The Relationship Between Interoception and Proprioception in Athletes and Non-Athletes at Washington and Lee University

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Abstract

Proprioception and interoception are two complex physiological measures believed to be dependent on a variety of factors. The present study examined the relationship between proprioception and interoception in a sample of undergraduate students at Washington and Lee University. With a focus on the athlete status of the participants, the researchers investigated the relationship in the context of its potential connection to physical activity. Participants completed two main tasks: a heartbeat discrimination test of interoceptive accuracy and a joint position matching test of proprioceptive accuracy at the elbow joint. Participants additionally filled out a questionnaire to determine their status as a varsity athlete at the university. The proprioceptive and interoceptive accuracy scores were analyzed across the entire sample and compared between the sub-groups of athletes and non-athletes. The results showed no significant differences in the relationship between proprioceptive accuracy and interoceptive accuracy across the entire sample ($r_s = 0.16$, $p = 0.47$) and similarly, no significant difference in the relationship between athletes and non-athletes ($q = 0.76$, $p = 0.11$).

Keywords: interoception, proprioception, physical activity

The Connection Between Proprioception and Interoception in Athletes and Non-Athletes at Washington and Lee University

For a long time, popular culture and the internet have linked proprioception and interoception. Yoga, meditation, and other mindfulness activities are praised for their ability to improve proprioceptive and interoceptive sensitivity, and meditators and yoga practitioners regularly claim that they have heightened sensations about the states of their bodies. Despite this common belief amongst lay people, the scientific community has yet to establish a firm conclusion regarding the connection between proprioception and interoception. In this study, the researchers intended to explore this relatively unstudied relationship and how it may relate to physical activity and athletics.

What is Interoception?

Interoception broadly describes one's ability to sense and have conscious awareness of the body's internal state, such as heart rate and temperature (Ceunen, Vlaeyen, & Van Diest, 2016). Recently, interoception has come under increasing analysis in the field of psychophysiology. It is hypothesized that individuals whom are more attuned to their internal bodily responses may differ in their emotional responses, decision making, and many other abilities (Weins & Katkin, 2000; Werner et al., 2013). To study these phenomena, researchers have developed standardized measures, tasks, and definitions for interoception (Garfinkel, Seth, Barrett, Suzuki, & Critchley, 2015). Heartbeat discrimination tasks prevail as the main method for interoceptive measures, as they are the most precise and simplest to measure (Brener & Ring, 2016). In heartbeat discrimination tasks, participants track and report the synchronicity of their heartbeat with an external stimulus, like a pulse of light or sound (Kleckner, Wormwood, Simmons, Barrett, & Quigley, 2015). Known as the modified Whitehead heartbeat detection task, this procedure was adapted from one of the original studies on interoception performed by Whitehead et al. (1977) and continues to be used in interoceptive studies into the present.

What is Proprioception?

Proprioception, a comparable but different physiological measure, describes one's ability to determine the position of their body in space (Goble, 2010). Pure proprioception relies predominantly on neurotransmission between the brain and mechanoreceptors of the skin and muscle spindles and does not require any additional visual or somatosensory input (Goodwin, McCloskey, & Matthew, 1972). In real life, the proprioceptive, visual, and somatosensory input are not completely segregated. By isolating proprioception from visual and somatosensory signals, however, researchers can determine how proprioception independently impacts sensorimotor activities. A common method to assess proprioceptive acuity is known as the joint position matching task. Sometimes referred to as the joint position sense task, the joint position matching task has been used to investigate proprioception in a myriad of clinical scenarios, including in Parkinson's disease and elderly populations (Zia, Cody, & O'Boyle, 2000; Pickard, Sullivan, Allison, & Singer, 2003). The joint position matching task evaluates an individual's ability to recreate a joint angle without any visual input. Those individuals with larger position matching errors have lower proprioceptive accuracy, and those individuals with smaller errors have higher proprioceptive accuracy (Goble, 2010; Sevrez & Bourdin, 2015).

The Relationship Between Exteroception and Interoception

A certain degree of uncertainty remains in our understanding of interoception, and controversy arises in the hard boundary drawn between interoceptive and exteroceptive processes. According to research on heart transplant patients, the hard boundary between these two systems may not be as clear as originally believed. Individuals who have endured a heart transplant, and therefore have changed the nerve supply to their heart, do not have decreased interoceptive accuracy when compared to individuals who have never undergone heart surgery (Barsky et al., 1998). In other words, despite the interoceptive nerve supply around the heart being dramatically changed, interoceptive accuracy remained unchanged. The results of this study prompt two considerations. First, the interoceptive signaling pathway may not acting along in the case of these heart transplant patients. The lack of change in interoceptive accuracy in these patients compels us to consider the involvement of other, non-interoceptive systems. For example, proprioception, a sensation customarily classified as exteroceptive, may impact the sensation of visceral activities too. Second, the novelty and limited quantity of research on the connection between exteroception and interoceptive systems means that there still may be undiscovered or unstudied components of interoception that explain the phenomenon illustrated in these heart transplant patients. On the whole, interoception is a relatively recent topic of study and did not appear in scientific journals until the 1940s and 1950s (Ceunen et al., 2016). The gaps in our knowledge and novelty of the research in this discipline necessitate more research and are the impetus for this study.

The Role of Physical Activity

Researchers have recently started investigating the relationship between proprioceptive acuity and physical activity. Using samples of athletes, individuals with high level training in physical activity, researchers have found higher proprioceptive acuity in athletes compared to their non-athlete counterparts (Euzet & Gahery 1995; Muaidi, Nicholson, & Refshague, 2008). More sport-specific analyses continue to be conducted, and their results continue to demonstrate the same result: athletes with physical training have heightened proprioceptive acuity. In a sample of basketball players, for instance, free-throw accuracy had a positive correlation with proprioceptive acuity at the wrist and elbow joint (Sevrez & Bourdin, 2015). Proprioceptive abilities have been measured in athletes of varying disciplines and skill-levels, including Olympic athletes (Muaidi et al., 2008). Generally speaking, all of these studies demonstrate higher proprioceptive acuity in athletes than in non-athletes at joints that are required for the athletes' sport-specific skills.

