditions from PRR001, an Exemplar Participant.

T test results for an exemplar participant, PRR001, comparing the different touch task conditions (T vs LW vs TLW) showed considerable differences in sensorimotor areas. Through the comparisons, greater BOLD was observed in the superior temporal gyrus, inferior parietal lobule, superior parietal lobule, medial prefrontal cortex, dorsal anterior cingulate cortex, frontal lobe, superior frontal gyrus, occipital lobe, precuneus and postcentral gyrus. These images showed the greatest difference when comparing the average of touch and listen-watch conditions to the Touch-Listen-Watch condition ((T+LW/2) vs TLW) and comparing the touch-listen-watch condition to the Listen-Watch condition (TLW vs LW).

TLW compared to LW conditions revealed less BOLD in the sensorimotor areas. Comparing TLW vs LW, most of the activation was shown in the thalamus ($p<0.05$). Insignificant levels of BOLD were found in superior parietal lobule, and postcentral gyrus

($p>0.05$). Considering ((T+LW/2) vs TLW) conditions (Figure 4 third row), BOLD was shown in brain regions in which there was no BOLD during (TLW vs (T+LW/2)) (Figure 4, first row). The average of T and LW compared to TLW conditions were predominantly shown in the cerebellum, inferior parietal lobule, superior temporal gyrus, middle temporal gyrus, middle frontal gyrus, and inferior temporal gyrus ($p<0.05$) (Figure 4 third row). There was a lack of BOLD in the somatosensory and visual cortex region; most was concentrated in the cerebellum. TLW compared to the average of T and LW demonstrated no significant BOLD in the thalamus or the cerebellum but in somatosensory regions such as postcentral gyrus (SI) and superior parietal lobule (SII) ($p<0.05$) BOLD was also shown in the visual cortex and prefrontal cortex (Figure 4 top row). TLW compared to T shows higher BOLD in somatosensory regions, prefrontal cortex, middle frontal gyrus, and superior parietal lobule ($p<0.05$) (Figure 4 bottom row).

