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A Novel Method for Assessment of Proprioception

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Summary

Proprioception is the sense of the relative position of body parts and movement, as detected by mechanoreceptors located in muscles, joints, and fascia throughout the body. Various attempts have been made to quantify this sensory function. Furthermore, its impairment has been documented in humans with viral infection that specifically damages proprioceptive neurons of the central nervous system. To test the proprioceptive acuity of high school athletes, we sought to establish a quantitative assessment of proprioception. In this study, we hypothesized that varsity-level athletes would have a superior sense of body positioning and thus perform better than non-varsity athletes, irrespective of sport. A novel approach was developed that utilizes two motor tasks of shoulder-arm positioning: arm placement at defined clock-face positions and random radial arm movement on an x,y plane. Using these quantitative methods, we provide a 'proprioceptive index' for each athlete as a measure of sensory integration and motor output. Participants were grouped by participation in sports: soccer, hockey, basketball, or dance. We found a significant correlation between dancers and their ability to precisely reproduce motor movements.

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Introduction

Like all human behaviors, movement is controlled by the brain. The stimulus that activates motor function can be external, such as running away from a fire; or internal, such as deciding to stand up. Generic movements such as walking or jumping in humans are stereotyped, or invariant, as the behavior is the same from person to person. Fine motor control is widely variable, yet it is often the distinguishing trait of high-performing athletes and world-class instrumentalists.

Animals use the five classic senses to coordinate movement. Visual cues and touch, in particular, help humans navigate through the world. Proprioception can be understood as a sixth sense, incorporating the sensory signals that relay information about the relative position of body parts and the force of movement. The brain integrates sensory information from mechanoreceptors embedded, for example, in muscle tissue that detect changes in muscle length. To perform a simple motor task like raising one's hand, proprioceptive sensory feedback allows one to know the position of the hand relative to the shoulder and head, even in the absence of additional visual or tactile sensory feedback. As with other senses, attempts have been made to quantify proprioception (4). Three prominent methods are: threshold to detection of passive motion (TTDPM), joint position reproduction (JPR), and active movement extent discrimination assessment (AMEDA). TTDPM involves applying a passive force to one of a variety of joints and measuring the threshold at which movement is perceived. JPR measures the error in reproduction of various joint movements. AMEDA measures the ability to make specified angles at various joints. This study employs a novel method of assessment, which combines JPR and AMEDA and was simple enough to conduct with students in a high school setting. We sought to test the hypothesis that varsity athletes would perform better on an assessment of proprioception than non-varsity athletes, regardless of the type of sport each athlete plays. A 'proprioceptive index' was calculated for each athlete by testing individuals on motor tasks involving shoulder rotation with an extended arm placed at various positions. Using these data, we examined whether varsity-level participation in sports, self-reported athleticism, gender, and perception of completing the task accurately correlated with the individual's proprioceptive index. Furthermore, by grouping subjects by primary sport played, we tested whether participation in a particular sport enhanced proprioception.

Results

The novel method for assessing proprioception used in this study employed a simple hand-built pulley apparatus (**Figure 1**). The angle generated by movement of the subject's arm was calculated based on length measurements taken on the pulley apparatus (**Figure**