The relationship between interoception and physical activity has also come under more thorough investigation recently. General physical activity has been correlated with increases in interoceptive accuracy; children with higher interoceptive accuracy performed significantly better on a physical performance task and exercised more regularly over the five-day span prior to the study (Georgiou et al., 2015). In addition to general physical activity, interoceptive awareness also appears to aid an individual's ability to pace themselves during intense physical exercise (Herbert, Ulbrich & Schandry, 2007). In the self-pacing study, participants' interoceptive accuracy was measured with a heartbeat perception task, followed by a self-paced cycling exercise. Individuals with higher accuracy on the heartbeat perception task had significantly lower heart rates, stroke volumes, and cardiac output while cycling compared to individuals with lower accuracy on the heartbeat perception task (Herbert et al., 2007). This means that those individuals who could better sense their own heart rates paced themselves better during physical exertion. Preliminary research presents a positive correlation between physical activity (and other related activities such as pacing) and interoceptive accuracy (Georgiou et al., 2015; Herbert et al., 2007).

Anatomical evidence collected from elite adventure racers also supports a positive correlational relationship between physical activity and interoceptive accuracy. Elite adventure racers subjected to increasing inspiratory breathing loads showed heightened insular activity (Paulus et. al., 2012). The insula is important in self-awareness and re-representing the internal state of the body (Craig, 2002). Increased activation in these regions implies more re-representations of the internal state of the body for the adventure races and suggests that adventure racers may have better interoceptive sensitivity during the physiological stress of high-level physical activity.

The Relationship Between Interoception and Proprioception

A modest amount of research has been conducted on the relationship between proprioceptive and interoceptive sensation. Of the studies conducted, nearly all of them found that interoception is not a significant predictor for proprioceptive drift (Crucianelli, Krahé, Jenkinson, & Fotopoulou 2018; David, Fiori, & Aglioti 2014; Cebolla et al. 2016; Xu et al. 2016). Proprioceptive drift is a unique construct measured in the rubber hand illusion. The rubber hand illusion places participants with one arm out of sight and a lifelike rubber hand in its place. By stroking the visible rubber hand and the participant's hidden hand in synchronicity, the illusion can elicit the participants to claim ownership of the rubber hand in place of their own hand

(David et al., 2014). Proprioceptive drift takes advantage of the subjective transfer of ownership to the rubber hand and measures the extent to which the participants' perception of their real hand location shifts towards the rubber hand (Cebolla et al., 2016). More specifically, proprioceptive drift can be recorded as the difference between the actual and perceived locations of the participants' real hand after the stroking; individuals with a larger difference between the actual and perceived locations have higher proprioceptive drift (Crucianelli et al., 2018). A higher proprioceptive drift score in these studies represents a worsened proprioceptive accuracy and body awareness, as participants with higher scores were less aware of the true location of their hand in space (Cebolla et al., 2016).

The proprioceptive measures used in these studies require further analysis. Almost all of the previous studies used the rubber hand illusion and measured proprioception via proprioceptive drift. This measure is not necessarily the best measure for proprioceptive accuracy, as it is based on a unique outcome from the illusion; it is difficult to create comparable measures for other tasks. The connections between proprioceptive drift measures in the rubber hand illusion and proprioceptive measures like the joint position matching task have yet to be studied and do not necessarily correlate with one another. The rubber hand illusion generates a major sensory conflict and most likely functions differently than other proprioceptive measures (Tsay et al., 2014). The visual input of the rubber hand in the task, for instance, contrasts the notion that the task relies solely on proprioceptive signals (Mehling et al., 2009). The rubber hand illusion may be more suitable for multisensory measures of bodily awareness, rather than measures of interoception and proprioception alone (Crucianelli et al., 2018). As a result, the researchers planned to implement the joint position task as a measure of proprioceptive accuracy.

The interoceptive measures in all four of these studies require additional consideration, however. Crucianelli et al. (2018) used the heartbeat counting task as a measure of interoceptive sensitivity. The validity of this test is called into question, as there is no way to determine whether a participant's reported heartbeat count is based on sincere counting during the time frame or the participant's previous knowledge about their own heart rate. Participants who have a preconception of their heart rate could provide accurate counts solely from previous knowledge, without counting any beats during the experimental trial (Brener & Ring, 2016). Other studies used self-report questionnaires to measure interoceptive awareness: Body Perception Questionnaire (David et al., 2014) and Multidimensional Awareness of Interoceptive Awareness (Cebolla et al., 2016; Xu et al., 2016). Self-report questionnaires are subjective by nature, as participants rate and analyze their own behaviors. The heartbeat discrimination task implemented in the present study differs from the heartbeat counting task and self-report questionnaires and has higher objectivity and validity as a measure for interoceptive accuracy.

None of the previous research on the relationship between proprioception and interoception investigates the role of physical activity. As previously illustrated, physical activity can independently affect proprioception and interoception (Muaidi et al., 2008; Georgiou et al., 2015). Physical activity may represent a key linkage between interoception and proprioception, yet previous studies have only analyzed the relationship in samples with relatively similar physical activity levels. The participants in the present study include separate groups of NCAA Division III athletes and non-athletes to account for the influence of physical activity.