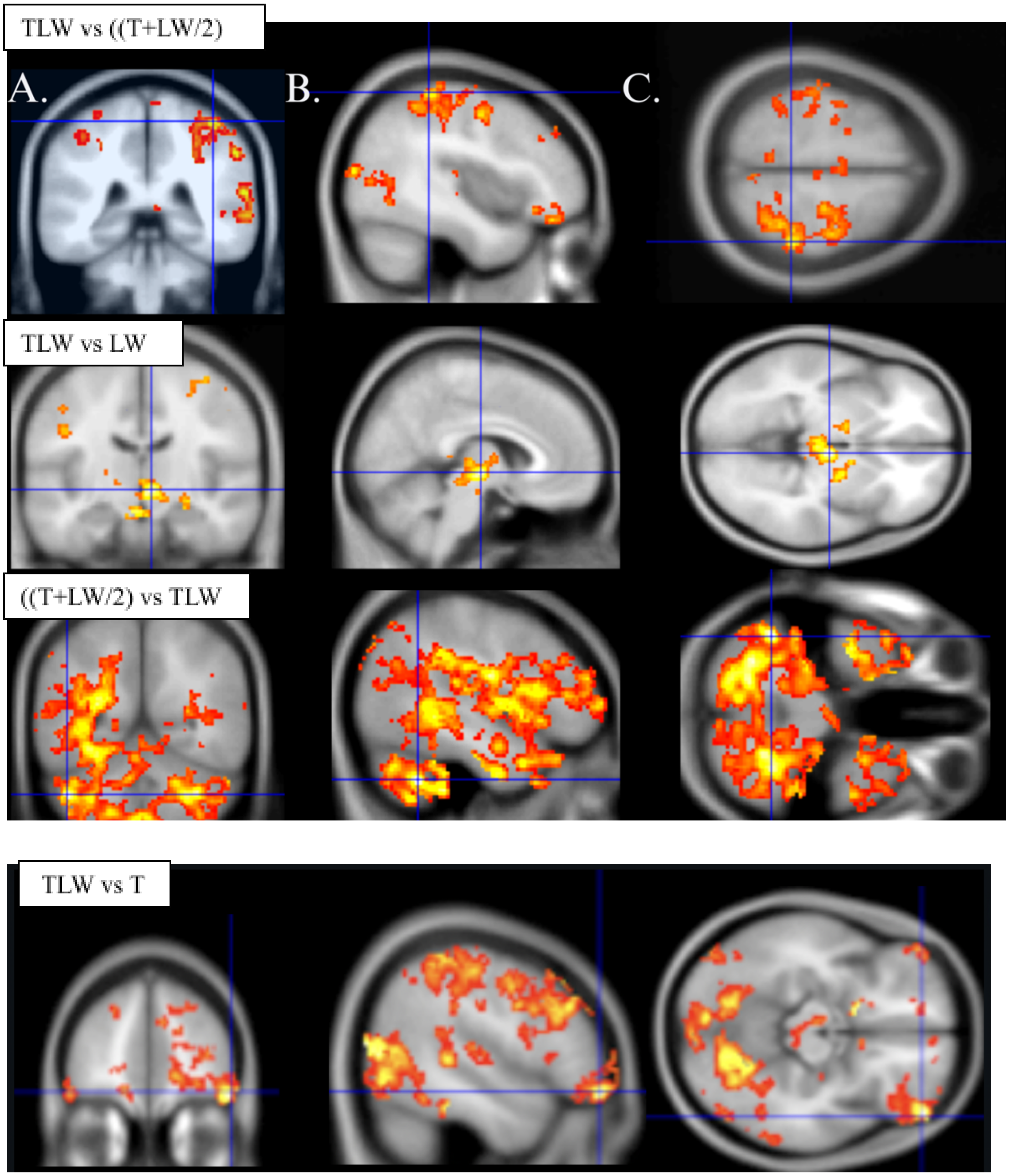


Figure 4. Statistically significant BOLD during different touch task conditions as evidenced by these contrasts of exemplar participant PRR001 ($p<0.05$).

Figure 4 shows BOLD from TLW vs the average of T and LW (TLW vs ((T+LW/2)), TLW vs LW, average of T and LW vs TLW ((T+LW/2) vs TLW), and TLW vs T in (A) axial (coronal) slices; (B) sagittal slices and (C) transverse slices. The t test shows that regions show more BOLD signals in the average of the T and LW conditions than TLW conditions.