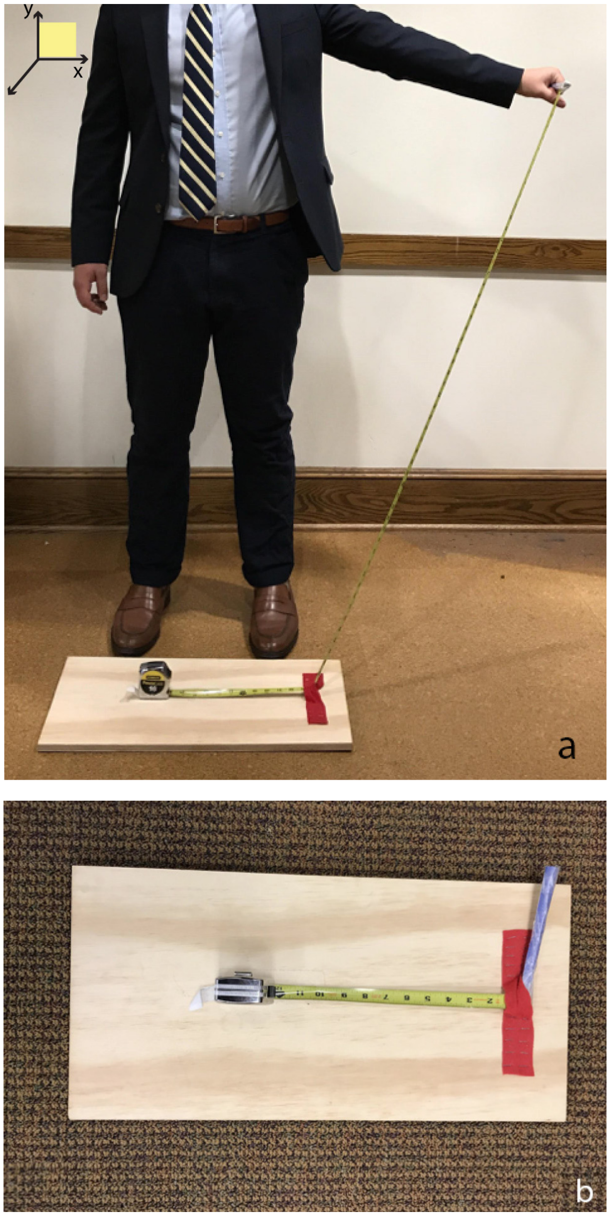


Figure 1. Pulley apparatus designed for proprioception testing. Two tasks of shoulder-arm positioning were tested: First, arm placement to match a specified clock-face position and second, displacement of the extended arm above or below the horizontal x-axis to a randomly determined position. A) The participant holds the handle with their left hand, while standing perpendicular to the tape measure and their left foot in line with the piece of felt attached to the wooden board. Arm movement was restricted to the x,y plane (denoted by yellow square). The distance pulled was measured where the tape crossed the felt. B) The pulley apparatus is shown from a top-down view with the handle that was attached to the tape measure resting above the felt.

2). For each motor task of arm placement, the angle generated by the subject was compared to a reference angle. The magnitude of error was computed by taking the absolute value of the difference, in degrees, of the two angles. Less error produced a lower score. By averaging the magnitude of error across two separate motor tasks, a proprioceptive index was determined for each subject. Thus, a lower index score indicated better proprioceptive acuity in reproduced motor tasks.

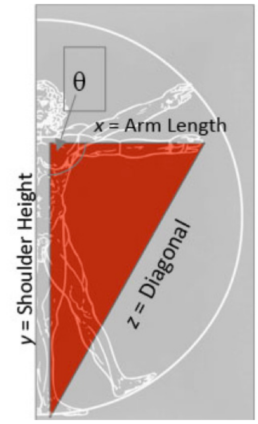


Figure 2. Calculation of the angle formed by shoulder-arm rotational positioning. To calculate the angle θ generated by each arm movement, two initial measurements were taken with the subject standing and holding one arm extended out to the side. First, the subject's arm length was measured from shoulder to fingertip to establish the x-value in the horizontal direction. Second, the foot to shoulder height was used to mark the vertical y-value. The x- and y-values were specific to the subject and therefore fixed. Subsequently, the extension of the tape by the subject, as measured on the pulley apparatus at each position, was recorded as the z-value. For each movement task, the angle θ was calculated using the law of cosines. Thus, on a reproduced task, the difference between two angle measurements amounted to the magnitude of error. The lower the error, the better the performance on the task.

Prior to testing, participants were surveyed on their varsity-level participation, self-assessed athletic ability, and primary sport played. Fifty high school-aged participants were surveyed then tested to determine their proprioceptive index. We initially hypothesized that varsity athletes and people who self-reported better athleticism would perform better on testing. However, participants who judged their athleticism to be high (on a scale of 1-5, 5 considered most athletic) did not perform better, on average (p=0.819, **Figure 3**). Furthermore, there was no significant difference in performance between varsity and non-varsity level of competition (p=0.679, **Figure 4a**). Males performed only slightly better on average, with a mean index score of 3.75 degrees, than females with a mean score of 4.17 degrees (p=0.986, **Figure 4b**).

By contrast, there was a correlation between one's perceived confidence on performing the proprioception tasks and the individual's calculated proprioceptive index. Those who thought they performed very well on the assigned motor tasks, generally showed a lower index score, meaning smaller magnitudes of error on both motor tasks (p=0.687, **Figure 5**).