Overall, considerable research has been conducted in proprioception and interoception independently. Nonetheless, very little research has been conducted to analyze the relationship between the proprioceptive and interoceptive senses. Of the research studies conducted, none have looked at the role of physical activity in the interaction of proprioception and interoception. This research intends to investigate this relationship using a sample of full-time students at Washington and Lee University, including both student-athletes and non-athletes. Evidence from the literature shows a positive correlation between physical activity and proprioception and between physical activity and interoception. Therefore, the researchers hypothesized that there would be a positive correlation between interoceptive accuracy and proprioceptive accuracy in the entire sample. Likewise, the literature shows increased interoceptive and proprioceptive accuracy in individuals with higher physical activity levels. Accordingly, the researchers generated two hypotheses. First, the researchers hypothesized that athletes would have higher proprioceptive and interoceptive accuracy than non-athletes. Second, the researchers hypothesized that athletes would have a higher, positive correlation between proprioceptive and interoceptive accuracy than non-athletes. In other words, physical activity was hypothesized to act as a moderator for the correlation between proprioception and interoception.

Method

Participants

Volunteers were recruited from the campus of Washington and Lee University. The sample of participants consisted of full-time students attending Washington and Lee University in Lexington, Virginia ($N = 25$). All participants gave informed consent and received financial compensation of ten dollars for their participation. All of the procedures conducted were approved by the Institutional Review Board at Washington and Lee University in Lexington, Virginia.

Materials and Procedure

Interoception Measures

After participants arrived at the laboratory and gave informed consent, the general procedures and equipment required for the interoceptive task were explained. For their first exercise, all participants completed a heartbeat perception task to assess their interoceptive accuracy. The task, known as the modified Whitehead task, evaluated each participants' ability to determine the synchronicity of an external stimulus with their heartbeat (Barrett et al., 2004). The original task was developed in Whitehead et al. (1977) and has been modified in more recent studies.

Researchers hooked up the participants to the electrocardiogram (EKG) by attaching three electrodes to the participants. Two electrodes were placed just below the clavicle and the third was placed on the lower left abdomen. The participants were instructed to sit up as straight as possible, with their lower back pressed against the chair and were reminded to remain still during each trial. Before testing began, there was a five-minute adaptation period in which the researchers looked at the EKG signal, ensuring the T-wave was below the QRS complex. These five minutes allowed the researchers to troubleshoot any instances where the T-wave was higher than desired. After adaptation, a total of 40 trials were completed, in accordance with recommendations from Klecker et al. (2014). For each trial, the participant heard a series of 10 beeps. For 20 trials, the beeps were synchronous with their heartbeat and for the other 20 trials the beeps were asynchronous with their heartbeat. The order of the synchronicity was generated randomly by the randomization function in Microsoft Excel, and each participant had a different mixture of the synchronous and asynchronous trials. The synchronous and asynchronous beeps played exactly 250ms and 550ms after the peak of the R-wave, respectively. Values in these ranges were shown to have the most validity when matching heartbeat timing with the perceptual delay experienced by participants (Brener & Ring, 2006; Wiens & Palmer, 2001). For each trial, a series of 10 tones played, and the participants answered whether or not they perceived the tones as synchronous or asynchronous with their heartbeat. In addition, participants scored their relative confidence in their determination on a scale from 1 to 100, with 1 representing very little confidence and 100 representing complete confidence.

Researchers removed any trials deemed inaccurate at the end of data collection. These trials included those in which more than one beep sounded for a singular heartbeat or if a beep was skipped. This did not happen commonly, and many participants did not have any trials removed. All testing was performed using LabChart interoception trace programs.

Proprioception Measures

Following interoception assessment, participants were given instructions about the joint position matching task, an assessment of proprioceptive accuracy. The joint position matching task is a widely accepted method of measurement and has high validity and accuracy for measuring proprioception (Goble, 2010). The joint position matching task evaluates an individuals' ability to reproduce a joint angle. The researchers followed a procedure similar to that of Sevrez and Bourdin (2015) and used ipsilateral limb matching tasks. All the participants use the same limb, their dominant arm, in tandem to create the desired angle.

Participants stood next to a cabinet for this task, placing their dominant arm on the cabinet. The participants were asked to turn their head away from their arm so that they could not see any part of their hand or arm. The task was based solely on proprioceptive input from the muscles and joints; visual input was not meant to aid in the completion of the task. Participants began with their dominant arm out the side at 0° and head turned toward their non-dominant arm. Using a digital protractor, the researcher moved their dominant arm up into the air, forming an angle of either 20°, 45°, 70°, or 90° with the horizontal surface of the cabinet (See Appendix A). The participants held the angle for five seconds and were instructed to play close attention to its position. The researcher then instructed the participant to move their arm back to the cabinet, at the baseline of 0°, waited five seconds, and asked them to regenerate the same angle to the best of their ability. Using a digital protractor, the new angle created by the participant was measured and recorded in the table. The researcher continues this process eight times, forming the angles in the following random order: 45°, 20°, 70°, 45°, 70°, 90°, 20°, 90°, 70°. This order was kept consistent across all participants.

Physical Activity Questionnaire

After completion of the interoceptive and proprioceptive measures, participants filled out a brief, untimed questionnaire on their physical activity levels and athlete status (See Appendix B). The questionnaire was completed on Qualtrics online survey software. Answers to the first question about athlete status directed participants to different sets of questions. Non-athletes answered questions about general physical activity, while athletes answered questions about more sport-specific physical activities.

Data Analysis

Interoceptive Accuracy

Researchers measured a hit rate and false alarm rate for each participant in accordance with signal detection theory. The hit rate represented the total number of times a participant correctly identified the beep sequence as synchronous with their heartbeat (250ms) divided by the total number of times the beep sequence was actually synchronous with their heartbeat (Stanislaw & Todorov, 1999). In this study, the total number of times was always twenty, regardless of participant. The false alarm rate represented the number of times a participant incorrectly identified a beep sequence as synchronous with their heartbeat when it was, in fact, asynchronous (550ms) divided by the total number of times a beep was asynchronous with their heartbeat (Stanislaw & Todorov, 1999). Once again, the total number of times was always twenty, regardless of participant. The hit rate and false alarm rate for each participant was used calculate a *d*' value. A *d'* value measures the difference between the false alarm and hit means in units of standard deviations and serves as a measure of sensitivity (Stanislaw & Todorov 1999). A *d'* value of zero meant the individual was incapable of distinguishing between synchronous and asynchronous beeping sequences, while larger positive numbers indicated that the individual was better at distinguishing between synchronous and asynchronous conditions.