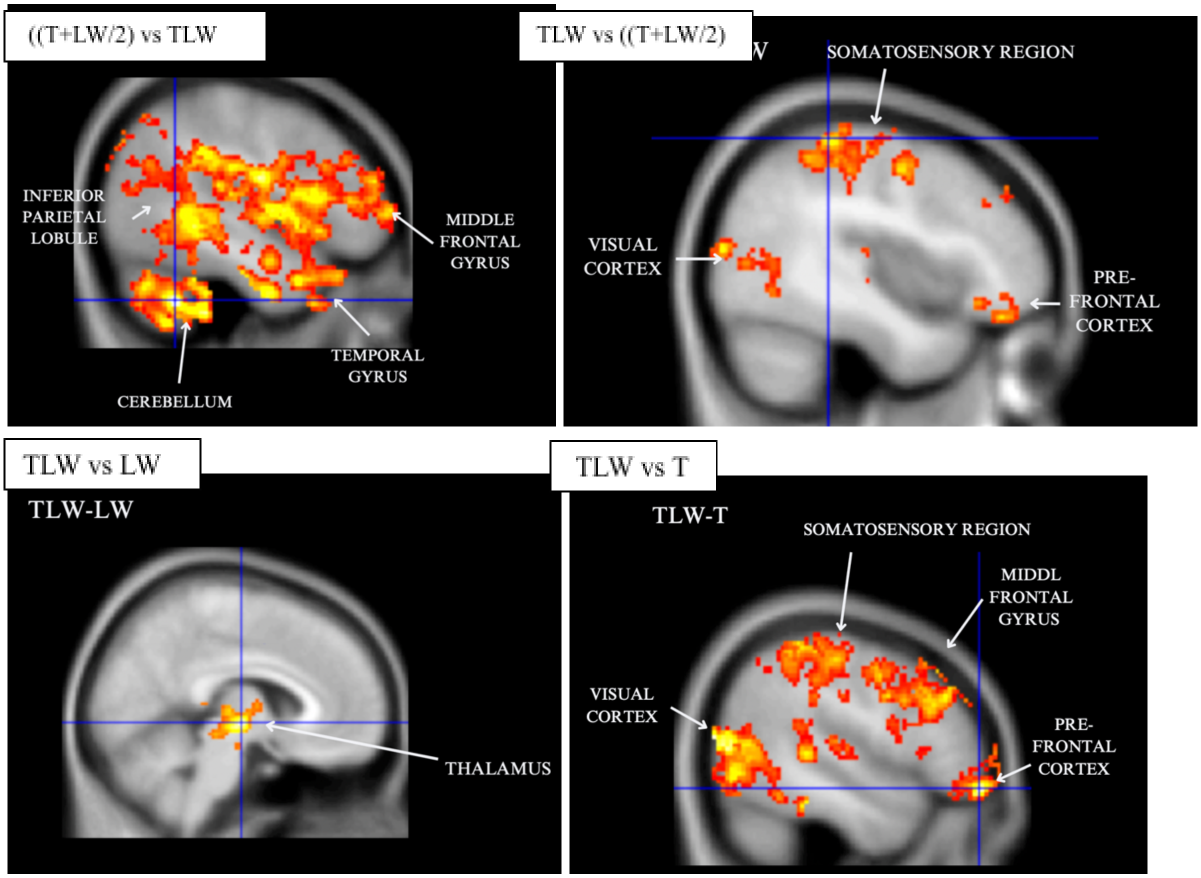


Figure 5. Labeled images of BOLD brain regions during touch task conditions in exemplary participant PRR001.

Figure 5 shows labeled brain regions of BOLD from TLW vs the average of T and LW (TLW vs (T+LW/2)); upper right panel), TLW vs LW (left lower panel), average of T and LW vs TLW ((T+LW/2) vs TLW) (upper left panel), and TLW vs T in the sagittal slices of PRR001 (right lower panel).

3.3 BOLD Contrasts between T, LW, and TLW in the group of 11 participants.

Contrasts to evaluate the difference between the conditions amongst the 11 participants, showed significant BOLD for TLW vs the average of T and LW depicted significant results in the superior temporal gyrus, precuneus, and thalamus regions (p<0.0005). Group contrasts to evaluate the difference between TLW and LW, showed BOLD only found near the postcentral gyrus and superior parietal lobule (p<0.001) TLW vs T depicts BOLD in the planum polare and the superior frontal gyrus (p<0.001). The average of T and LW compared to TLW showed no suprathreshold clusters (p<0.001). This shows that TLW had greater BOLD than the average of T and LW conditions, opposite to what we saw in PRR001 (Figure 6).

