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The Influence of Joint-site, Limb Preference, and Physical Activity on Joint Position Sense

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THE INFLUENCE OF JOINT-SITE, LIMB PREFERENCE, AND PHYSICAL ACTIVITY ON JOINT POSITION SENSE

by

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List of Abbreviations

AMEDA………Active Movement Extent Discrimination Apparatus

JPS……………..Joint Position Sense

WFQ-R……….Waterloo Footedness Questionnaire

WHQ………….Waterloo Handedness Questionnaire

Chapter 1: The Influence of Joint-site and Lateral Preference on Joint Position Sense

Abstract:

Joint position sense provides the body with information about where limb segments are relative to one another in three-dimensional space. The ability to utilize this sense is imperative for smooth, coordinated, and accurate movement in everything from activities of daily living to competitive sport (Ghez & Sainburg, 1995). Researchers currently use joint position sense as a measure of proprioceptive acuity. However, limited research has investigated the influence of potential confounding factors on proprioception. Specifically, literature on how joint-site specificity and lateral preference influence proprioception displays several incongruent findings. Therefore, the purpose of the current study was (1) to determine if joint-site influences proprioception across the body; (2) to determine whether joint position sense depends upon limb preference; and (3) to determine if direction of movement during active joint repositioning influences proprioceptive error. Joint position sense was measured bilaterally in 55 healthy right-handed young adults at the elbows, wrists, knees, and ankles using active-active joint repositioning with a Vernier© goniometer. The results showed that each joint-site does in fact have different joint position sense acuity. No significant differences were found between the left and right side in any of the measured joints, although the elbows and wrists displayed trends of making smaller errors with the non-preferred joint than the right. When all measures in each limb were combined, the left arm was shown to make significantly fewer errors than the right arm; however, no differences were seen between the legs. Finally, movement direction had no influence on joint position sense at any

joint. Therefore, the results suggest that each joint has different proprioceptive acuity, and that preference influences the joints differently depending on the limb being measured.

INTRODUCTION:

Overview of the proprioceptive system:

Proprioception is defined as the perception of the position and movement of joints in space. In 1907 Sherrington proposed that proprioception is made up of two components: kinesthesia and joint position sense (JPS). Kinesthesia is considered the ability to sense movement in a joint, while joint position sense is the ability to know the stationary relative position of body segments. Both components work together by integrating feedback about changes in joint angles from mechanoreceptors that are found throughout the body (Riemann & Lephart, 2002; Ribeiro & Oliveira, 2007). In general, mechanoreceptors are specialized sensory receptors that primarily recognize stimuli in the skin, such as touch and heat. More specifically, the mechanoreceptors that the proprioceptive system relies on are primarily the muscle spindles, although the golgi tendon organs and joint receptors are also important contributors (Riemann & Lephart, 2002; Moore, 2007). Muscle spindles, located within the skeletal muscles, detect changes in muscle length. On the other hand, golgi tendon organs, which are found in muscle tendons, provide information about changes in muscle tension. Finally, joint receptors, found in and around joints, collect information about limb position and joint position throughout dynamic movement. Collectively these specialized mechanoreceptors are referred to as proprioceptors.

In order for the proprioceptors to relay information to the brain, a series of action potentials must travel from the proprioceptors through three levels of afferent sensory neurons before arriving in the somatosensory cortex, where the message is relayed via neurotransmitters. The signal initially ascends through the peripheral process of a pseudounipolar 1st order sensory afferent neuron from the proprioceptor to the spinal cord, where its central axon synapses with a 2nd order afferent neuron. The signal then ascends through the brain stem up to the diencephalon, where it decussates to the contralateral side of the brain. The 2nd order afferent neuron then terminates in the surrounding shell of the ventral posterolateral nucleus of the thalamus. Here it synapses with a 3rd order afferent that terminates in the somatosensory cortex. Proprioceptive information from the upper body terminates in the postcentral gyrus, while information pertaining to the lower body terminates in the paracentral lobule of the parietal lobe (Dougherty & Tsuchitani, 2015). While *proprioception* is simply the perception of limb position and movements in space, *proprioceptive performance* is defined as the quality of proprioceptive information available and the ability to integrate this information to determine limb position and movement. Therefore, an individual's ability to use proprioceptive information requires both afferent input and central processing of sensory information. All proprioceptors work together to provide information on both joint position and limb movement, which are essential for smooth and coordinated movements (Ghez & Sainburg, 1995).

Proprioception as a measure of motor function:

In healthy young adults the proprioceptive system works effectively in executing desired movements. However, injury, movement disorders, and aging can greatly impact the accuracy of this system. In both research and clinical settings proprioception is used as one of many measures of motor function, as deficits can lead to a decrease in motor performance (Ghez, Gordon, & Ghilardi, 1995). Since proprioception is often used to diagnose impairments in patients, is it imperative that the measure accurately represents an individual's proprioceptive ability. Thus it is extremely important for clinicians to be aware of any factors that could influence or bias a measurement of proprioception in order to ensure that clients are diagnosed correctly. Unfortunately, researchers who have investigated some of the major factors that are predicted to affect proprioception have provided mixed and contradictory findings. Therefore, more research is needed to determine which factors have the potential to influence measurements of proprioception to ensure that clinical diagnoses of proprioceptive acuity are accurate and correct.

Factors influencing measures of proprioception:

Proprioception is a complex sense to measure in research, as it encompasses various aspects that cannot be detected through a single test. The two components of proprioception, kinesthesia and joint position sense, can each be further broken down into multiple aspects. Kinesthesia, which is the ability to sense movements, is comprised of the ability to detect the onset of movement, as well as the threshold at which movement can be detected. Joint position sense is also broken into multiple components including the ability to match a position with the opposing limb (joint matching), the ability to reposition a limb to the same position (joint repositioning), as well as the ability to discriminate differences between multiple positions (joint discrimination). Therefore, when measuring proprioception, researchers are faced with the difficult decision of which specific aspect of proprioception will best reflect what they wish to measure. To further complicate matters, each aspect of proprioception is measured differently, thus making comparisons across studies quite difficult. With so many ways to measure the same sense, it is not surprising that the findings in previous research are incongruent and inconclusive, as researchers have often tried to equate a single aspect measured to represent global proprioception. Previous literature suggests three factors that may be contributing to mixed results in proprioception research: joint-site dependence, limb preference, and inconsistent measures.

Joint-site Dependence

Currently there are two different interpretations on how the joint-site (i.e. elbows compared to knees) may affect proprioception. First, the Pre-existing Global Deficit Hypothesis suggests that proprioception in all joints is dependent on higher-order processing, and therefore proprioceptive performance should be moderately correlated across different joints in the body (Goldie, Evans, & Bach, 1994; Han, Adams, Waddington, & Anson, 2013a). Waddington and Adams (1999b) measured the movement discrimination aspect of proprioception, which is defined as the ability to distinguish differences between several angles. The researchers tested movement discrimination at the ankles and knees of male soccer players and found no difference between the ankles and knees in the left and right limbs, thus showing support for the notion that proprioception is consistent across the body. However, it is important to note that the movement discrimination tasks used in this study have come under much scrutiny, therefore the results in this study may not reflect true proprioceptive measures. A closer look at the AMEDA reveals that while the developers claim it measures globalized proprioceptive function (Adams & Waddington, 1999a), the test may in fact be measuring something entirely different. Both Tremblay (2013) and Krewer et al. (2016) have suggested that the AMEDA is not a standard measure of proprioception, and the validity of the test should be questioned (Tremblay, 2013; Krewer, Winckel, Elangovan, Aman, & Konczak, 2016). Further, Krewer and colleagues have argued that the AMEDA does not measure the proprioceptive function at specific joints, but rather the multi-modal, multi-joint, measure of a multi-segment posture (Krewer et al., 2016). Therefore, further research that utilizes accepted and standardized measures of proprioception is needed to determine the true influence of joint-site on joint position sense.

In contrast, Hall and McCloskey (1983) found that the elbow, shoulder, and wrists have different kinesthetic acuity. Specifically, the shoulders had the lowest error, while the index finger had the highest error; thus suggesting that the more proximal the joint, the better the acuity. More recently, the idea of site-specific proprioception has been supported by Tremblay (2013). The author argues that while higher-order processing is involved, other factors can have a greater impact on individual joint-sites, such as the nature and density of peripheral proprioceptors at different body sites and the influence of intense site-specific training. In addition, Han and colleagues (2013a) examined proprioception in the ankle, knee, spine, shoulder, and finger joint-sites of 40 healthy young adults. All participants were right-handed, as measured on the Edinburg Handedness Inventory, and only the joints on the preferred side of the body were tested. Proprioception was measured using the Active Movement Extent Discrimination Apparatus (AMEDA), which has been previously claimed to measure movement discrimination acuity (Waddington & Adams, 1999a), which is the ability to discriminate between similar angles. The researchers hypothesized that all joints would be at least moderately correlated, in accordance with the Global Deficit Hypothesis, whereby all joints would exhibit similar proprioceptive acuity. However, the results indicated that there were no correlations between the joints, suggesting that proprioception is dependent on the site of the joint (Han et al., 2013a). A second study by Han et al. (2013b) using the same measures examined both the left and right joints at each site. Results once again revealed a joint-site proprioceptive dependence, where all joint-sites differed from one another on each side of the body (Han, Anson, Waddington, & Adams, 2013b). Interestingly, although not discussed by the authors, the mean scores for each of the measured joints followed the same pattern as described by Hall and McCloskey. The mean error in the upper limbs was lowest at the most proximal joint (shoulder, M=.65 degrees) and highest at the most distal joint (finger, M=.78). The same trend was observed in the lower limbs, where the lowest error was in the knees (M=.56) and the highest error was in the ankles (M=.64). Therefore, it can be concluded that the proximal-distal trend in this study is significant in both the upper and lower limbs. As discussed earlier, proprioception involves several different components, each of which are measured differently, thus making it difficult to compare one measure of proprioception to another. Hall and McCloskey (1983) measured movement discrimination, which is a component of kinesthesia. In contrast, the studies by Waddington and Adams (1999b), and Han et al. (2013a, 2013b) used the active movement extent discrimination assessment (AMEDA), which claims to measure broad proprioceptive function (Adams & Waddington, 1999a). However, there is currently no single, universally accepted test for measuring proprioception due to the various components and senses it encompasses. Consequently, while Adams and Waddington (1999b) and Han and colleagues (2013a, 2013b) have claimed to have measured proprioception across multiple joints, the results should be interpreted with caution.Therefore, the relationship between joint-site and proprioception should be further investigated to determine whether joints across the body have the same or different proprioceptive acuity.

Limb Preference:

Several researchers have suggested that limb preference may be a second factor contributing to the mixed results in proprioception. However, the literature has shown two conflicting findings about the influence of lateral preference on proprioception: a) lateral preference has no effect on proprioception, and b) lateral preference has a significant influence on proprioception. Voight and colleagues found that passive joint repositioning sense at the shoulder did not differ between the arms of healthy young adults (Voight, Hardin, Blackburn, Tippett, & Canner, 1996). As well, work by Adamo and Martin (2009) investigated the influence of limb preference on a position matching task in the wrists. Again, the researchers found no difference between the left and right wrists. However, it should be noted that limb matching tasks have been shown to be less reliable than other joint position sense tests, such as limb repositioning, and thus the type of measure may have influenced the results. Lastly, Ramsay and Riddoch (2001) investigated the influence of dominance on position matching acuity in professional ballet dancers and healthy controls (ages 19-36) at the elbows and shoulders. The researchers reported that three individuals were left handed while the other 17 were right handed, as determined by the writing hand. The results showed no difference in position sense between the shoulder and elbow joints, however there were several limitations to this study. First, upper limb dominance was determined by simply asking which was the writing hand, despite research clearly indicating that writing hand misidentifies individuals, particularly left handers. Instead, hand preference inventories, such as the Waterloo Handedness Questionnaire (Steenhius, Bryden, Schwartz, & Lawson, 1990) should be used. Second, in the analysis both right handers and left handers were grouped together, and the joints were analyzed by splitting them into preferred and non-preferred sides. Yet, research has consistently shown that right handers and left handers perform very differently on unimanual tasks (Kilshaw & Annett, 1983), thus grouping them together should be done with a great deal of caution. Finally, it should be noted that this study used contralateral limb matching, which is less sensitive to differences in acuity than other measures of position sense (Goble & Brown, 2007, 2008, 2009). Accordingly, the results from the work by Ramsay and Riddoch (2001) should be interpreted with discretion.