Proprioceptive Accuracy

Proprioceptive accuracy scores were generated for each trial. The proprioceptive accuracy scores were calculated by taking the absolute value of the actual angle minus the angle generated by the participant. These values were generated for all eight angles and then added together and divided by eight. This final number represented the proprioceptive accuracy score and was used for later analysis. Larger numbers indicate a lower proprioceptive accuracy, while smaller numbers indicate a higher proprioceptive accuracy.

Statistical Analysis

All statistical calculations were made in SPSS Version 26. From previous research, the researchers hypothesized a positive correlation between interoceptive accuracy and proprioceptive accuracy across the entire sample A value for Spearman's r was generated for the *d'* values and proprioceptive accuracy scores for comparison across the entire sample.

The two sub-samples of participants, athletes and non-athletes, were then analyzed separately, as the main goal of this study was to determine if any differences existed between the groups. The researchers hypothesized that athletes would have higher proprioceptive and interoceptive accuracy compared to non-athletes. The proprioceptive accuracy and interoceptive accuracy (*d'* values) were compared between groups using two separate ANOVA procedures. Moreover, a Cohen's d was calculated for each ANOVA to determine effect size (Cohen's d = $\frac{\mu_1-\mu_2}{s_{pooled}}$) (Rosnow & Rosenthal, 2003).

Additionally, the researchers hypothesized a higher, positive correlation between proprioceptive accuracy and interoceptive accuracy in athletes than in non-athletes. Two values for Spearman's r were generated for proprioceptive and interoceptive accuracy scores, one for athletes and one for non-athletes. Then, a Fisher's r to z transformation was performed to identify any difference between the correlation for athletes and non-athletes. A Cohen's q was calculated to determine effect size (Cohen's q = $Z_{r1} - Z_{r2}$) (Rosnow & Rosenthal, 2003).

Results

Demographic Data

One of the participants had an exceptionally high score for interoceptive accuracy that varied drastically from any of the other 24 participants. Statistical analyses were conducted with and without this participant's data. It was determined that the data from this participant impacted the magnitude of the of the relationship between proprioception and interoception in non-athletes, so results were reported without this participant.

Out of the total 24 individuals who participated in the study, more were females (*n* = 16) than males (*n* = 8). The participants ages ranged from 18 to 21 years (*M* = 20.00, *SD* = 1.06). The participants were split into two groups according to their status as athletes (*n* = 11) and non-athletes (*n* = 13), and athletes were defined as any member of one of the 24 varsity sports teams at Washington and Lee University. The ratio of sexes did significantly differ in the athlete and non-athlete sub-samples ($X^2 = 0.17$, $p = 0.68$). The mean proprioceptive accuracy score for all participants was 4.44 degrees (*SD* = 2.33) and for interoceptive accuracy, *d'* values, was 0.06 (*SD* = 0.35) (see Tables 1 and 2).

Interoceptive and Proprioceptive Accuracy

The researchers first hypothesized that there would be a positive correlation between interoceptive and proprioceptive accuracy across the entire sample. Contrary to the hypothesis, a Spearman's correlation indicated there was no significant relationship between proprioceptive and interoceptive accuracy within the entire sample ($r_s = 0.16$, $p = 0.47$) (See Figure 1). When looking at the sub-sets of participants separated by athlete status, the researchers additionally predicted both higher proprioceptive accuracy and interoceptive accuracy in athletes when compared to non-athletes. The 11 athletes had a mean proprioceptive accuracy score of 3.92 degrees (*SD* = 2.76) and a mean interoceptive accuracy score of 0.09 (*SD* = 0.39), while the 13 non-athletes had a mean proprioceptive accuracy score of 4.87 degrees (*SD* = 1.90) and a mean interoceptive accuracy score of 0.044 (*SD* = 0.38). There was no significant difference in proprioceptive accuracy scores ($F = 0.990$ $d = 0.15$, $p = 0.33$) or interoceptive accuracy scores (*F* = 0.008, *d* = 0.07, *p* = 0.80) for athletes and non-athletes (See Figures 2 and 3). Finally, the researchers hypothesized a higher positive correlation between proprioceptive and interoceptive accuracy in athletes compared to non-athletes. Separately, there was no significant relationship between proprioception and interoception for athletes (r_s = -0.16, *p* = 0.63) or non-athletes (r_s = 0.53, *p* = 0.06). Athletes followed the predicted trend, and as their proprioceptive accuracy score decreased, their interoceptive accuracy score increased, while non-athletes followed the opposite trend, and as their proprioceptive accuracy score increased, their interoceptive accuracy also increased (See Figures 4 and 5). When looking at the coefficients for both sub-samples, the correlation between proprioceptive and interoceptive scores was nearly significant between athletes and non-athletes and was relatively large in size (*z'* = -1.59, *q* = 0.76, *p* = 0.11).

Table 1

Participant Characteristics

Characteristic	*M*	*SD*
Age (years)	20.00	1.06
Proprioceptive Accuracy	4.44	2.33
Interoceptive Accuracy (*d'*)	0.06	0.35

Note. N = 24. The outlier is not included in this demographic data.