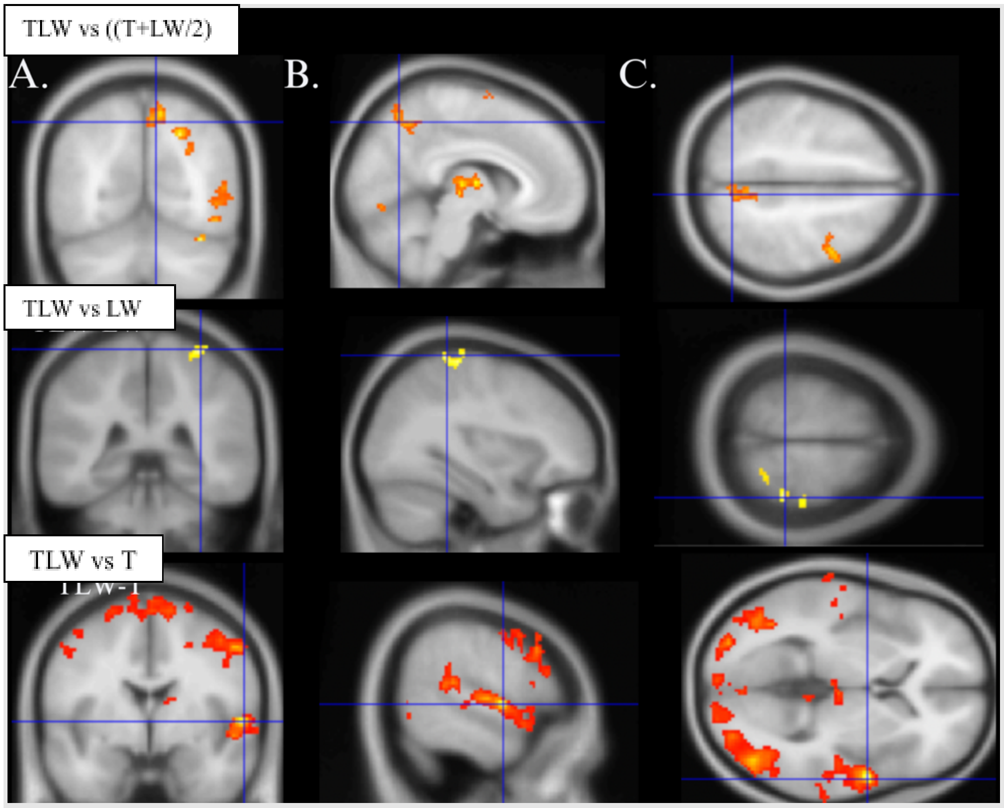


Figure 6. Statistically significant BOLD during touch task conditions of 11 participants. Figure 6 shows BOLD from TLW vs the average of T and LW (TLW vs (T+LW/2)), TLW vs LW, and TLW vs T in (A) axial (coronal) slices; . (B) sagittal slices and (C) transverse slices. TLW compared to the average of T and LW showed the greatest BOLD while TLW vs LW

showed the least BOLD. Average of T and LW vs TLW showed no BOLD that surpassed the suprathreshold cluster.