In contrast, many studies have found that lateral preference has a significant influence on proprioception. Goble and colleagues (2008, 2009, 2010) have repeatedly shown that position matching in the elbow is significantly more accurate in the non-preferred arm compared to the preferred arm. More recently, Han et al. (2013b) tested movement discrimination across the ankles, knees, shoulders and fingers in healthy young adults. Handedness and footedness were determined via the Edinburg Handedness Inventory and the Foot Preference Inventory, respectively. The results revealed the non-preferred joint was significantly better than the preferred joint across all of the joint-sites tested. Overall, research on the influence of lateral preference on proprioception has shown opposing findings. Additionally, little to no research has looked at joint position sense using limb repositioning, which is superior to other methods of measuring joint position sense (Adamo & Martin, 2009; Goble, 2010). Clearly more research is needed in order to determine whether joint position sense is dependent upon limb preference in both the upper and lower limbs.

A Neurological Perspective on Lateral Preference:

A common assumption regarding limb preference is that the preferred limb should perform with fewer position sense errors than the non-preferred limb. However, many researchers have found the opposite, where the non-preferred limb produced fewer errors on proprioceptive tests than the preferred limb (Goble et al., 2008, 2009, 2010; Han et al., 2013b). This is consistent with the *dynamic dominance hypothesis of handedness*, which suggests that the preferred limb is primarily used for trajectory control, whereas the non-preferred limb is responsible for static limb positions and postures (Sainburg, 2002). The hypothesis suggests that right handers, who have a left hand advantage for proprioceptive acuity, may in turn have a right hemisphere specialization for processing of proprioceptive feedback. That is, the non-preferred upper limb is typically used in stabilizing objects in a specific position to allow for manipulation by the preferred upper limb, such as hammering a nail. Likewise, the non-preferred lower limb is typically used for stabilizing balance, while the preferred lower leg performs an action, such as kicking a ball (Han et al., 2013b). Another way in which researchers have studied the influence of lateral preference on proprioception is through clinical research on individuals with head injuries. In particular, individuals who have incurred injury to the right hemisphere have been shown to have greater difficulty in determining kinesthetic targets and matching movements than individuals with similar injuries in the left hemisphere (Leonard & Milner, 1991a, 1991b; Rains and Milner, 1994; Goble, Hurvitz, & Brown, 2009). Most recently, Goble and colleagues (2009) found that the affected arm in children with hemiplegic cerebral palsy performed with greater error in elbow joint matching than typically developed children. However, deficits were only present if the damage was in the right hemisphere, supporting the notion that the right hemisphere has greater responsibility for proprioceptive feedback processing.

To further investigate the influence of lateral preference on proprioception, researchers have begun looking at the neurological basis through various brain imaging techniques. Brain imaging studies conducted on healthy adults have also supported the dynamic dominance theory, as they have shown a non-preferred limb advantage for proprioception. For instance, researchers found that in healthy adults, goal-directed reaching by the non-preferred (left) hand showed greater activation in the temporoparietal cortex in the right-hemisphere than activation in the left-hemisphere elicited by reaching by the preferred limb (Butler et al., 2004). Therefore, the right-hemisphere has greater activation than the left during reaching, thus suggesting a right-hemisphere (left-hand) reliance for proprioceptive processing. Moreover, two studies by Natio and colleagues (2005, 2007) on wrist proprioception further support the dynamic dominance hypothesis. The results showed that during non-preferred (left) arm proprioceptive tasks, increased activation in the higher order somatosensory processing areas was present in the right hemisphere only. This relationship was not found in the left hemisphere when the task was performed with the preferred (right) arm (Natio et al., 2005, 2007). Taken together, the majority of research has found a non-preferred limb advantage for proprioceptive feedback, thus supporting that limb preference has an effect on proprioception. However, the results still vary, likely due to the large discrepancies in the way in which researchers have measured proprioception. Therefore, more research is needed in order to clearly determine how limb preference influences proprioception.

Inconsistent Findings:

Measurement of Joint Position Sense

Previous literature has measured proprioception in several ways, which may account for some of the inconsistencies in findings. Joint position sense has typically been measured through two different methods: joint matching and joint repositioning. Joint matching involves placement of a joint by the experimenter at a specific angle, where the participant is asked to match the same angle with the contralateral (opposite) limb. Thus one joint is used as an online reference for the other joint, and no memory of joint position is required. While this provides a good measure of the ability to position a joint, a review by Goble (2010) suggested some limitations to this task. First, since the reference limb provides online information about the desired joint angle, it is difficult to determine if errors in matching arise from the reference limb, the matching limb, or both. Furthermore, the transfer of information between limbs requires more transfer between the cerebral hemispheres than ipsilateral matching, thus creating more room for error caused by interhemispheric communication issues (Goble, 2010). As such, this task does not have the ability to differentiate between errors caused by poor proprioception and errors caused by central processing. In addition, work by Adamo and Martin (2009) highlighted the difficulties in comparing the limbs to one another. The authors concluded that it was unknown whether increased error was caused by the reference limb providing poor sensory input, or by the matching limb being unable to utilize the proprioceptive information.

The second joint position test commonly used is joint repositioning, which requires the replication of a reference target angle in the ipsilateral (same) limb. Typically, the joint is placed in a position, held for several seconds, and then returned to the starting position. The participant is then asked to reposition the joint to the same position as accurately as possible. The only known limitation to this method is the influence of memory, since the individual is required to remember the position without online feedback (Goble, 2010). In summary, it is important to consider that both ipsilateral and contralateral positioning requires some cognitive components, and therefore they are not measuring proprioception alone. Although both methods have their flaws, research has suggested that ipsilateral joint repositioning provides a better representation of joint position sense as fewer factors have been identified as confounders (Goble, Lewis, Hurvitz, & Brown, 2005; Goble & Brown, 2007, 2008, 2009) and the task clearly dictates which limb is responsible for the errors in positioning (Adamo & Martin, 2009).

Active and Passive Repositioning

The ipsilateral joint repositioning task involves moving the joint to a target position twice; first to create a reference angle, then to match the position. Prior to movement to each target angle the researcher ensures that the joint is at a consistent starting position. When using joint repositioning the experimenters must decide whether they will use passive positioning, active positioning, or a combination of both. Passive positioning requires no muscular effect to be made by the participant, and instead the joint is slowly moved either by a machine or a researcher to a target position. In contrast, active positioning requires the participants to move the joint on their own to a target position. Previous research has typically used three different combinations of movement type: passive-passive, passive-active, and active-active (Lonn et al., 2000; Gay et al., 2010). In passive-passive conditions the joint is passively moved to the target position as a reference, then again passively moved towards the target position. The participant then signals the point when the joint has reached the target position either by pressing a button or by verbal confirmation. In comparison, passive-active conditions require the joint to be passively moved to the initial target position, then the participant actively repositions the joint to match the previous position. Lastly, active-active conditions require the participant to actively move the joint to the target position (typically signaled through an auditory cue), then the participant once again actively moves the joint to match the previous position. Work by Gay and colleagues (2010) compared the passive-passive and passive-active methods to determine which one best shows differences in position sense acuity. The authors suggest limitations to both methods whereby passive-passive repositioning had poorer precision and repeatability, but passive-active repositioning combined two different types of sensory inputs. Overall the experimenters concluded that passive-active repositioning is better able to detect proprioceptive errors, and therefore is superior to the passive-passive method (Gay et al., 2010). Moreover, Lonn et al. (2000) compared all three methods of repositioning and found that active-active repositioning was superior to both passive-passive and passive-active methods. The researchers suggested that since the active-active method showed significantly lower absolute error, it would be more sensitive to detect small changes in positioning than the other methods (Lonn, Albert, Crenshaw, Djupsjobacka, Pedersen, & Johansson, 2000). Taken together, when measuring joint position sense, it is best to use ipsilateral repositioning to avoid cross-hemisphere uncertainty, and it is best to do so using the active-active method.

Angular & Directional Repositioning

The manner in which a joint is moved during joint position sense measurements is also important to consider. Joint position sense can either be measured through linear angles about the joint (i.e. flexion and extension) or by rotating the joint to specific orientations. However, to date no researchers have compared the two methods to determine if they provide different measures of JPS. When measuring linear flexion and/or extension, researchers have determined that joint position sense can be influenced by the starting position and target angles. Specifically, joint positions in extreme flexion or extension can interfere with repositioning accuracy (Lonn et al., 2000). When joints are close to maximal flexion or extension, joint capsules and golgi tendon organs become activated and provide extra feedback to the central nervous system. Thus when measuring joint position sense, it is important to avoid angles that approach the joint extremes to ensure position sense acuity is being measured without additional sensory input. Another important consideration is the difference between the direction of joint movement to a target angle. For example, if the starting position for the elbow is at 90-degrees, flexion to a target position would require muscular control of the biceps brachii, while extension to a target position would require the use of the triceps brachii. To date only one study has compared the influence of movement direction on joint position sense. Ramsay and Riddoch (2001) compared an extended, mid-range, and flexed target angle at the elbows in a contralateral position matching task. Unfortunately, the study failed to provide information about the angle sizes used for the target positon; however, the discussion states that the bony olecranon process could have been used as feedback in extension, but cutaneous feedback from skin apposition was avoided in elbow flexion. Thus, it can be assumed that elbow extension approached the joint extreme, while elbow flexion and elbow mid-range did not. Elbow extension showed the least error, likely due to the extra sensory inputs from the activated joint receptors and golgi tendon organs. This finding solidifies the importance of staying within relatively mid-positions when measuring JPS, however it remains unknown whether the direction of movement, without approaching joint extremes, has any influence on joint position sense.

Inconsistencies in Equipment

Unfortunately research in joint position sense has used a wide range of equipment that varies from types of dynamometers and goniometers to custom-made devices. Many studies on joint position sense have used custom-made devices that aim to investigate specific joints or angles. However, few studies have tested the reliability and/or validity of the devices, therefore caution must be taken when interpreting the results. Alternatively, both dynamometers and goniometers have been shown to be reliable and valid measures of joint position sense. The Biodex dynamometers have been shown to provide reliable measures of both kinesthesia and joint position sense (van Meeteren, Roebroeck, & Stam, 2002; Drouin, Valovich-mcLeod, Shultz, Gansneder, & Perrin, 2004). However, this instrument is typically used when measuring only one joint-site since the equipment takes a long time to set-up for each joint. A more time efficient tool for measuring multiple joint-sites that has been used extensively in previous studies is the goniometer. The most common type of goniometer used in literature is the electro-goniometer, which displays a digital reading of the angle directly on the device. The angle can then be transmitted to a computer through an A/D converter (Goodwin, Clark, Deakes, Burden, & Lawrence, 1992). The majority of electro-goniometers used in past research were heavy and not portable (You, 2005). However, a newer goniometer by Vernier© is portable and connects directly to a computer software program that provides digital interpretations of joint angles. The portable goniometer allows the experimenter to collect data from various locations more easily, thus proving to be an ideal device for measuring multiple joints in a participant both quickly and accurately.

In summary, the inability to reproduce consistent findings in the literature suggests that there are limitations to the methods and measures used in previous studies. Moreover, few researchers to date have used a consistent method to test joint position sense across the body. As well, the influence of limb preference on joint position sense remains highly controversial and the use of inconsistent measures of joint position sense may be to blame for some of the disparities in previous research. Therefore, the purpose of the current study was three-fold; first, to determine whether joint positioning acuity is dependent on the joint being measured; second, to determine the influence of limb preference on joint position sense across multiple joints in the body; and third, to determine the influence of movement direction on joint position sense. It was hypothesized that joint repositioning acuity would differ between each of the joint-sites measured. As well, preference was hypothesized to influence joint position sense, whereby the non-preferred limb was expected to have better positioning acuity than the preferred limb across all joint-sites. Finally, it was hypothesized that the direction of joint movement in the repositioning task would affect joint position sense acuity, such that joint position sense would differ between flexion and extension movements about the joint-sites.

METHODS:

Participants

A total of 60 participants between the ages of 18-30 were tested. Exclusion criteria included the diagnosis of a degenerative joint disease (i.e. arthritis) or any neurological deficits, which were screened through the use of a background questionnaire. One participant was excluded due to a childhood brain tumour that left her with major movement impairments in the wrists and ankles. In addition, four left-handed participants were excluded from the study as left handers typically perform differently than right-handers on manual asymmetry tasks. Thus, a total of 55 right-handed young adults (M = 19, F = 36) remained in the study, with a mean age of 22.53 (±2.32). Participants were recruited through posters at Wilfrid Laurier University and through convenience sampling. The study was approved by the Research and Ethics Board at Wilfrid Laurier University, and all participants signed an informed consent form (see Appendix D).