Table 2

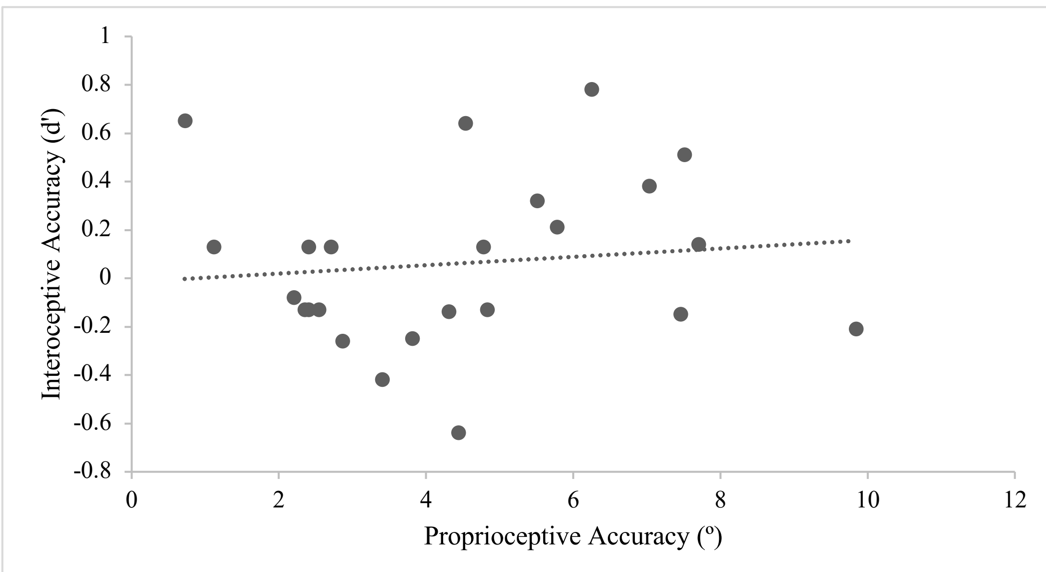
Categorical Participant Characteristics

Characteristic	*n*	%
Male	8	33
Female	16	67
Athlete	11	46
Non-athlete	13	54

Note. N = 24. The outlier is not included in this demographic data.

Figure 1

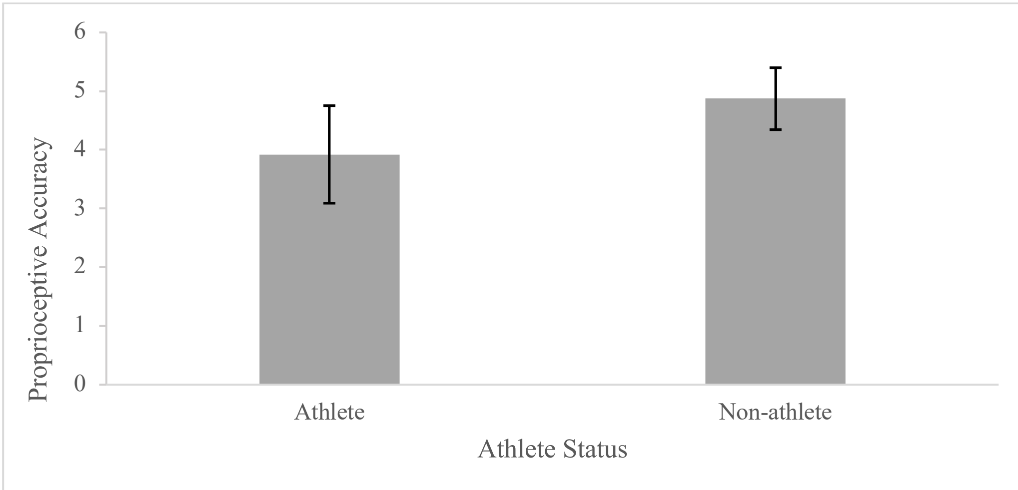
Proprioceptive and Interoceptive Accuracy Scores



Note. This depicts the relationship between interoceptive and proprioceptive accuracy across the entire sample (N = 24).

Figure 2

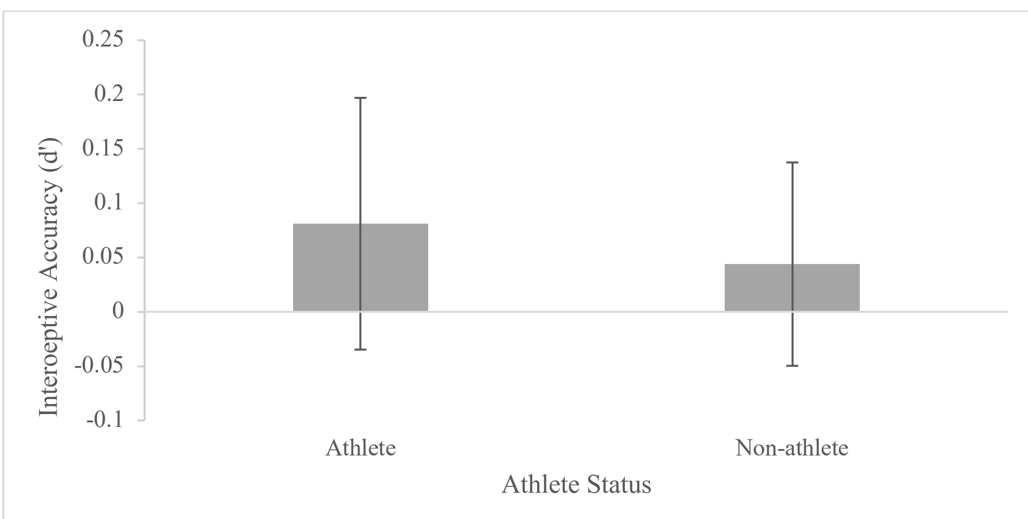
Mean Proprioceptive Accuracy Scores for Athletes and Non-athletes.



Note. Error bars represent the standard error of the mean.