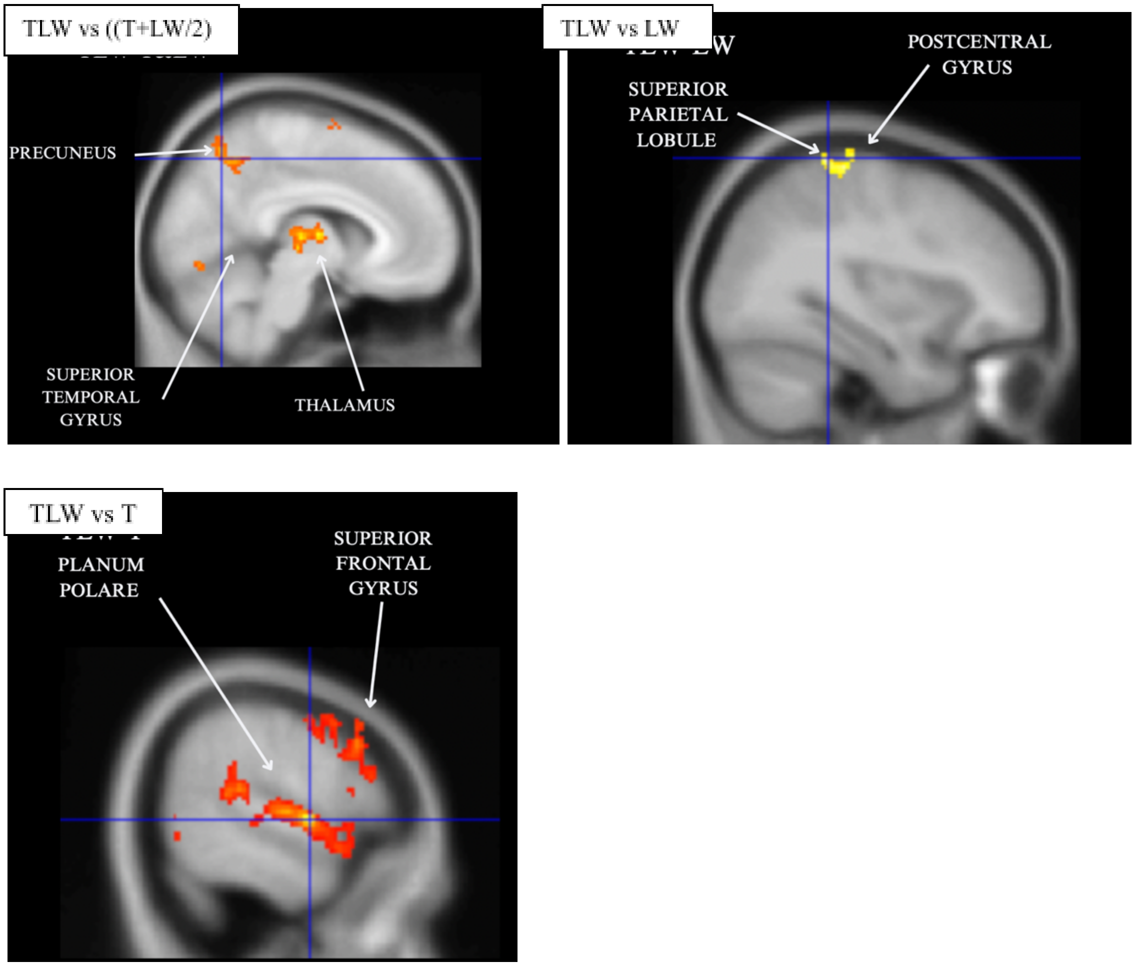


Figure 7. Labeled images of BOLD during touch task conditions in a group of 11 participants. Figure 7 depicts labeled images of BOLD from TLW vs the average of T and LW (TLW vs (T+LW/2)), TLW vs LW, and TLW vs T in the sagittal slices of group contrast. These panels show BOLD in precuneus, superior temporal gyrus, thalamus (upper left panel), superior parietal lobule, and postcentral gyrus (upper right panel) and planum polare and superior frontal gyrus (lower left panel).

The extent threshold of clusters of individual voxels passes a threshold of p<0 and k=100 voxels for all contrasts. TLW vs LW and T had 7 tests of interest. The expected voxels per cluster was k=2.72. For TLW vs LW, there was 1 test of interest. The expected voxels per cluster was k=3.79. For TLW vs T there were 9 tests of interest. The expected voxels per cluster was k=3.79. The height threshold was T=4.14 for TLW minus LW, TLW minus T, T and LW minus TLW. TLW minus LW and T had a height threshold of T=4.59.

Table 4. Conditions of all BOLD observed at FWE-corrected cluster level p<0.05.

	Peak-level t-value	Peak-level p-value corrected	Peak-level q-value corrected	Peak-level Z score	Peak voxel	Expected voxels per cluster <k>
TLW vs (T+LW/2)						2.72
Superior temporal lobe	12.5	0.068	0.768	5.20	(70, -28, 18)	
Thalamus	8.73	0.991	0.768	4.55	(7.54, -7.97, 7.59)	
Precuneus	7.75	1.00	0.768	4.32	(7.54, -64.6, 51.4)	
TLW vs LW						3.39
Postcentral gyrus	6.95	1.00	0.970	4.11	(40, -26, 54)	
Superior parietal lobule	6.15	1.00	0.970	3.87	(34, -38, 70)	
TLW vs T						3.79
Planum polare	17.5	0.003	0.129	5.77	(58, -2, 2)	

Table 4. depicts BOLD observed in the Superior temporal lobe, thalamus, precuneus, postcentral gyrus, superior parietal lobule, and planum polare amongst different comparisons of conditions.

4. Discussion

This thesis presents the feasibility and initial findings of a task designed to elicit understanding of brain mechanisms involved in a human-human touch interaction involving sound, music, creative movement and tactile cues. This group of individuals had mild cognitive impairment. Future work will examine the brain mechanisms in younger adults as well as neurotypical older adults.

4.1 TLW vs LW group contrast comparison

Based on the group contrast of 11 participants, we observed in the TLW vs LW contrast BOLD that we can assume it was a result due to the variable touch. During the T condition we observed significant BOLD in the postcentral gyrus and superior parietal lobule. As the post central gyrus is a part of the primary somatosensory cortex, BOLD observed through touch conditions is justifiable as the brain region is stimulated through visual stimuli that implies sound, touch, or smell. BOLD seen in the superior parietal lobule through touch conditions agrees with previous work as the superior parietal lobule is linked with the occipital lobe and is involved in aspects of attention, spatial perception, and memory (Johns, 2014).