Materials

The current study used the 20-item Waterloo Handedness Questionnaire (WHQ) and the 10-item Waterloo Footedness Questionnaire (WFQ-R) to determine limb preference in the upper and lower limbs. Next, joint position sense was determined at multiple joints using a digital goniometer. Lastly, participants completed a health and physical activity questionnaire to determine the influence of various factors on joint position sense.

Waterloo Handedness and Footedness Questionnaires

The WHQ and WFQ-R measured handedness and footedness, respectively. Items included questions about which limb the individual uses to complete a variety of tasks, such as which hand is used to hold a needle while sewing, and which foot is used to kick a soccer ball. The participant circled the response that best represented their preference for each question (left always, left usually, equal, right usually, or right always), which was then converted to an item score ranging from negative two to positive two, respectively. The sum of all the items for each questionnaire was then computed into a laterality score, which represented the degree of laterality for each participant; a negative score represented left-limb preference, while a positive score represented right-limb preference (further detail on the computation of the laterality score will be discussed in the results section).

Joint Repositioning Task

Ipsilateral joint position sense (joint repositioning) was measured bilaterally using a Vernier© digital goniometer (Vernier Software & Technology, Oregon, USA) at the elbow, wrist, knee, and ankle joint-sites. The goniometer was connected via a USB port to a laptop with LoggerPro software (Vernier Software & Technology, Oregon, USA) to record each trial. The range of the Vernier goniometer is from zero to three-hundred and forty degrees, and it has an accuracy of plus or minus one degree. The goniometer was comprised of a hinge with two arms, which was attached to the segments surrounding each joint using self-adhesive tape. A starting position was chosen as the midpoint of the range of motion for the joint (i.e. elbow at 90 degrees), as starting positions in extreme flexion or extension can interfere with repositioning accuracy (Lonn, Crenshaw, Djupsjobacka, Pedersen, & Johansson, 2000). The starting position was kept consistent for all trials in a joint, and this was the point at which the goniometer was calibrated as 'zero'. From the starting position, two target angles were measured: one in flexion and the other in extension. All angles tested were in a mid-range of motion to limit activation from joint capsule receptors, which are more active at extreme joint positions (Clark & Burgess, 1975). The participant was asked to keep their eyes closed and their head facing straight ahead during all conditions to prevent visual bias. During each trial the participant used visual feedback from the LoggerPro software to actively find the starting position, which was calibrated as 'zero' on the screen. To begin the trial, the experimenter instructed the participant to close their eyes and slowly move their joint from the starting position to the target angle, at which point the experimenter said 'hold'. The participant was instructed to hold their joint at the target position for approximately five seconds, then was asked to return the joint to the starting position, at which point the experimenter said 'hold' again. The participant was then told to return their joint to the target position and tell the experimenter when they felt they reached the target angle, after which the trial was concluded. The total testing time including all trials for each participant was approximately 60 minutes, and no time-constraints were placed on the trials. Error was measured as the difference between the target angle, and the angle that was reproduced by the participant, in degrees. This procedure was repeated three times for each angle at each joint, on each side of the body, for a total of 48 trials. The order of testing for the preferred and non-preferred limbs was randomized across participants, where some participants started with the left side, and other started with the right. This order remained consistent across all joint-sites, and the order in which the joint-sites were tested remained the same for all participants: elbows, wrists, knees, then ankles. Both the preferred and non-preferred sides were tested consecutively at each joint-site. The angles measured at each joint were customized based on previous literature to provide the best possible measurement of joint position sense and are described below.

Elbows

To attach the goniometer to the elbows, the arms of the goniometer were taped to the outside of the forearm and upper arm of the participant while the palm was supine. During the elbow trials, the participant was seated and was asked to ensure their arm did not contact their torso or the chair to avoid the use of tactile feedback. The participant was also reminded to ensure their wrists remained supine throughout each trial. The target angles were at 30 degrees of flexion and 30 degrees of extension from the starting position, which was at approximately a 90-degree elbow bend (See Figure 1a).

Wrists

For the wrist, the goniometer arms were attached to the outside of the forearm and hand. The participant sat with the majority of their forearm supported by a desk and their wrist hanging off the end to avoid fatigue and tactile feedback. The wrists remained prone with the starting position parallel to the ground (approximately 180 degrees) while the target angles were 30 degrees of flexion and 30 degrees of extension from the starting position (See Figure 1b).

Knees

The goniometer arms were attached to the outside of the upper and lower legs to measure the knee joints. The participant sat on a tall desk with their legs hanging down and their upper legs hanging off the desk a few inches to avoid tactile feedback from the popliteal fossa, which has been found to interfere with proprioception (Panics, Tallay, Pavlik, & Berkes, 2008). A chair was provided for the participant to rest the leg that was not being tested in order to avoid the use of online feedback during the trials. The participant's starting position was where their legs hung comfortably, at approximately a 110-degree angle. The target angles were 30 degrees of flexion and 30 degrees of extension from the target position (See Figure 1c).

Ankles

Finally, in the ankle trials the participant sat with their legs on the desk and their ankles and a few inches of their lower leg hanging off the end, again to avoid tactile feedback and fatigue. The goniometer arms were attached to the inside of the lower leg and foot. Since the range of motion for the ankles is much smaller than that of all the other joints tested, the ankles were re-calibrated for each direction of movement to avoid activation of the joint capsules. As well, the angle was changed to 20-degrees rather than 30-degrees to prevent the target angle from approaching the extremes of the joint. Thus, the starting position, or 'zero', for dorsiflexion was calibrated as 'zero' at 40 degrees from maximal dorsiflexion, and for plantar flexion was calibrated as 'zero' at 40 degrees from maximal plantar flexion (See Figure 1d). All joint angles moved through the sagittal plane.

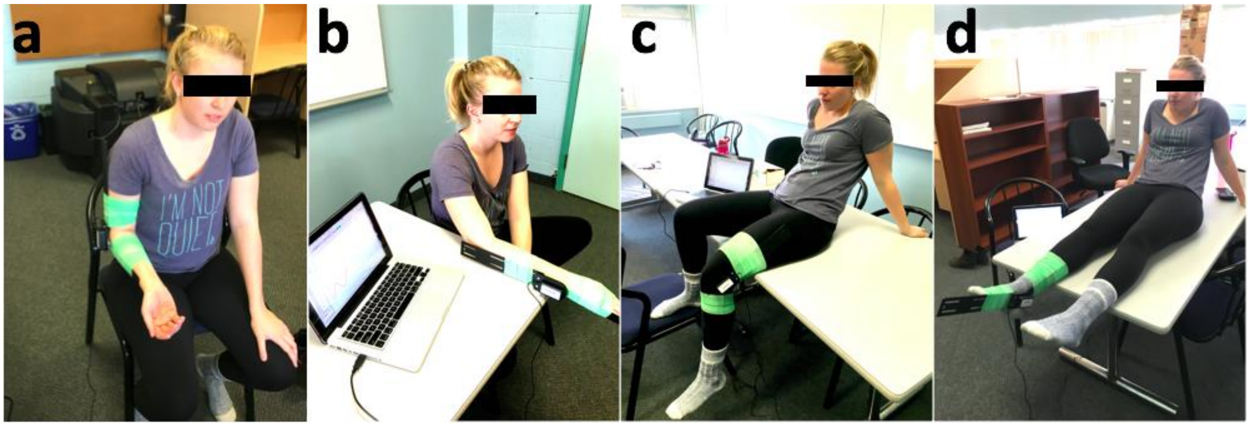

Figure 1. Goniometer set-up of the (a) elbow, (b) wrist, (c) knee, and (d) ankle joints.

Health and Physical Activity Questionnaire

The health and physical activity questionnaire consisted of three parts: demographics, general health, and physical activity participation. First, questions were asked about basic demographic information, such as age, sex, height, and weight. Next, information about basic health was requested. This included items such as previous injuries to any of the joints that were tested, any diagnoses that the individual felt may have affected their performance in this study, and a general scaled rating of the participant's perceptions of their physical health (poor to excellent). Finally, information regarding the individual's past and current participation in physical activity was collected. This portion of the questionnaire was based off of the standardized Modifiable Activity Questionnaire (MAQ) and was used to determine what types of activity were related to better position sense. The information gathered in this portion included: the type of activity, the typical duration of each activity session, the frequency per month, and how many months/years the individual participated in the given activity.

DATA TREATMENT:

Joint Position Sense Trials

A total of 48 joint repositioning trials were completed by each participant. The raw data were displayed via a line plot in the LoggerPro software (see Figure 2), which were then exported into an excel spreadsheet, which displayed the goniometer angle at every millisecond throughout the repositioning trial. Each trial was independently analyzed by the researcher to determine the starting angle, target angle, return-to-start angle, and estimated target angle. Since each angle was held actively by the participant, the angle often changed slightly from the beginning of the held the position to the end. Therefore, the determined angles were decided by taking the average across the last six milliseconds prior to moving to the next position in the protocol. To determine how much constant error was made on each trial, the difference was found between the starting angle and target angle, as well as the difference between the return-to-start angle and the estimated target angle. The difference between those two values was then computed to generate the overall error for the trial. In other words, ***overall error= (target angle – starting position) – (estimated target angle – return-to-start position)***. The overall error was calculated for each trial for every participant. From the overall error scores, the data was grouped in several ways by taking the average across trials to provide an overall representation of various measures of joint position sense error in the joint-sites. The data was grouped by directional error, lateral preference error, joint-site error, and limb error (see Table 1).

Table 1. Grouping of data based on direction, lateral preference, joint, and limb. Each row represents a score used in the analysis, which was calculated by taking the average of the listed trials.

Joint	Directional error	Preference error	Joint error	Limb error
Elbows	6 flexion	6 left	12 elbow	6 elbow
	6 extension	6 right		+
Wrists	6 flexion	6 left	12 wrist	6 wrist
	6 extension	6 right		
Knees	6 flexion	6 left	12 knee	6 knee
	6 extension	6 right		+
Ankles	6 dorsiflexion	6 left	12 ankle	6 ankle
	6 plantar flexion	6 right		

Checking for Normality

SPSS® Version 22 was used for all statistical analyses, with a critical p-value of 0.05. Descriptive statistics were run to investigate skewness, kurtosis, and normality of the dataset. The output showed that the data was slightly positively skewed, however since all skewness statistics were less than 2, the data still fell under a normal distribution (Kim, 2013). All of the kurtosis statistics were positive, and since all values were less than 7, the data was still considered to be part of a normal distribution (see Table 2).

Table 2. Skewness statistics, kurtosis statistics, and Shapiro-Wilk normality tests significance (Normality sig.) before and after data transformation at all joints tested. The results show the dataset had a normal distribution following logged transformation.

Joint	Skewness		Kurtosis		Normality (sig)	
	Original	*Transformed*	*Original*	*Transformed*	*Original*	*Transformed*
Elbows	1.705	.332	5.667	1.052	<.001	.538
Wrists	.651	.014	.209	-.198	.145	.993
Knees	1.078	.298	1.586	-.367	.003	.399
Ankles	.990	.114	1.032	-.196	.004	.763

It was important to consider that the limits set for normal distributions based on skewness and kurtosis are subject to much debate, as some researchers argue that the limits should be lower for skewness (Blumer, 1979) and kurtosis (Bryne, 2010). Therefore, while skewness and kurtosis provided a general sense of normality, the disparities in the agreed upon limits of normality made it difficult to definitively determine if the data was normal. This is where the third check for normality became important, the Shapiro-Wilk test, as it is the standard test in determining normality. As three out of the four joints had Shapiro-Wilk statistics with a significance level of $p<.001$, it was determined that the dataset was significantly different from a normal distribution (see Table 2).

Table 3. Original data scores showing mean error (in degrees) and standard deviation at each joint, in each direction, on each side of the body This original data was not used in any analyses, as it had to be transformed to reach normality.