Figure 3

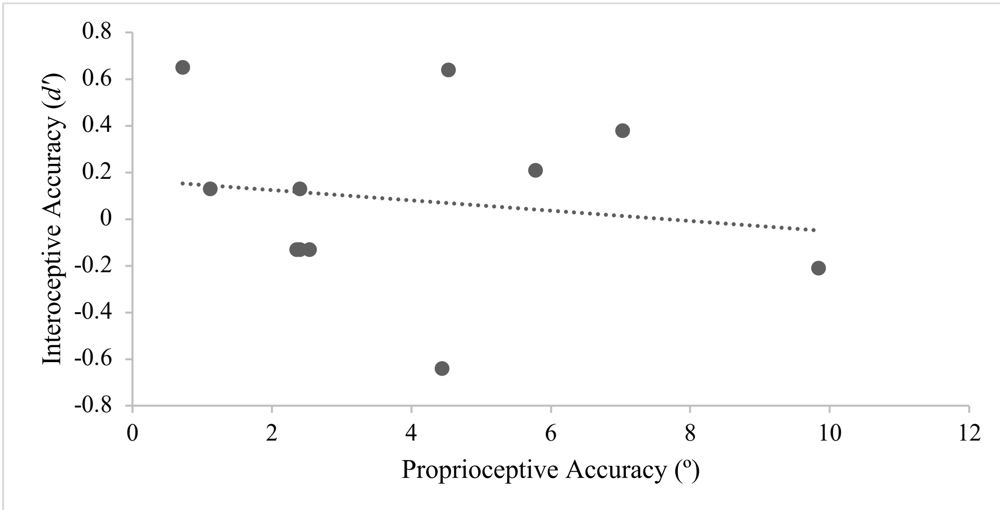
Mean Interoceptive Accuracy Scores for Athletes and Non-athletes.



Note. Error bars represent the standard error of the means.

Figure 4

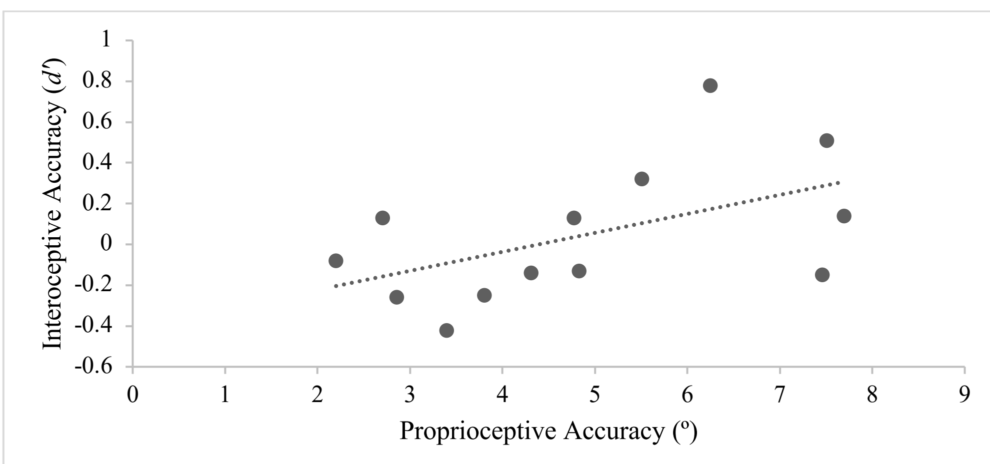
Proprioceptive and Interoceptive Accuracy Scores in Athletes.



Note. This data represents scores for athletes only (n = 11). Lower proprioceptive scores and higher interoceptive scores represent more accuracy for the measures.

Figure 5

Proprioceptive and Interoceptive Scores in Non-athletes.



Note. This data represents scores for non-athletes only (n = 13). Lower proprioceptive scores and higher interoceptive scores represent more accuracy for the measures.

Discussion

This study aimed to investigate the role of physical activity in the relationship between proprioception and interoception. A considerable amount of research has already been conducted on the relationships between proprioception, interoception, and physical activity as pairs. Studies on proprioception have found improved proprioceptive acuity in samples of athletes, individuals with high levels of physical activity (Euzet & Gahery, 1995; Muaidi et al., 2008). Likewise, research on interoception has found increased interoceptive accuracy in individuals with higher levels of physical activity (Georgiou et al., 2015). Nonetheless, previous research has yet to consider the modulatory influence of physical activity on the relationship between proprioception and interoception. This gap in knowledge prompted the analyses conducted in this investigation.

The researchers first hypothesized a positive correlation between interoception and proprioception across the sample. A small negative correlation was discovered, but correlational analysis did not reveal any significance in the relationship (. Participants were then separated according to athlete status, and researchers hypothesized that athletes would have higher proprioceptive accuracy and interoceptive accuracy compared to non-athletes. Two separate ANOVAs conducted for proprioceptive accuracy and interoceptive accuracy discovered small, insignificant differences between the groups. The researchers predicted a higher positive correlation between interoceptive accuracy and proprioceptive accuracy in the athletes than in the non-athletes. Separate correlations on each sub-sample revealed insignificant relationships between proprioception and interoception for both sub-samples. In non-athletes, interoception and proprioception were nearly significant and more closely related, however. An analysis of the difference between correlation coefficients for the sub-samples showed a nearly significant and large relationship between the sub-samples.

Hypothesis One: Positive Correlation Between Interoception and Proprioception

Contrary to the researcher's hypothesis, correlational analysis did not uncover a significant relationship between proprioception and interoception in the entire sample of 24 participants. Moreover, the relationship followed a trend opposite of the predicted direction. A small, negative correlation between proprioception and interoception was discovered in this research (due to the fact that proprioceptive and interoceptive accuracy scores improve in opposite directions, this meant a positive correlation coefficient). The insignificance of the relationship aligns with previous research (Crucianelli et al., 2018; David et al., 2014; Cebolla et al., 2016; Xu et al., 2016). It is critical to note, however, that previous research has only analyzed proprioception in the specific context of the rubber hand illusion. The rubber hand illusion is believed to function differently than other proprioceptive measures, like the joint position task performed in this investigation (Tsay et al., 2014). Therefore, the results of these previous studies were not necessarily hypothesized to match the results of this study. The parallels to previous studies, in other words, were not predicted. Nonetheless, the analogous results motivate further analysis of proprioceptive measures, as proprioceptive measures in the rubber hand illusion may have more similarity to the proprioceptive measures of the joint position task than originally speculated. In the future, research could be conducted on the parallels between proprioceptive tasks, like the joint position task and rubber hand illusion, to determine if they truly measure the same construct.