4.2 TLW vs T group contrast comparison

In the TLW vs T contrast, we see BOLD that is specific to the LW condition. The LW condition activates the planum polare and the superior frontal gyrus in the group contrast. The planum polare is the cortical area posterior to the auditory cortex and is involved with language and music. The activation of the planum polare during the LW condition accurately reflects the participants' ability to listen to the tango music. However, results do not show that the LW condition alone could induce mental imagery; LW conditions do not seem adequate for participants to successfully imagine themselves dancing while watching the partnered dance video. If the participants were able to successfully imagine themselves dancing, BOLD would have been depicted at least within the precuneus, primary somatosensory cortex (S1), primary motor cortex (M1), or visual cortex. These patterns of activation in S1 or M1 would have suggested that the observers' perception of dance actions was enhanced by embodied processes, the use of our bodily experience and processes to understand our own emotional experiences and the experiences of others (Bricks & Steven, 2011). Furthermore, activation in the visual cortex which receives and processes visual information should have been visible.

4.3 TLW vs (T+LW/2) group contrast comparison

When comparing TLW to the average effects of T and LW conditions, BOLD was depicted in the precuneus, thalamus, and superior temporal gyrus. When comparing the average effects of T and LW conditions to TLW, there were no suprathreshold clusters. This confirms that TLW had a greater effect on neural activation than the average effects of T and LW conditions presented alone in the group analysis. The precuneus is responsible for visuospatial imagery. The activation shown in the precuneus area provides evidence that the mental imagery created with all three conditions together was greater than the mental imagery created by LW conditions alone. This analysis supports the claim that the touch conditions in addition to LW conditions helped the participants better imagine themselves dancing during the protocol. BOLD in the thalamus shows that motor and sensory signals are greater relayed to the cortex through TLW than through T or LW separately. This fact supports the idea that greater sensory and visual information is present and transmitted through all three conditions together (TLW). The superior temporal gyrus is the site of processing auditory information and processing aspects of visual perception. BOLD in the superior temporal gyrus supports the idea that there is heightened information processing and cognitive functioning.

4.4 (T+LW/2) vs TLW comparison in PRR001

However, when looking at the BOLD patterns of exemplary participant PRR001, it shows that the average of T and LW conditions had a greater effect on neural activation than the combined effect of TLW condition. This contradicts what was seen in the group contrast of (T+LW/2) vs TLW as no supraclusters were shown. No BOLD was shown in somatosensory regions, meaning that the effects of touch separately and in TLW were the same. However, considerable BOLD was observed in the cerebellum, temporal gyrus, and frontal gyrus, supporting the concept that LW had a greater effect on motor learning, visual perception, and attention in this participant. This finding could be due to the participant's inability to follow instructions, or the participants' not having adequate rest blocks between each condition or other currently not well understood mechanisms.

4.5 TLW vs (T+LW/2) comparison in PRR001

Considering the BOLD patterns comparing TLW to the average of T and LW conditions, TLW had greater effects in the somatosensory region, visual cortex, and prefrontal cortex. TLW conditions were shown to have the opposite effect of (T+LW/2) conditions, depicting BOLD in areas where (T+LW/2) did not. BOLD in the somatosensory region demonstrated that the touch condition in TLW had a greater impact on neural activation than the touch condition separately. BOLD shown in the visual cortex depicts that the TLW condition received and processed more visual information than LW only.

4.6 TLW vs LW comparison in PRR001

Significant BOLD was in the thalamus region during the touch condition in PRR001 when isolated through the TLW versus LW contrast. The isolated touch condition in TLW depicts the significant BOLD shown in the thalamus as sensory information is processed and transmitted to the somatosensory regions. The BOLD in the thalamus shows us that touch is responsible for the activation shown in sensorimotor areas.