Joint	**Side**	**Direction**	**Mean**	**Standard deviation**
Elbow	*Left*	*Flexion*	2.74	1.56
		Extension	3.35	1.78
	Right	*Flexion*	2.94	1.64
		Extension	3.49	2.53
Wrist	*Left*	*Flexion*	3.97	1.75
		Extension	3.72	1.69
	Right	*Flexion*	4.44	2.18
		Extension	4.16	2.03
Knee	*Left*	*Flexion*	3.20	1.83
		Extension	3.21	1.67
	Right	*Flexion*	2.99	1.55
		Extension	3.15	1.80
Ankle	*Left*	*Dorsiflexion*	2.64	1.43
		Plantar flexion	2.33	1.20
	Right	*Dorsiflexion*	2.61	1.42
		Plantar flexion	2.38	1.12

The data was then transformed by Log_{10} and normality was assessed once again. All skewness and kurtosis statistics of the transformed data were less than ±2, and the significance for all of the Shapiro-Wilk statistics were >.5 (see Table 2). Therefore, the logged transformation of the data resulted in a normally distributed dataset. All statistical analyses and figures were completed using the normalized data, however for reference the original data scores are provided below (see Table 3).

Dealing with Outliers

The original data was searched for outliers using boxplots and descriptive statistics prior to starting the statistical analysis. Seven JPS error scores were identified as extreme values through boxplots and descriptive statistics (see Table 4). However, following data transformation only two extreme values remained in the dataset, both of which were at the elbow joint. A closer look revealed that the extreme scores were not due to data errors or sampling errors, and that the participants who completed these trials were legitimate cases sampled from the desired population. Neither of the participants had any previous injuries to the elbows, nor did they have any neurological deficits at the time of the study.

Table 4. Extreme values, mean, and standard deviation at each joint before and after data transformation.

Joint	**Original dataset**		**Transformed dataset**	
	Extreme(s)	*Mean (SD)*	*Extreme(s)*	*Mean (SD)*
Elbows	5.832	2.216 (.831)	.766 -.096	.319 (.153)
Wrists	5.004 4.521	2.898 (.741)	N/A	.448 (.110)
Knees	4.669	2.240 (.702)	N/A	.331 (.129)
Ankles	3.544 3.364 3.195	1.778 (.605)	N/A	.227 (.143)

Since the transformed data was normally distributed, there was a 1% chance that some of the scores could fall within the 3rd standard deviation from the mean without being considered an outlier (Osborne & Overbay, 2004); and it turned out that both of the scores fell within three standard deviations of the mean (see Table 4). Taken together, both of the extreme values were legitimate cases, were not due to sampling error, and were within three standard deviations from the mean, and thus they were kept as legitimate scores in the data analysis.

Handedness & Footedness Questionnaires

Items on the questionnaires were scored based on the answers provided, ranging from positive two (right always) through negative two (left always). All items were summed to provide a total score, and then divided by the maximum score to create a laterality quotient comparable across the WHQ (maximum score = 40) and WFQ-R (maximum score = 20). All participants (N=55) were right-handed, therefore the WHQ laterality quotient was able to dictate the degree of reliance on the preferred limb. To determine the degree of reliance on the lower limbs, only participants who were also right footed (n=53) were included in the WFQ-R laterality quotient.

RESULTS:

Demographics

Initially, the influence of various demographic factors on joint position sense was examined. A sex x age MANOVA was used to determine if sex and age had any influence on the average normalized scores at the elbows, wrists, knees, and ankles. No effect of sex ($p>.05$) or age ($p>.05$) was found for any of the dependent measures. Next, a correlation was conducted to determine if participant height was related to the amount of error, as taller participants would have a larger moment arm about their joints. Analysis revealed no significant influence of height on any of the measures tested ($r<\pm.20$, $p>.10$), thus moment arm length was not related to JPS acuity.

Influence of Joint-site

Next, the joints were compared to one another to determine if joint-site had an influence on JPS. The error scores were averaged to create a single total error score for each joint-site, thus eliminating side and direction as factors. A 4 (joint) repeated measures ANOVA revealed a main effect of joint ($F_{(3,162)}=36.397$, $p<.001$), which meant that the total error in the joints significantly differed from one another. Furthermore, Fisher's least significant difference (LSD) post hoc revealed that the elbows (M=0.319, SD=0.153) had significantly smaller errors than the wrists (M=0.448, SD=0.110) ($p<.001$). In contrast, the elbows had significantly greater error than the ankles (M=0.227, SD=0.143) ($p=.001$), but did not differ from the knees (M=0.331, SD=0.129) ($p=.578$). Furthermore, the wrists had significantly greater error than the knees ($p<.001$) and ankles ($p<.001$), and the knees had significantly greater error than the ankles ($p<.001$). In other words, all of the joints significantly differed from one another except when comparing the elbows to the knees ($p=.585$) (see Figure 2). The joint with the greatest error was the wrist joint (M=0.448), while the ankles had the least error (M=0.227)

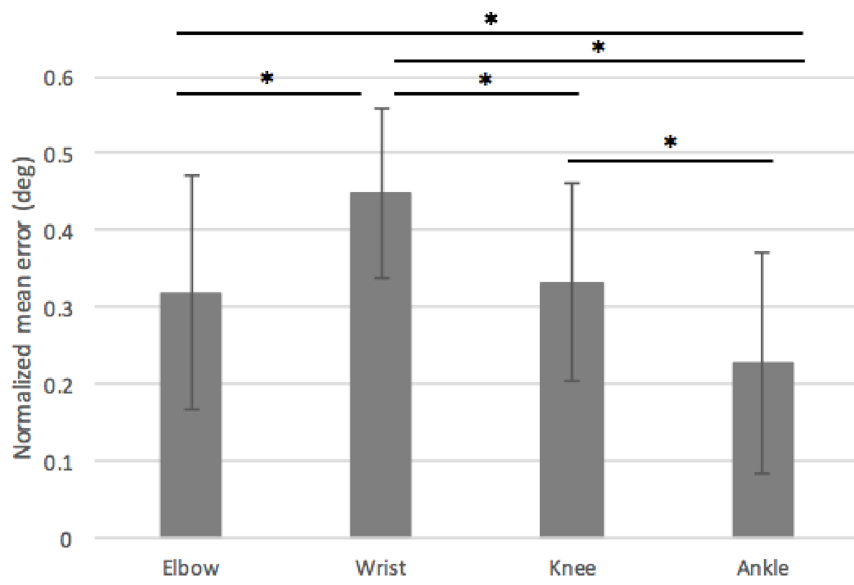

Figure 2. *Normalized mean error was collapsed across side and direction to show total joint error. All joints differed significantly from one another ($p \leq .001$) except the comparison between the elbows and the knees ($p=.578$).*

Influence of Lateral Preference

Next, a 4 (joint) x 2 (side) repeated measures ANOVA was conducted to compare the total error on each side of the body at each joint. The analysis revealed no main effect of side ($F_{(1,54)}=1.870$, $p=.309$), suggesting that limb preference did not significantly influence joint position sense at individual joint-sites (see Figure 3). Each joint-site was further investigated through paired-samples t-tests, and once again no significant differences were found between the elbows ($t_{(54)}=-1.262$, $p=.212$), wrists ($t_{(54)}=-1.885$, $p=.065$), knees ($t_{(54)}=0.930$, $p=.357$), and ankles ($t_{(54)}=-0.331$, $p=.742$).

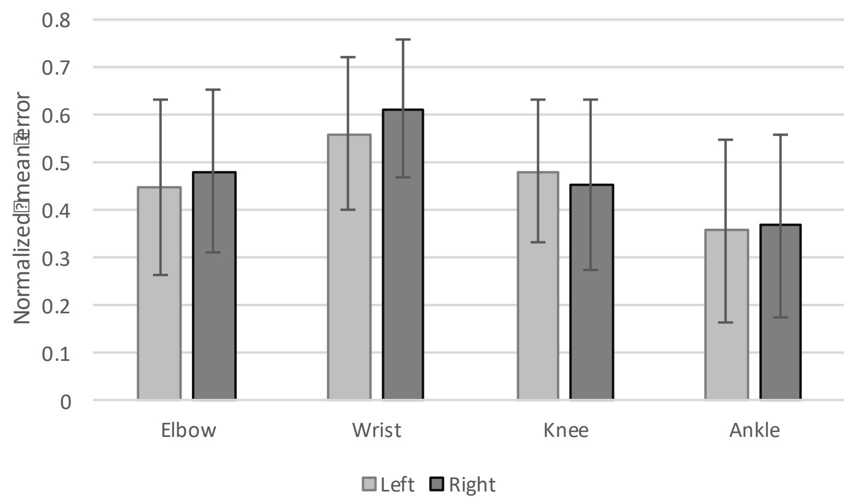

Figure 3. Normalized mean error for each joint on each side of the body. No significant influence of preference was found on any of the joints.

However, a visual inspection of the error scores of the joints in each limb reveals that a visual bend emerged; the non-preferred upper limb appeared to be making fewer errors than the preferred upper limb, whereas the joints in the lower limbs did not differ much between sides (see Figure 3). The observed trend guided the researcher to conduct a 2 (limb) x 2 (side) repeated measures ANOVA to compare the total average error scores between the two upper limbs the two lower limbs. The test revealed a main effect of limb ($F_{(1,54)}$=53.717, $p<.001$) in which the upper limbs had significantly greater error than the lower limbs. In addition, an interaction between side and limb approached statistical significance ($F_{(1,54)}$=3.893, p=.054). To look closer at the interaction between side and limb, paired-samples t-tests were conducted between the two upper limbs and the two lower limbs. The results revealed that in the upper limbs, the left side (M=0.503, SD=0.133) made significantly fewer errors than the right (M=0.545, SD=0.133) ($t_{(54)}$=-

2.231, p= .03), however there were no differences between sides in the lower limbs (p=.728) (see Figure 4).

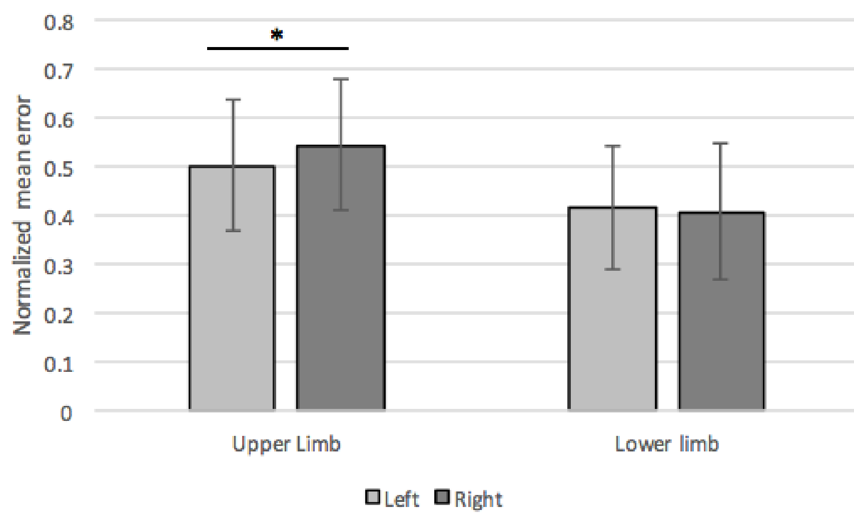

Figure 4. Normalized mean error scores of the total limbs comparing the left side to the right side. A significant difference was found between the left and right upper limbs (p=.030); however, no difference was found between the lower limbs.

Relationship Between Lateral Preference Scores

As discussed above, the influence of lateral preference across the joints was stronger in the upper limbs than in the lower limbs. A laterality quotient was determined for both the Waterloo Handedness Questionnaire and the Waterloo Footedness Questionnaire, which was used to describe the degree of lateral preference in the upper and lower limbs. A paired samples t-test was used to compare the laterality quotients in the handedness scores to the footedness scores. While all participants in the study were right-handed, 2 of the participants were cross-lateralized, meaning they were right-handed but left-footed. Therefore, for the purpose of comparing the laterality scores for handedness and footedness the crossed-lateralized participants were excluded from this analysis as their footedness scores were negative values and would thus skew the results.

The findings indicated a significant difference between the two scores ($t_{(49)}$= 9.057, $p<.001$), where the WHQ scores (M=0.732, SD=0.153) were significantly more lateralized than the WFQ-R scores (M=0.458, SD=0.234). This finding suggests that the upper limbs were more reliant on the preferred limb than were the lower limbs (see Figure 5). To determine if the strength of laterality affects JPS, a correlation was conducted between the WHQ and WFQ-R laterality quotients and each of the joints on each side of the body. The results showed a medium correlation (t-tailed p level =.01) between error in the right elbow and laterality scores on the WHQ (r=.313, p=.024), where those who were more lateralized in the upper limbs tended to make larger JPS errors in the trials at the right elbow. No other correlations were found between strength of laterality and JPS errors at any of the measured joints.