Hypothesis Two: Higher Proprioceptive and Interoceptive Accuracy in Athletes

Participants were separated according to their status as varsity athletes at Washington and Lee University. In contrast with the hypothesis, proprioceptive accuracy scores and interoceptive accuracy scores did not significantly differ between athletes and non-athletes. Physical activity has previously been shown to improve both proprioceptive accuracy and interoceptive accuracy (Sevrez & Bourdin, 2015; Muaidi et al., 2008; Georgiou et al., 2015; Herbert et al., 2007). Nonetheless, the results of this study do not resemble these previous studies.

In part, these differences may relate to the operational definitions of physical activity. Past investigations of physical activity and interoception do not define physical activity by athlete status. Georgiou et al. (2015) measured physical activity as the number of hours a participant exercised for the five days immediately prior to the study, while Herbert et al. (2007) used a self-paced cycling workout to evaluate physical activity. Athlete status does not necessarily compare to the measures used in these studies. Specifically, the definition of physical activity as athlete status does not match the temporal proximity of physical activity measured in previous studies. Athletes in the midst of their NCAA season most likely exercise more than those athletes in the off-season. As a result, exercise within five days prior to the study, as analyzed by Georgiou et al. (2015) may not correspond to higher exercise for off-season athletes in this study. Both the study conducted by Georgiou et al. (2015) and the study by Herbert et. al. (2007) measured physical activity levels in a range of time close to the measures of interoception: a few days or a few minutes, respectively. In the current investigation, however, the timeframe for exercise was not considered. If physical exercise only acts as a modulator in the short-term, then a measurement of athlete status, a better measure of long-term exercise tendencies, may not affect the relationship. The difference in short-term and long-term physical activity measures could potentially explain the inconsistencies between this study and previous research. To address this discrepancy, future research could be conducted on differences between in-season and off-season athletes.

In a similar manner, previous research on physical activity and proprioception also differed slightly in terms of methodology. Research conducted by Sevrez and Bourdin (2015) measured proprioceptive acuity in basketball players at the wrist and elbow joints. The wrist and elbow are key body parts for basketball-specific skills, such as free throw shooting, and were valid joints to analyze in a sample of basketball players. In this study, athletes from a variety of sports teams participated: golf, track and field, volleyball, cross country, lacrosse, soccer, riding, and wrestling. Each of these sports requires a distinct set of skills and body movements. Participants on the golf team, for instance, most likely use their wrist and elbow joints more frequently in their sport than participants on the soccer team. Based on this assumption, golf players may be more likely to have better proprioception at their elbow joint than soccer players, even though both groups of individuals fall under the category of athletes. This study did not take into account the specificity of different sporting activities and analyzed proprioception at the same joint for all participants, the elbow. Repetitive physical activity at a specific joint, rather than generalized physical activity, may have a stronger impact on the resultant proprioceptive accuracy at that joint. The lack of specificity in joint selection in this study, consequently, may have impacted the proprioceptive accuracy measures in the sub-sample of athletes.

In future studies, these issues should be addressed in the methodology. Primarily, athletes could be asked for the number of hours dedicated to their sporting activity in the last week to integrate temporal proximity into the definition of physical activity. Additionally, a sub-sample of athletes from the same sport could be analyzed in comparison to non-athletes. This could help determine if repetitive physical activity at one joint, rather than generalized physical activity levels, impacts proprioception more strongly.

Hypothesis Three: Higher Correlation with Proprioception and Interoception in Athletes

The relationship between proprioception and interoception did not have any significant relationships in either sub-set of participants. The size and directions of the relationships did differ for athletes and non-athletes, however. Athletes followed the predicted direction, and as their proprioceptive accuracy scores decreased, their interoceptive accuracy scores increased. Non-athletes, however, followed the opposite trend, and as one of their accuracy scores increased so did the other. Furthermore, the relationship between proprioception and interoception for the non-athletes was much stronger than the relationship for athletes.

The stronger relationship between for non-athletes may relate to the seasonal variations in physical activity that athletes undergo. In-season athletes exercise at a high intensity for long durations, while off-season athletes may be in recovery or rest. The average non-athlete, on the other hand, can continue with a steady course of physical activity without facing the exhaustion an in-season collegiate athlete may experience. If proprioception and interoception are mainly modulated by recent exercise, as mentioned earlier, then the relationship may be lower for athletes in this study do to the seasonal variation of their athletic competition seasons. The sample in this study consisted of both in-season and out-of-season athletes, so the levels of recent exercise for athletes could have been very scattered, generating a weaker relationship between proprioception and interoception.

The difference in the direction of the relationship also prompts further analysis. Athletes followed the hypothesized direction while non-athletes did not. The direction of the relationship, therefore, may relate more to the type and intensity of physical activity, rather than the amount of recent physical activity. The increased intensity of organized, collegiate athletics, for example, may affect proprioception and interoception in the same way. While the lower intensity of generalized exercise may affect interoception and proprioception differently, making it so that an improvement in one measure does not correspond to an improvement in the other measure.

At a first glance of the statistics for this hypothesis, the impact of athlete status on relationship between interoception and proprioception was technically insignificant. When considering the small sample size, however, the relatively small p-value ($p = 0.11$) suggests that a significant relationship may become apparent with a larger pool of participants. The effect size ($q = 0.76$), likewise, suggests that athlete status has a strong influence on the relationship between interoception and proprioception. Similarly, the negative correlation between proprioception and interoception in non-athletes also had a low p-value ($p = 0.06$) and a medium effect size ($d = 0.53$). In the context of this study, a relationship appears to be present, and again, with a larger sample size a significant relationship could become more apparent.