4.7 TLW vs T comparison in PRR001

Significant BOLD indicates that touch and watch in the TLW condition is the cause of most neural activation in the ROIs. With BOLD seen in the visual cortex and somatosensory regions, it is evident that touch and watch conditions were being processed by the brain. The lack of BOLD shown in the planum polare shows that the listen condition in TLW for PRR001 had no significant effect on brain activation.

4.8 Similarities between exemplary participant PRR001 and group contrast results

Similarities between the group results and the exemplary participant results in the TLW vs (T+LW/2) condition helps us further confirm that the TLW condition helped participants the most when it came to them being able to imagine themselves dancing. With TLW depicting greater BOLD in the somatosensory and visual cortex region for both the group contrast and PRR001, it is evident that the touch condition is a crucial aspect along with LW that helps participants feel like they were dancing.

However, it is also seen that BOLD was depicted in different areas when comparing the same conditions between the group and individual contrast. This could be due to PRR001 having greater or lesser cognitive impairments than the group, the protocol being carried out dissimilarly amongst participants, adequate rest blocks not being administered, or the conditions just having different effects on the participants due to personal, environmental, or social reasons.

4.9 Conclusions

The effects of partnered dance on adults with MCI has been a topic of interest amongst researchers in the scientific community for the last decade. By learning more about the neurophysiological mechanisms behind partnered dance, specifically human-human touch interactions, we hoped to gain a better understanding on its ability to improve motor-cognitive functioning in MCI participants. The TLW condition seemed to have the greatest effect on participants as it showed BOLD in regions that correlate with mental imagery, sensory processing, visual perception, auditory processing, and motor learning, neural functioning that should be seen with the touch task protocol.

The touch condition activated somatosensory regions such as the postcentral gyrus (S1) and the superior parietal lobule as affective touch was processed. The activation in the S1 could be the result of mirror neurons working to "mirror" the action and behaviors of others and helping the participant better perceive the dance actions (Jang & Pollick, 2011). Individuals without MCI are shown to have affective touch represented in more differentiated areas of somatosensory cortex with stronger emotional responses (Lee Masson, Pillet, Amelynck et al., 2019). The thalamus is essential for smooth cortical functioning and cognitive performance. BOLD showed in the thalamus region of PRR001 proved that the thalamus played a role in the perception of touch. Insignificant BOLD shown in the thalamus region for the group contrast may be the result of cognitive impairments.

The LW condition seemed to elicit BOLD in areas of visual and auditory processing. The combination of visual-auditory stimulation helps elicit mental imagery and elevated physiological responses (Hagni et al., 2008). While the touch condition was removed, we can see the true effects of observing people dancing in ROIs. Individuals with neurodevelopmental disorders show no activation in the somatosensory cortex or superior temporal gyrus during observation of social touch (Masson et al., 2019). As BOLD was shown in the somatosensory region for PRR01 but not in the group contrast (TLW vs T), cognitive impairments could have prevented participants from depicting neurotypical brain activation to observing social touch.

This research supports the idea that partnered dance is an impactful therapy that enhances function in older adults with mild cognitive impairments (MCI). By looking at human-human touch interactions in the context of partnered dance, we see the neural mechanisms and effects behind touch interactions involving music and visual stimuli for people with MCI. Our results depict that the touch task protocol is a valid method to determine the effects of touch interaction and observing tango dance in the brain of people with MCI. However, larger standardized fMRI studies are necessary for us to definitively determine the effects of the touch task conditions on MCI participants.

4.10 Limitations

4.10.1 Study Sample

Out of the 32 participants that underwent a baseline fMRI scan, only 11 participants were further analyzed. We hope to analyze all 32 participants through group contrasts to gain a better understanding of the effects of each condition on MCI participants. Furthermore, we hope to gain fMRI results after participants undergo tango intervention classes and compare it to their baseline scans. Increased BOLD would tell us that partnered dance is improving their cognitive functioning.

4.11 Future Directions

Gaining knowledge from the touch task protocol can help us develop improved dance therapy programs for those facing MCI. By comparing neural activation from the touch task conditions before and after participants undergo tango dance interventions, we can assess if there are increases in BOLD levels which would support our idea that the intervention sessions are improving motor-cognitive functioning.

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