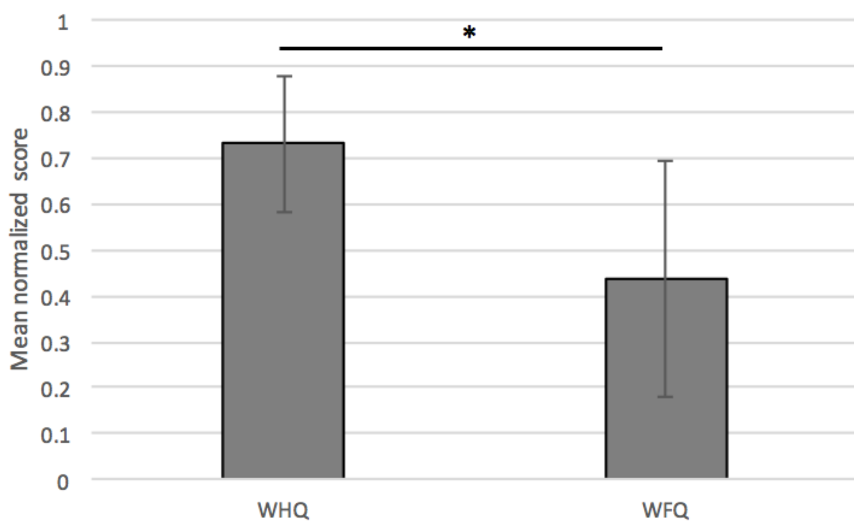

Figure 5. Mean normalized scores from the Waterloo Handedness Questionnaire (WHQ) compared to the Waterloo Footedness Questionnaire (WFQ). The handedness scores were found to be significantly greater, or more lateralized, than the footedness scores (p<.001).

Influence of Direction

The direction of the repositioning task was examined by averaging the sides across each joint. The new grouped data allowed for a comparison between flexion and extension at each joint type, regardless of which side of the body the joint was on. A 4 (joint) x 2 (direction: flexion or extension) repeated measures ANOVA was used to determine whether the direction of movement influenced error on the joint repositioning task. The results showed that there was no main effect of direction of movement on joint position sense ($F_{(1,54)}$=.410, p=.524). Therefore, the direction of the movement was shown to have no impact on joint position sense (See Figure 6).

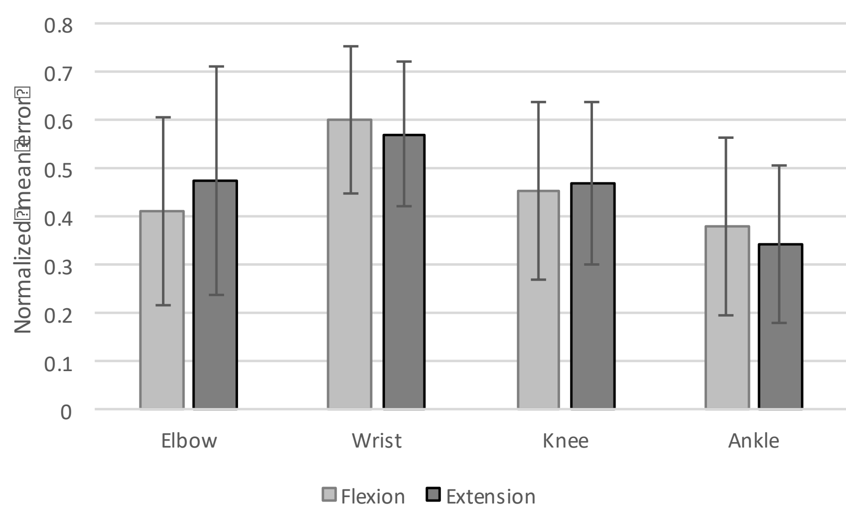

Figure 6. A comparison between joint position sense in each direction at each joint-site. Note: for graph simplicity ankle dorsiflexion is labelled as flexion and ankle plantar flexion is labeled as extension. No significant differences were found.

Influence of Injury

Participants were asked to list all previous injuries to any of the joints being tested in the Health and Physical Activity Questionnaire. It should be noted that the type of injury and date that the injury occurred were not recorded. In excel, participants were coded as having injured, or having not injured each joint. Further, the joints were broken into the left and right side, thus providing a list of whether participants had any previous injuries, and if so on which side of the body the injury occurred. Therefore, in the current study the injury data was used to determine if having any kind of previous injury influenced the joint position sense errors, and thus influenced the above results. Independent samples t-tests were conducted to compare joint position sense error for individuals who had a previous injury to those who did not, for each joint. The results showed no influence of having previous injury to a joint on joint position sense errors. Specifically, elbow injuries did not influence JPS at the left ($t_{(45}$=1.066, p=.292), or right ($t_{(45)}$=.662, p=.511) elbows, wrist injuries did not affect injuries at the left ($t_{(45)}$=.445, p=.167) or right ($t_{(45)}$=.712, p=374.) wrists, knee injuries did not affect JPS at the left ($t_{(45)}$=-.345, p=.732) or right ($t_{(45)}$=.403, p=.689) knees, and ankle injuries did not affect JPS at the left ($t_{(45)}$=.639, p=.526) or right ($t_{(45)}$=.1.608, p=.120) ankles.

Discussion

Proprioception is a very complex sense made up by several different aspects, which are each determined through different measures. The various aspects require different sensory input and integration; thus each one only represents a small portion of the overall proprioceptive sense. Unfortunately, to date there is no universally accepted measurement of global proprioception; thus researchers must make the decision of how proprioception should be measured to best answer their research questions. Since each aspect measures a different portion of proprioception it is difficult to compare one measure to the next, which subsequently limits the applicability of results from one study to another. The large discrepancies in research guided the aim of the current study, which was to bring forth more detailed information about differences in a single aspect of proprioception across the whole body. Therefore, the current study measured proprioception in the joint position sense component, and specifically the joint repositioning aspect. Joint repositioning was measured bilaterally in 55 healthy young adults across the elbows, wrists, knees, and ankles, using active-active repositioning.

Three important findings emerged from the current study. First, joint position sense acuity differed depending on the site of the joint being tested. Positioning about the ankle joint was superior to the other joints, while positioning about the wrist was inferior to the other joints. Each joint-site differed from one another, except when comparing the elbows and knees, which had similar positioning acuities. Second, limb preference had a significantly greater impact on joint position sense in the upper limbs than in the lower limbs, which may be explained by the greater lateralization found in the upper limbs than in the lower limbs. However, the influence of limb preference on individual joints was not significant. Third, the direction of movement from the starting position to the target position had no influence on joint position sense acuity. Specifically, no differences were found between flexion and extension about the elbows, flexion and extension about the wrists, flexion and extension about the knees, and dorsiflexion and plantar flexion about the ankle. Each finding will be further explained in the following sections.

Influence of Joint-site on JPS

At the present time only a limited number of studies have assessed how proprioception is influenced by joint-site. Of these studies, one group of researchers found no difference between joint-sites (Waddington & Adams, 1999), while two others have found significant differences (Hall & McCloskey, 1983; Han et al., 2013a, 2103b). However, the way in which proprioception was measured in the studies was inconsistent, as one measured kinesthesia (Hall & McCloskey, 1983), while the other three used the AMEDA (Waddington & Adams, 1999; Han et al. 2013a, 2013b). Furthermore, some researchers have argued that the AMEDA does not measure proprioceptive functioning (Tremblay, 2013; Krewer et al., 2016). Therefore, only one study, which was conducted more than thirty years ago, has examined joint-site differences using a universally accepted measure of a component of proprioception (Hall & McCloskey, 1983). This lack of consistent, reliable findings highlights the need for more research in proprioceptive joint-specificity. It is important to recognize that numerous other studies have measured proprioception in more than one joint, however they failed to compare the joints to one another and thus they do not contribute to the knowledge of joint-site specificity (Waddington, Seward, Wringley, Lacey, & Adams, 2000; Li, Xu, & Hong, 2008; Riddoch & Ramsay, 2008).

The lack of knowledge on joint-site differences led to one of the main purposes of the current study, which was to determine if joints across the body have the same proprioceptive acuity, specifically in joint repositioning. Considering the vast differences in functional specialization associated with different joints in the body, it was hypothesized that each joint-site would behave differently. The current study used active-active repositioning to assess joint-site position sense across the elbows, wrists, knees and ankles. The average of all trials completed at each joint-site was determined, regardless of the side or direction, which provided an overall JPS error score for the elbow, wrist, knee, and ankle joint-sites. Several important findings were observed. First, the results revealed that most of the joints significantly differed from one another. In fact, the only joints that did not differ were the comparison between the elbows and knees. Since the elbows and knees are both mid-limb joints, they are typically used for gross motor control, specifically in guiding the distal part of the limb (hand or foot) to a desired goal. Therefore, the similarity in joint function between the two joints may account for the similarities in their position sense acuity.

Second, the wrists had the highest average error (M=0.448) compared to all the other joints. Particularly in the upper limb, the finding that the distal joint (wrist) was less accurate than the proximal joint (elbow) is supported by Hall and McCloskey's (1983) findings in that kinesthesia was better in the elbows than in the fingers, thus showing a proximal-distal favour for proprioception. As well, though not reported by the authors, the study by Han et al. (2013b) showed a proximal-distal relationship in movement discrimination, where the shoulders had lower errors than the wrists, and the knees had lower errors than the ankles. Interestingly, in the current study the proximal-distal relationship was only shown in the upper limbs, as the ankles had far superior acuity than the knees in the joint repositioning task. The discrepancies in proximal-distal findings may be attributed in the different aspects of proprioception measured in the studies, however it is clear that more research is needed for a definitive answer to whether proprioception follows a proximal-distal pattern.

A third important finding in the current study was the difference in the limbs, where the upper limbs made significantly greater errors than the lower limbs. Since the elbows did not differ from the knees, it can be concluded that this observation was driven by the distal joints: the wrists and ankles. This finding suggests that in joint repositioning, the ankles have greater proprioceptive dependence than the wrists. Again however, only the joint repositioning aspect of JPS was measured, thus the results may differ depending on the aspect of proprioception being investigated.

Taken together, significant differences were found between most of the joint-sites tested. Therefore, the findings support the general consensus that joint position sense is site-specific. As well, a proximal-distal relationship in positioning acuity was observed in the upper limbs, but not in the lower limbs. And finally, the upper limbs had significantly greater joint repositioning error than the lower limbs, which was driven by the distal joints. Overall, the findings suggest that researchers cannot measure repositioning in a single joint and equate it to overall repositioning sense in the body, nor should repositioning be compared across studies unless both studies measured the same joint-site.

Influence of Preference on Joint Position Sense

Previous research has provided mixed findings on how limb preference influences joint position sense. While some findings support the notion that preference has little or no influence on proprioception (Voight et al., 1996; Riddoch & Ramsay, 2008; Adamo & Martin, 2009), other work has supported that proprioception is affected by preference (Goble et al., 2006, 2009, 2010; Han et al., 2013b). The current study proposed that the incongruent findings in previous research may be explained by the lack of consistency in the joint-site that was measured, which was shown by the current study to influence JPS acuity. As well, previous literature has measured different aspects of proprioception, thus it is difficult to compare the results of one study to another. Therefore, the current study measured joint repositioning bilaterally across four joint-sites to determine how lateral preference influences joint position sense across the body. The influence of lateral preference on each joint was determined by taking the average repositioning error across all trials in the joint-site on each side. Several important findings were revealed. First, the results showed that there were no significant differences between the preferred and non-preferred sides for each of the joint-sites measured, thus contradicting the original hypothesis, which predicted that the non-preferred joint at each joint-site would have better positioning acuity than the preferred joint.