Limitations

Methodology

The methodology of this study is relevant when analyzing the results. Each participant completed 40 trials of the interoceptive accuracy task. Kleckner et al. (2014) demonstrated that researchers can safely use up to a maximum of 100 trials without a significant decrease in the participants' performance, effort, and engagement. These researchers also recommended a minimum of 40 trials to ensure enough data for an accurate effect size. The use of 40 trials fell far under this maximum, yet they provided sufficient data for analysis. The participants in this study likely did not experience exhaustion or boredom during the 40 trials of the interoceptive tasks. Along the same lines, however, participants' effort and attention may have diminished in the proprioception task. This study was conducted in concurrence with seven other studies. The proprioception task was the seventh task the participants completed. After about an hour of testing beforehand, participants may have lost motivation and exerted less effort in this task. In future research, it might be meaningful to conduct the interoception and proprioception tasks in an isolated experimental setting, so as to prevent boredom and exhaustion on behalf of the participants.

Sample Size and Composition

In addition to methodology, the size and composition of the sample must also be considered in the context of this study. The total sample size included 24 individuals. A sample of 24 is relatively small and generates very little power in analyses. The significance of statistical analyses depends on sample size, so the insignificance of the analyses in this study could relate more to sample size than the actual relationship under study. Effect sizes including Cohen's d and Cohen's q were calculated for statistical analyses, however. These test statistics do not depend on sample size and help show the strength of the relationships under examination.

Despite the less than ideal sample size, the composition of the sample was excellent for analysis by athlete status. The sample consisted of nearly half athletes and included athletes from a variety of teams at Washington and Lee. Plus, there were relatively equal numbers of female and male athletes. The balanced composition of the sample helped ensure that no sub-sample had an extremely small number of individuals compared to the others.

Conclusion

Overall, this study demonstrates a potential impact of athlete status on the relationship between proprioception and interoception. The small sample size impaired the significance of the results, but the medium and large effect sizes suggest that a relationship may become more apparent with more examination. Future work should build on these concepts with a bigger sample size and should attempt to integrate other measures of physical activity, taking into consideration the timeframe and type of physical activity measured. With further exploration, we could enhance our understanding of the relationship between proprioception and interoception and more broadly, the potential relationship between proprioception and exteroception.

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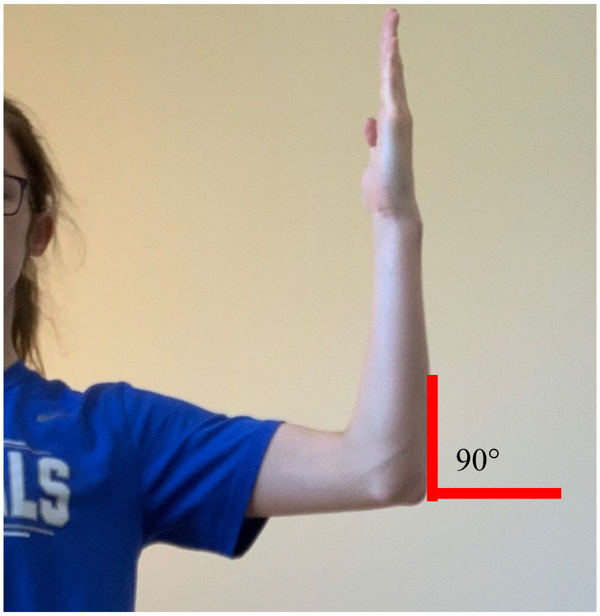
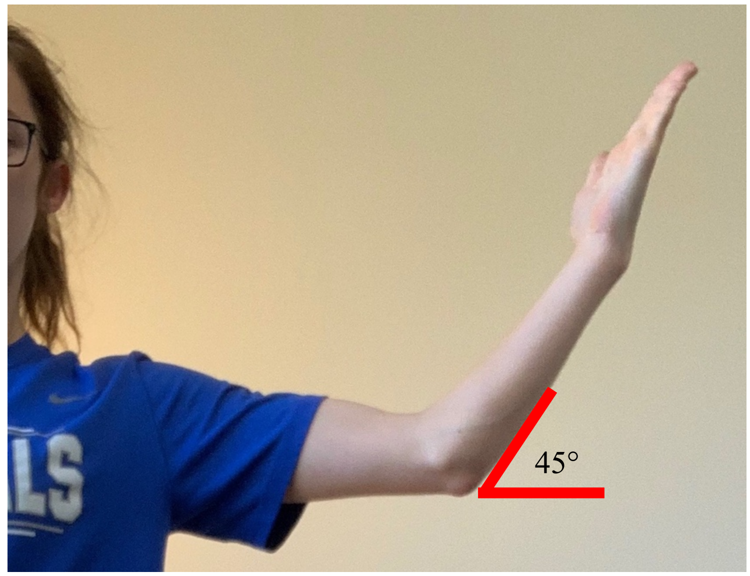
Appendix A

Joint Position Matching Task Angles



90°: arm perpendicular to ground



45°: between 0° and 90°

Appendix B

Physical Activity Questionnaire

Question One: Are you a current member of one of the 24 varsity athletic teams at Washington and Lee University?

a. Yes
b. No

If answered "Yes" to Question One:

Question two: To which of the 24 varsity teams are you a member?

Options: Baseball, Men's Basketball, Men's Cross Country, Football, Men's Golf, Men's Lacrosse, Men's Riding, Men's Soccer, Men's Swimming, Men's Tennis, Men's Track and Field, Wrestling, Women's Basketball, Women's Cross Country, Field Hockey, Women's Golf, Women's Lacrosse, Women's Riding, Women's Soccer, Women's Swimming, Women's Tennis, Women's Track and Field, Volleyball

Question three: How many **hours** per week (on average) do you dedicate to training for your sport?

If answered "No" to Question One:

Question two: How many **hours** per week (on average) do you dedicate to your physical fitness?

Final Question (for everyone):

Are you primarily left-hand or right-hand dominant?

a. Left-hand dominant
b. Right-hand dominant