However, while none of the differences between joint-sites were significant, a non-significant trend was revealed that may explain how the influence of preference on JPS differs based on the joint-site measured. Both joint-sites in the upper limbs (elbows and wrists) showed differences, though non-significant, where joints in the non-preferred, left arm made fewer errors than those in the preferred, right arm (see Figure 3). The differences in the influence of preference on JPS between the upper and lower limbs are further supported by paired samples t-tests at each joint-site. In the upper limbs, the elbows (t= -1.262, p=.212) and wrists (t=-1.885, p=.065) had fairly high t-statistics and low p-values; however, in the lower limbs the knees (t=0.930, p=.357) and ankles (t=-0.331, p=.309) had lower t-statistics and higher p-values. Taken together, this potential trend of a greater difference between the upper limbs guided the researcher to compare the entire limbs to one another to determine how preference influences the upper and lower body, separately. When all trials at each limb (both joint-sites) were averaged, a second important finding was observed. The trend previously shown in the upper limbs became significant, where the non-preferred arm made significantly fewer errors than the preferred arm (p=.03). However, no differences were found between the preferred and non-preferred lower limbs (p=.728). One explanation for the disparity in positioning acuity in the upper and lower limbs is the difference in tasks that are typically completed by each set of limbs. The upper limbs are heavily relied on for completing unimanual tasks, such as writing or brushing the teeth. In contrast, the lower limbs are typically used for bipedal tasks, such as locomotion and balance. Therefore, limb function may contribute to the differences found between the upper and lower limbs.

Another finding that may help to explain the differences observed between the limbs can be gleaned from the handedness and footedness questionnaires. The lateral preference questionnaires were used to determine a laterality quotient that indicates how often the preferred limb is chosen to complete a variety of tasks. A handedness laterality score of 100% meant the participants chose 'right always' for every item on the questionnaire (score = 40/40), while a score of 50% meant that the participant typically chose 'usually right' for every item (score = 20/40). Any score below 50% meant that the participant chose 'equal', 'left usually' or 'left always' for at least one of the items (score <20/40). The results revealed that right-handed participants (n=55) used the preferred hand for 73.9% of the tasks. In contrast, right-footed participants (n=53) only used the preferred foot on 43.7% of the tasks. A paired samples t-test revealed that the participants were significantly more lateralized on the handedness items than the footedness items ($t_{(49)}=9.057$, $p<.001$), therefore showing that the reliance on the preferred limb was greater in the upper limbs than in the lower limbs. The differences found between the limbs are supported by Coren (1993), who also found that right handers were more lateralized in handedness scores than in footedness scores. As mentioned earlier, the differences between the limbs in joint repositioning in the current study was greater in the upper limbs than in the lower limbs. The further analysis of lateral preference in the limbs suggested that the apparent differences may be attributed to the greater lateralization within the upper limbs. Therefore, the non-dominant JPS superiority found in the upper limbs supports the dynamic-dominance theory of handedness, however the lower limbs did not follow this same relationship.

Taken together, limb preference did not significantly affect joint position sense in any of the individual joints measured. However, differences were found when comparing the entire limbs in the upper and lower body. The non-preferred upper limb performed significantly better than the preferred upper limb, yet no differences were found between the two lower limbs. Importantly, the results suggest that investigating the influence of lateral preference on position sense in the upper limbs would result in different findings than in the lower limbs. The current findings may help to explain some of the discrepancies in current literature, in which there is great variability in the limbs chosen to measure proprioception.

Influence of direction on JPS

Past research has often used very inconsistent methods in determining joint position sense, which has been thought to account for some of the discrepancies in research. In particular, the way in which the joint is linearly moved varies between flexion and extension. An issue arises when comparing across studies, as it is currently unknown how muscles around the joint affect joint position sense. Opposing muscle groups are used for flexion and extension about a joint; therefore, it is possible that the JPS measured at a joint could be biased by the direction of joint movement chosen by the researchers. Previous work by Li et al. (2008) and Xu et al. (2008) suggested that movement direction may influence kinesthesia; however, little is known about its influence on joint position sense. Therefore, the current study sought to determine whether JPS is influenced by movement direction at the elbow, wrist, knee, and ankle joint-sites. The average error was taken across trials for each direction at each joint-site. A joint-site by direction repeated measures ANOVA revealed that direction had no influence on joint position sense in any of the joints ($p=.524$). The results suggest that in joint repositioning, direction does not have any influence on positioning error when the starting and target angles are not approaching joint angle extremes. Therefore, comparisons between studies that have measured linear joint repositioning can be made without concerns for the direction of movement to the target angle.

Limitations

The results from the current study contribute important findings to research in joint position sense. However, it is important to address some limitations to the study. First, the limb that each participant started with was randomized, which is consistent with previous studies testing joint position sense. However, the starting limb was not recorded by the researcher. Therefore, the limb that first experienced the joint repositioning task had the potential to be influenced by a learning effect. The possibility of a learning effect for one side of the body could potentially have masked the effects of preference on JPS. While this may explain why preference differences were not found within each joint, it is not possible to determine if this was the case.

A second limitation to the study was the limited information about previous injury to the joints. While the health and physical activity questionnaire asked about previous joint injuries, few participants declared the type of injury to the joint (i.e. ACL tear, ankle sprain), and instead just listed on which side of the body the injury occurred. Previous research has consistently found significant influences of various major injuries on proprioception, such as ACL tears; therefore, it is possible that participants in the study had previously incurred a major injury to a joint without the researcher's knowledge. Future research should thus attain more detailed information about joint injury to ensure all that the participants being tested do not have previous injuries that could bias the results.

Applications

Two important applications arise from the current study. First, the findings provide knowledge to researchers to help them better interpret and understand the disparities in previous literature on joint positon sense. Specifically, researchers should be careful comparing results across studies that have measured different aspects of proprioception, used different joint-sites, or failed to account for lateral preference. Second, the findings provide evidence for researchers to use caution when choosing methods used for measuring proprioception. Not only should the researcher consider the most appropriate aspect of proprioception to answer their desired questions, but researchers also need to consider confounding variables when creating their protocol. For example, when measuring joint position sense in the upper limbs, joint-site and preference could significantly confound the results, and thus need to be accounted for. In addition, researchers and clinicians who use proprioceptive acuity as a diagnostic measure must account for these confounding variables, as they have the potential to bias the outcome of proprioceptive tests.

Future Directions

While the current study has provided valuable information about the influence of joint-site and preference on joint position sense, more research is critically needed in this area. The results revealed an influence of preference on whole-limb joint repositioning; however concrete results were not found for the influence of preference at each joint-site. Since the starting limb was not recorded, it is possible an influence of preference on joint-site was masked by a learning effect. Therefore, future research should account for a learning effect in order to determine the true influence of preference on joint repositioning. Interestingly, the results showed a greater influence of preference in the upper limbs, which was consistent with the greater lateralized found in the upper limbs. Future research should investigate this relationship further to determine if it is consistent in other joints, such as the fingers or the shoulders, and whether the same relationship exists in other aspects of proprioception. Finally, researchers should continue to strive to create a more global measure of proprioception, as testing each aspect individually creates many disparities in the literature.

Chapter 2: The Influence of Physical Activity on Joint Position Sense

Abstract:

Previous research has shown that some types of physical activity can improve proprioceptive acuity, namely tai chi, golf, and dance. However, the findings are mixed, which is likely due to the incongruences in measurements of proprioception as outlined in Chapter 1. These disparities in research lead to a secondary purpose to the current study, which was to investigate how physical activity can affect joint repositioning. The same participants and data from Chapter 1 were used for the secondary analysis, however the focus for the current chapter was on the relationship between JPS and the Health & Physical Activity Questionnaire. First, Pearson correlations were conducted between the number of minutes of physical activity per month, and the joint position sense acuity at each joint-site. Next, participants were grouped into categories based on the type of physical activity in which they primarily participated (dance, activities with a stick/racquet, and activities with ball manipulation). One-way ANOVAs were then run between participation in the grouped activities and joint-site position sense. The results revealed no significant influence of physical activity minutes, nor the type of physical activity, on joint position sense across the body. The researcher proposed that the lack of findings may be a result of a heavily active sample. Together, the results suggest that for noticeable improvements in proprioception to occur more intense exercise is required and a more sedentary group of participants should be used as a control.

Introduction:

In healthy young adults, proprioception works successfully to create smooth, coordinated movement (Ghez & Sainburg, 1995). However, many factors can lead to impaired proprioception, such as injury, movement disorders, and aging (Baker, Bennell, Stillman, Cown, & Crosley, 2002; Ribeiro & Oliveira, 2010). In particular, reduced proprioceptive acuity that has been linked with aging is directly related to the increased risks of falls and hospitalization of seniors (Goble et al., 2009). Researchers have begun investigating ways to improve proprioception to help individuals whose proprioceptive systems are not working at an optimal level. Several studies have found that proprioception-based exercise programs improve joint position sense in individuals with joint injuries, such as ankle instability and anterior cruciate ligament tears (Carter, Jenkinson, Wilson, Jones, & Torode, 1997; Docherty, Moore, & Arnold, 1998). Specific exercise programs are beneficial for injury rehabilitation as they often target a single joint; however, they do not improve global proprioceptive function and thus have little application for older adults wishing to improve their proprioceptive acuity. Furthermore, such specific programs are not easily accessible to the public, thus hindering their benefits for the general population. These limitations have thus encouraged researchers to explore more global forms of exercise that are more easily accessible. To date, only one study has specifically investigated the relationship between general physical activity and proprioception. Ribeiro and Oliveria (2010) tested knee joint position sense in 4 groups: exercised young adults, non-exercised young adults, exercised older adults, and non-exercised older adults. The results revealed that the exercised young adults had greater positioning acuity than all other groups, while non-exercised older adults had the worst positioning acuity. Interestingly, exercised older adults had similar positioning acuity to non-exercised young adults. Thus the authors suggest that exercise can increase knee position sense in young adults, and can also help to improve position sense in older adults, which typically declines with age (Ribeiro & Oliveria, 2010). This study provides valuable information about one aspect of proprioception at one joint-site. However, as discussed earlier, the measurement of proprioceptive acuity can change depending on the aspect of proprioception that is measured and the joint-site that is tested. Therefore, more research is needed to determine if general physical activity benefits position sense at joints other than the knee, and whether the same relationship exists with other aspect of proprioception, such as kinesthesia.

While limited research exists about the influence of general physical activity on proprioception, researchers have begun to explore the influence of more specific forms of exercise. In particular, studies have focused on the influence of tai chi and ballet on proprioception. In tai chi, long-term practitioners have been shown to have better position sense and kinesthesia in the ankle and knee joints than active and sedentary age-matched controls (Tsang & Hui-Chan, 2003; Tsang & Hui-Chan, 2004; Xu, Hong, Li, & Chan, 2004 Fong & Ng, 2006). As well, researchers have found that a shorter, intensive tai chi intervention for older adults improved rotational shoulder position sense (Li, Xu, & Hong, 2008). However, it is important to consider that all of these studies had only compared tai chi practitioners to sedentary controls, thus it was unknown whether the benefits arose from general physical activity or from tai chi itself. To date, only two studies have investigated whether the improvement in proprioception arose from specific tai chi training, or from general exercise. Xu, Hong, and Chan (2004) looked at differences in knee and ankle kinesthesia is healthy older adults who were either sedentary, long-term runners or swimmers, or long-term tai chi practitioners. The results showed that both the tai chi and running/swimming groups had superior kinesthesia to the sedentary controls. As well, the tai chi group had better kinesthesia than the runners/swimmers at the ankle, but not at the knee (Xu, Hong, & Chan, 2004). A second study by Liu and colleagues (2012) tested non-active elderly participants to compare differences in ankle position matching with three interventions: tai chi, physical exercise, and no exercise. The researchers found that participants in the tai chi and exercise interventions both had significantly better joint position sense acuity than the non-exercise group. However, no differences were found between participants who practiced tai chi and those who partook in general physical exercise (Liu et al., 2012). Therefore, research has shown that joint position sense in the ankle is equally improved by tai chi and general exercise, however it remains unknown whether the benefits are equal at other joint-sites and in other aspects of proprioception. Taken together, limited research has shown that tai chi may benefit aspects of proprioception, however more research should be done to determine if the benefits arose simply from being physically active, or from the movements involved in tai chi.

A second type of physical activity that has been commonly explored in relation to proprioception is dance. In particular, research has typically focused on ballet, as this form of dance relies heavily on the ability to recreate very precise positions of the arms and legs. Keifer and colleagues (2013) found that professional ballet dancers had better joint position matching in the ankle, knee, and hip joints than healthy controls, who had no previous experience in ballet. However, since physical activity level was not reported for the control group, it was unknown whether the individuals were active or sedentary. Furthermore, a study by Ramsay and Riddoch (2001) found that professional ballet dancers had better position matching accuracy in the elbow and shoulder joints than active non-dancers. Together the results suggest that professional ballet dancers have superior position sense across the body compared to healthy controls. However, the findings provide no indication about whether it was specifically the ballet training rather than the high level of physical fitness that contributed to better position sense; as well, it remains unknown whether the same benefits would arise from recreational ballet training. The work by Ramsay and Riddoch (2001) thus lead to a study by Marmeleira at al. (2009), who investigated the influence of creative dance on knee and shoulder joint position sense in sedentary older adults. Participants were split into two groups: group 1 attended creative dance sessions 3 times per week, while group 2 were sedentary controls. All participants were tested at the beginning of the study and at the 12-week mark. The results showed that the creative dance group significantly improved their joint position sense in the knees and shoulders from the beginning to the end of the 12 weeks. As well, when compared to the sedentary controls, the creative dance group had significantly better proprioception at both joints after the 12 weeks. However, the authors point out that it is not possible to determine if the benefits from the creative dance intervention were caused by dance or by general physical activity (Marmeleira et al., 2009). Therefore, more research is need to determine the influence of recreational dance as a means of improving proprioception.

Finally, some studies have investigated and compared the influence of multiple types of physical activity on aspects of proprioception. Li et al. (2009) compared recreational ice hockey players, ballet dancers, and runners and found that both hockey players and ballet dancers had superior ankle kinesthesia than the runners and sedentary controls. In addition, the runners did not differ from the sedentary controls, which the authors suggest may have been related to the notion that running does not involve as much precision in ankle joint angles as ballet and hockey (Li, Xu, & Hoshizaki, 2009). As well, a study by Tsang and Hui-Chan (2004) compared knee JPS differences in older adults who were either long-term practitioners of tai chi or golf, to sedentary controls. Here it was found that both tai chi practitioners and avid golfers had better knee position sense than the control group (Tsang & Hui-Chan, 2004). Therefore, it appears that some types of physical activity have the same positive influence on proprioception. While both studies support this theory, more research is needed to determine which types of physical activity are beneficial for proprioception.

Taken together, researchers have investigated the influence of various types of physical activity on several aspects of proprioception. While the majority of literature shows that specific types of physical activity can improve proprioception, some discrepancies are still apparent. First, it is unknown whether it is the specific types of physical activity that caused improved proprioception, or whether the benefits were derived from simply being physically active. As well, research on individual types of physical activity has tended to test professional athletes. While professional athletes can still afford important information on proprioception, they provide little practical application for older adults, who would be practicing at a recreational level. The discrepancies in the literature led to the secondary purpose of the current study, which was to investigate the influence of various types of recreational activity, as well as general physical activity, on joint position sense. It was hypothesized that individuals who were more physically active would display better joint repositioning than those who were less active. As well, individuals who participated in activities that require great positioning accuracy, such as dance, were hypothesized to have better joint positioning than the rest of the sample.

Methods:

This study involved a secondary analysis of the same data collected in Chapter 1.

Results:

Joint Position Sense Data

The joint-site data was transformed in the first analysis to fit a normal distribution. The joint-site variable was used in the current analysis, as it provided an overall representation of both joints within a single joint-site. The current analysis did not investigate the influence of lateral preference or movement direction on joint repositioning, therefore these trials were not isolated for the analysis.

Health and Physical Activity Questionnaire

The Health and Physical Activity Questionnaire was analyzed further for the current analysis. Participants were first asked to select from a list all of the activities in which they have participated in the previous 12 months. Next, participants filled out the following information for each of the selected activities: the average time spent performing the activity per session, the number of times per month the activity was performed, and the start date and end date for the activity. Participants also completed the same questions a second time, but this time they included all activities they engaged in during the past five years. To analyze the data, the number of minutes per month was calculated for each of the activities listed. This information was then used to calculate the total number of minutes per month each participant spent engaged in physical activity, as well as the number of minutes per month participants engaged in each type of activity. The level of physical activity ranged greatly between 525 minutes to 8765 mins per month (M=2551.09, SD=1624.16), with the majority of participants falling within one standard deviation of the mean (see Figure 7).

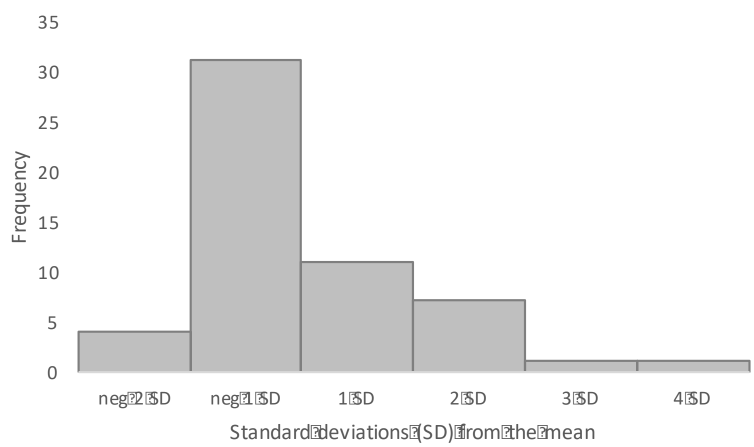

Figure 7. The distribution of the number of participants whose total physical activity minutes per month fell within each standard deviation from the mean.

Influence of General Physical Activity

To begin, Pearson correlations were conducted between the joint position sense error at each joint-site and the cumulative minutes per month spent engaging in physical activity. The correlations showed no significance at the elbows (r=-0.15), wrists (r=0.15), knees (r=0.07), or ankles (r=-0.03). When the joint-sites were combined to represent total limb error, again no significant correlations were found between the upper limbs (r=0.01) or lower limbs (r=0.01) and general physical activity (see Figure 8).

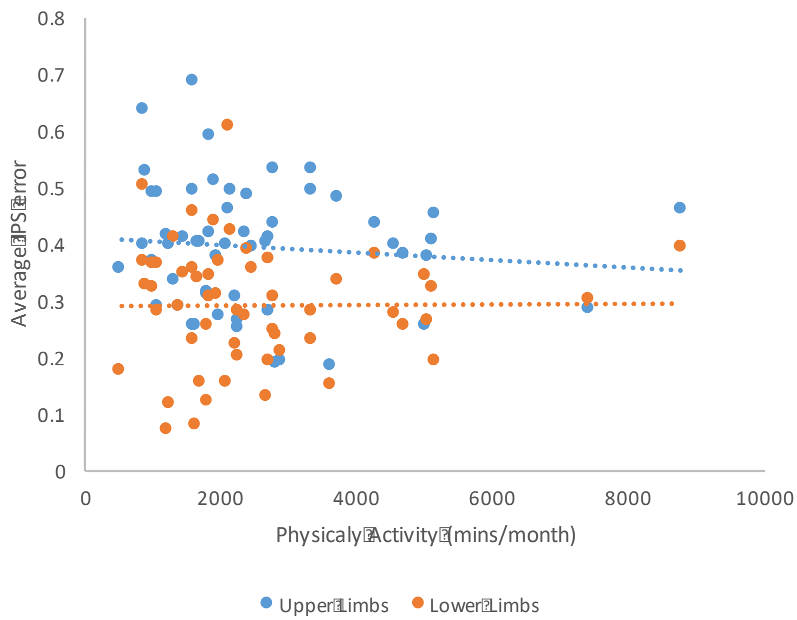

Figure 8. A scatterplot representing the relationship between the amount of physical activity pre month and JPS in the upper and lower limbs. No relationship was found between the variables.

Influence of Specific Physical Activities:

Next, one-way ANOVAs were conducted to determine if specific types of physical activity were related to better joint position sense. Since the study did not actively recruit participants involved in specific forms of physical activity, a wide variety of activities were examined, with only a small number of participants in each group. The only form of physical activity of interest to the researcher that more than ten participants listed was dance. Therefore, the remaining types of physical activity were grouped according to similar skill-sets as follows: sports with sticks/racquets (lacrosse, ball hockey, ice hockey, golf, tennis, softball, and baseball) and sports with ball manipulation (football, rugby, dodgeball, basketball, and volleyball).

First, dancers were compared to non-dancers using one-way ANOVAs at each joint-site. No significant differences were found between dancers and non-dancers at the elbows ($F_{(1,55)}$=0.019, p=.891), wrists ($F_{(1,55)}$=0.018, p=.892), knees ($F_{(1,55)}$=2.686, p=.107) or ankles ($F_{(1,55)}$=0.338, p=.564). When the joint-sites were combined to represent the entire limbs, again no differences were found between the dancers and non-dancers in the upper limbs ($F_{(1,55)}$=0.004, p=.949) or lower limbs ($F_{(1,55)}$=0.398, p=.531). To further investigate the influence of dance on joint position sense, the dancers were segregated from the remaining participants and Pearson correlations were run on only the participants with dance experience within the past 12 months. The results showed no correlations between the monthly number of minutes in dance, and joint position sense at each joint (see Figure 9).

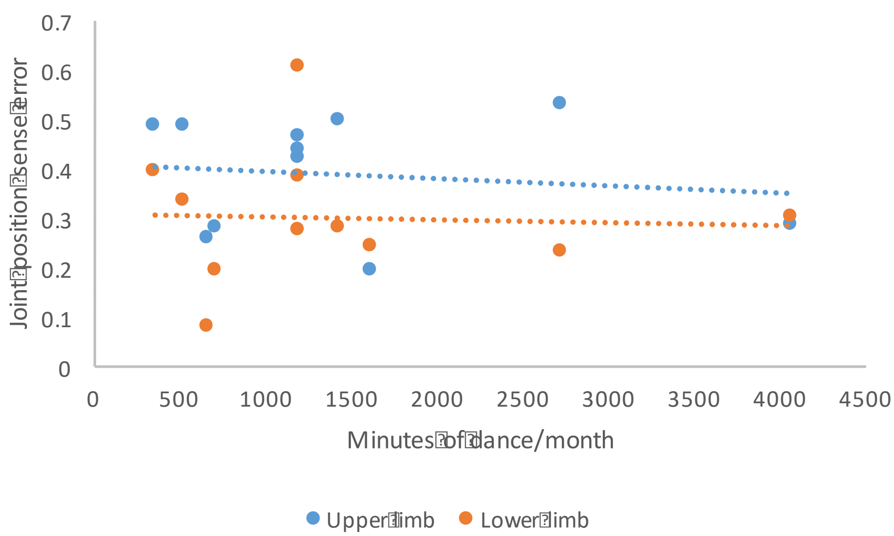

Figure 9. A scatterplot showing the correlation between the amount of dance per month and JPS in the upper and lower limbs. No correlation was found between the variables.

Next, the influence of participating in sports with a stick or racquet (lacrosse, ball hockey, ice hockey, golf, tennis, softball, and baseball) on joint position sense was investigated. One-way ANOVAs were conducted between participants who played, and did not play, sports with a stick or racquet in the previous 12 months on joint position sense at each joint-site. The results showed no influence of stick/racquet sports on the elbows ($F_{(1,55)}$=0.068, p=.795), wrists ($F_{(1,55)}$=0.889, p=.350), knees ($F_{(1,55)}$=1.782, p=.188) or ankles ($F_{(1,55)}$=0.724, p=.399). As well, no influence of stick/racquet sports was found in the upper limbs ($F_{(1,55)}$=0.101, p=.752) or the lower limbs ($F_{(1,55)}$=2.016, p=.161).

Finally, participants were grouped based on participation in sports involving ball manipulation (football, rugby, dodgeball, basketball, and volleyball). One-way ANOVAs between participants who played ball manipulation sports, and those who did not, were conducted at each joint-site. Again, the results showed that individuals who played ball manipulation sports had similar JPS error score to the group who did not play these types of sports at the elbows ($F_{(1,55)}$=0.092, p=.762), wrists ($F_{(1,55)}$=2.897, p=.095), knees ($F_{(1,55)}$=0.681, p=.413) or ankles ($F_{(1,55)}$=1.150, p=.289); no significant differences in the limbs were found in the upper limbs ($F_{(1,55)}$=0.582, p=.449) or the lower limbs ($F_{(1,55)}$=1.72, p=.194).

Discussion

Previous literature has typically focused on measuring joint position sense in professional athletes, which unfortunately has little application to the older adult population, who would benefit from proprioceptive improvements. Therefore, the current study sought to investigate the influence of general physical activity, as well as physical activity type, on joint position sense across the body in non-professional athletes. Surprisingly, the results showed no correlation between the amount of physical activity per month and joint position sense across the body. One possible explanation for this finding is the lack of diversity in the sample population. The majority of participants were recruited within the kinesiology department at Wilfrid Laurier University. It is well known that kinesiology students are more likely to participate in sports, and more likely to exercise regularly, than the typical population of young adults. The average amount of physical activity in the sample was 2551.09 minutes per month, which equates to approximately 90 mins of physical activity per day. A recent Statistics Canada report states that Canadians between the ages of 18 and 39 typically participate in just 34 minutes of moderate to vigorous physical activity per day (Trembley et al., 2011). Therefore, the participants in the current study are on average engaging in almost three times the amount of physical activity as the population. Only 6 participants had average daily physical activity levels less than or equal to the Canadian daily average. As well, even the least active participant (525 mins/month) met the recommended average of 30 minutes per day of physical activity (Haskell et al., 2007). Therefore, while the sample population of the current study had large variability in physical activity levels, all participants were considered to be at least lightly active. There is a chance of over reporting, however the number of over reported minutes is unlikely to reach a height that would counterbalance the sample to be equivalent of a typically-active Canadian level of physical activity. Consequently, the lack of findings in the current study may be a result of using a sample that was far more active than the typical young adult population in Canada. Future research should therefore test a variety of physical activity levels (sedentary, moderately active, and very active) when investigating the influence of physical activity on joint position sense, as well as other measures of proprioception.

Another interesting finding was the lack of a relationship between joint position sense and specific types of physical activity. No significant differences we found in dancers, which contrasts the previous literature showing dancers had better joint position sense than controls (Riddoch & Ramsay, 2001; Keifer, 2013). As well, no differences were found in participants who played sports the required the use of a stick or racquet, or those or played sports involving ball manipulation. Once again, the lack of findings may be a results of a highly active sample. It remains unknown whether the benefits in proprioception found in previous research arose from simply being physical active, or from the specific types of physical activity that were practiced. Therefore, using a sample in which all participants were fairly active could have confounded the results.

Taken together, the results from the current study did not coincide with the hypothesized results; neither general nor specific physical activity was found to influence joint position sense. It is suggested that the lack of findings may be the result of using a heavily active sample.

Future Directions

More research is needed to determine whether the benefits of physical activity found in previous literature on proprioception arise from simply being active, or from specific types of physical activity. Importantly, researchers should ensure their sample encompasses various levels of physically activity, including sedentary controls.

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Appendix A: Waterloo Handedness Questionnaire

The Waterloo Handedness Questionnaire

Each of the questions below offers five possible responses: RA (right always), RU (right usually), EQ (equal), LU (left usually), and LA (left always).

1. Which hand would you use to spin a top?

2. With which hand would you hold a paintbrush to paint a wall?

3. Which hand would you use to pick up a book?

4. With which hand would you use a spoon to eat soup?

5. Which hand would you use to flip pancakes?

6. Which hand would you use to pick up a piece of paper?

7. Which hand would you use to draw a picture?

8. Which hand would you use to insert and turn a key in a lock?

9. Which hand would you use to insert a plug into an electrical outlet?

10. Which hand would you use to throw a ball?

11. In which hand would you hold a needle while sewing?

12. Which hand would you use to turn on a light switch?

13. With which hand would you use the eraser at the end of a pencil?

14. Which hand would you use to saw a piece of wood with a handsaw?

15. Which hand would you use to open a drawer?

16. Which hand would you turn a doorknob with?

17. Which hand would you use to hammer a nail?

18. With which hand would you use a pair of tweezers?

19. Which hand do you use for writing?

20. Which hand would you turn the dial of a combination lock with?

21. Is there any reason (e.g. injury) why you have changed your hand preference for any of the above activities? YES NO (circle one) Explain.

22. Have you ever been given special training or encouragement to use a particular hand for certain activities? YES NO (circle one) Explain.

Appendix B: Waterloo Footedness Questionnaire

Waterloo Footedness Questionnaire

Please write your answer beside each question (R-right always, RU-right usually, EQ, equal, LU-left usually, and LA-left always).

1. Which foot would you use to kick a stationary ball at a target straight in front of you?

2. If you had to stand on one foot, which foot would it be?

3. Which foot would you use to smooth sand at the beach?

4. If you had to step up onto a chair, which foot would you place on the chair first?

5. Which foot would you use to stomp on a fast-moving bug?

6. If you were to balance on one foot on a railway track, which foot would you use?

7. If you wanted to pick up a marble with your toes, which foot would you use?

8. If you had to hop on one foot, which foot would you use?

9. Which foot would you use to help push a shovel into the ground?

10. During relaxed standing, people initially put most of their weight on one foot, leaving the other leg slightly bent. Which foot do you put most of your weight on first?

11. Is there any reason (i.e. injury) why you have changed your foot preference for any of the above activities?

12. Have you ever been given special training or encouragement to use a particular foot for certain activities?

13. If you have answered YES for either question 11 or 12, please explain:

Appendix C: Health and Physical Activity Questionnaire

Health and Physical Activity Questionnaire

Part A) Health Background

Age:_________ Sex: M / F / Other Height:___________ Weight:_________

1. Have you ever endured an injury to any of the following joints? Check all that apply.
   - ☐ Elbow
   - ☐ Wrist
   - ☐ Knee
   - ☐ Ankle

   If you checked yes to any of the above injuries, please briefly explain each injury below.

   ____

   ____

   ____

   ____

   ____

   ____

2. Have you ever been diagnosed with anything that may have affected your performance in the joint repositioning test that you just completed? (i.e. balance impairments, neurological disorders, movements disorders, etc.)

   ____

   ____

   ____

   ____

   ____

   ____

3. Please circle the answer that you feel best describes your physical health.

Poor Fair Moderate Good Excellent

Part B) Physical Activity Background

Please check off **all** activities listed that you have done more than 10 times in the **past year**.

- ☐ Jogging (outdoor, treadmill)
- ☐ Swimming (laps, snorkeling)
- ☐ Bicycling (indoor, outdoor)
- ☐ Softball/Baseball
- ☐ Basketball
- ☐ Yoga
- ☐ Pilates
- ☐ Skating (roller, ice, blading)
- ☐ Handball/Racquet-ball/Squash
- ☐ Aerobics (step. Water)
- ☐ Golf
- ☐ Tennis
- ☐ Skiing (water, land)
- ☐ Dance (not including ballet)
- ☐ Ballet
- ☐ Martial Arts (Karate, Judo)
- ☐ Tai Chi
- ☐ Toning exercises
- ☐ Walking for exercise
- ☐ Other

Please list all activities that you checked off and fill out the requested information for each.

- ☐ Activity 1: ____
  - Average # of minutes each time? ______________________________
  - How many times per month? __________________________________
  - I participated in this activity from ________________________ to ______________________. (Please provide approximate months/years).

- ☐ Activity 2: ____
  - Average # of minutes each time? ______________________________
  - How many times per month? __________________________________
  - I participated in this activity from ________________________ to ______________________. (Please provide approximate months/years).

- ☐ Activity 3: ____
  - Average # of minutes each time? ______________________________
  - How many times per month? __________________________________
  - I participated in this activity from ________________________ to ______________________. (Please provide approximate months/years).

- ☐ Activity 4: ____
  - Average # of minutes each time? ______________________________
  - How many times per month? __________________________________
  - I participated in this activity from ________________________ to ______________________. (Please provide approximate months/years).

☐ Activity 5:

____

- Average # of minutes each time? ______________________________
- How many times per month? __________________________________
- I participated in this activity from _________________________ to _____________________. (Please provide approximate months/years).

☐ Activity 6:

____

- Average # of minutes each time? ______________________________
- How many times per month? __________________________________
- I participated in this activity from _________________________ to _____________________. (Please provide approximate months/years).

Please check off **all** activities listed that you have done more than **10 times within a single year** in the **past 5 years**. Please do not include activities that you have already checked off above.

☐ Jogging (outdoor, treadmill)
☐ Swimming (laps, snorkeling)
☐ Bicycling (indoor, outdoor)
☐ Softball/Baseball
☐ Basketball
☐ Yoga
☐ Pilates
☐ Skating (roller, ice, blading)
☐ Handball/Racquet-ball/Squash
☐ Aerobics (step. Water)
☐ Golf
☐ Tennis
☐ Skiing (water, land)
☐ Dance (not including ballet)
☐ Ballet
☐ Martial Arts (Karate, Judo)
☐ Tai Chi
☐ Toning exercises
☐ Walking for exercise

Please list all activities that you checked off and fill out the requested information for each.

- ☐ Activity 1: ____
  - Average # of minutes each time? ________________________
  - How many times per month? ________________________
  - I participated in this activity from ____________________ to ____________________. (Please provide approximate months/years).

- ☐ Activity 2: ____
  - Average # of minutes each time? ________________________
  - How many times per month? ________________________
  - I participated in this activity from ____________________ to ____________________. (Please provide approximate months/years).

- ☐ Activity 3: ____
  - Average # of minutes each time? ________________________
  - How many times per month? ________________________
  - I participated in this activity from ____________________ to ____________________. (Please provide approximate months/years).

- ☐ Activity 4: ____
  - Average # of minutes each time? ________________________
  - How many times per month? ________________________
  - I participated in this activity from ____________________ to ____________________. (Please provide approximate months/years).

- ☐ Activity 5:

  ____

  - Average # of minutes each time? ________________________________
  - How many times per month? ___________________________________
  - I participated in this activity from __________________________ to ______________________. (Please provide approximate months/years).

- ☐ Activity 6:

  ____

  - Average # of minutes each time? ________________________________
  - How many times per month? ___________________________________
  - I participated in this activity from __________________________ to ______________________. (Please provide approximate months/years).

Appendix D: Informed Consent Form

WILFRID LAURIER UNIVERSITY INFORMED CONSENT STATEMENT

How does joint position sense change across the body, and what types of physical activity can help?

Amanda Forsyth

Supervisor: Dr. Pam Bryden

Department of Kinesiology and Physical Education

You are invited to participate in a research study. The purpose of this study is to investigate how our ability to know where our joints are in space (joint position sense) differs across the body. As well, we will be examining which types of physical activity can help to improve our joint position sense.

INFORMATION

This study involves 3 measures. First you will be asked to complete the Waterloo Handedness & Footedness Questionnaires, which ask a series of questions about which limb you would use in a variety of scenarios. You will then be asked to stand, and we will measure you joint position sense with a hinge-like apparatus that will be attached to your joints using Velcro straps. The researcher will move your joint to a target angle, then you will be asked to replicate this angle. These measures will be taken for your elbows, wrists, knees, and ankles. Finally, you will be asked to complete a health and physical activity questionnaire, which asks basic questions about your general health and the types of physical activity you have participated in over the years.

The approximate time that this study will require is 30-45 minutes and should not take any longer than 1 hour.

RISKS

As a participant, you may feel slightly fatigued during the joint positioning trials. We will provide an option for a break between joints to help prevent this from happening. If at any other time during the experiment you would like a break, please ask and we will allow as much time as you need.

BENEFITS

As a participant you will gain knowledge about research being conducted in Kinesiology. The results from this study may help in understanding how specific types of exercise can influence position sense. This can be applied to older adults who wish to improve their position sense in order to decrease their risk of falls.

CONFIDENTIALITY

All the data will be recorded using your participant ID number rather than names, and only the average data will be presented. Only the author of this study and her supervisor will have access to the data, which will be kept in a locked filing cabinet.

CONTACT

If you have questions at any time about the study or the procedures, (or you experience adverse effects as a result of participating in this study) you may contact the researcher, Amanda Forsyth, at fors2210@mylaurier.ca. This project has been reviewed and approved by the University Research Ethics Board. If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Dr. Robert Basso, Chair, University Research Ethics Board, Wilfrid Laurier University, (519) 884-1970, x4994 or rbasso@wlu.ca.

PARTICIPATION

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study, your data will be removed and destroyed. You have the right to omit any question(s)/procedure(s) you choose.

FEEDBACK

If you have any questions, we will gladly answer them for you at any point. The results from this study will be posted on the Lifespan PsychoMotor and Behaviour lab website for your viewing upon completion.

CONSENT

I have read and understand the above information. I have received a copy of this form. I agree to participate in this study.

Your Name: ______________________________________

Your Signature: ____

Date: ________________

If you would like to receive a brief executive summary of this study, please provide your email on the line below.

____