Finally, subjects were separated into groups based on primary sport. Five categories emerged: soccer, hockey, basketball, dance, and 'other' (**Figure 6**). There was a significant difference between the five groups (p=0.00345). Furthermore, pairwise testing revealed that dancers performed better than the average index

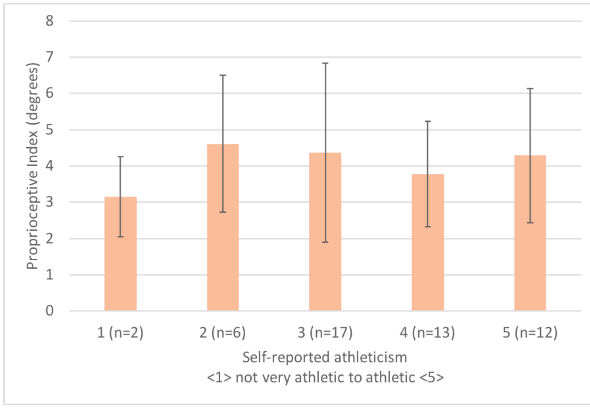


Figure 3. Relationship between proprioceptive index and self-rating of athleticism. Participants were surveyed on their overall athleticism on an assessment scale of 1 to 5 (5 considered most athletic). A one-way ANOVA concluded there was no significant difference between the means of the groups (p=0.819), indicating that athleticism does not correlate directly with enhanced proprioceptive ability (lower index score). Error bars show standard deviation.

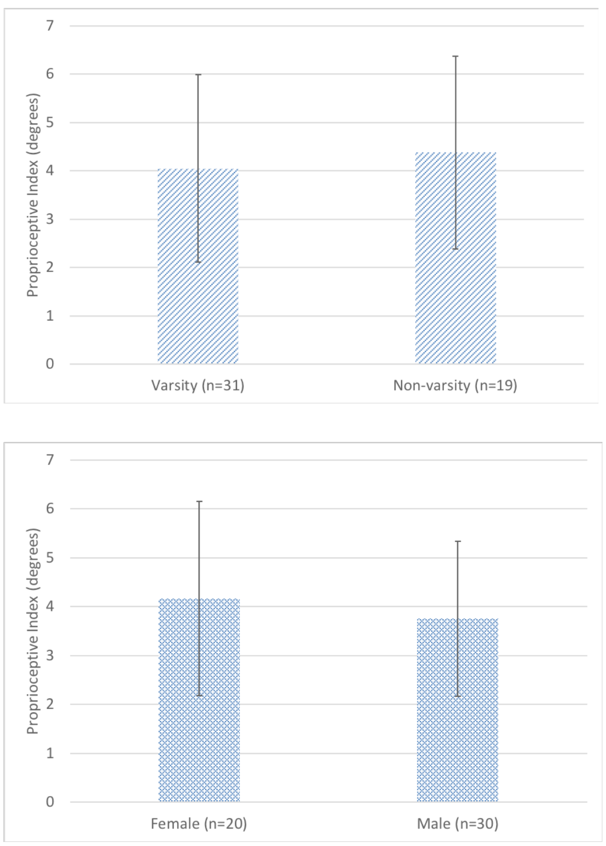


Figure 4. Summary of proprioceptive index comparisons. Varsity-level affiliation in at least one sport and biological gender were examined for a possible relationship to proprioceptive index. a) Varsity-level and non-varsity participation and b) gender. The Student's t-test showed no significant difference in either comparison, neither level of play (p=0.679) nor gender (p=0.986). Error bars show standard deviation.

score across all the other sport cohorts, and significantly better than soccer players and 'other' sports (p<0.05).

Discussion

This study aimed to develop a novel method for assessing proprioception in a population of adolescents who played at least one major organized sport. Athletes from four popular high school sports were sampled: soccer, basketball, hockey, and dance. We designed a proprioceptive test that involved shoulder-arm positioning about a fixed x,y plane. The error produced by the participant between the reference angle and the matched angle re-created by the subject was calculated into a proprioceptive index in units of degrees. By developing this experimental method, we were able to test the hypothesis that varsity-level athletes (in the sports represented within the sample) possess a superior sense of body positioning and would generate less error on repeated motor tasks.

Our data from 50 individuals tested show that neither varsity-level playtime, self-reported athleticism, nor gender predicted a lower proprioceptive index (i.e., less error). However, there was a correlation that emerged regarding self-assessment on the experimental test itself: the better a participant judged their own performance on the proprioceptive assessment, the lower their index score. Finally, when comparing the proprioceptive indexes between five cohorts-- soccer, hockey, basketball, dance, and 'other' sport— dancers had a lower index on average. Moreover, there was a statistical difference between dance and soccer, and between dance and 'other' sport, but not between any of the other pairings. These data lead us to conclude that varsity-level playing in organized sports or self-perceived athleticism does not amount to an improved sense of body positioning when assessed by this series of proprioception tests. However, our data suggest that a sport such as dance may better train athletes to perform controlled and precise body movements. Because fine motor movements require exquisite mind-body coordination, proprioception testing may provide an opportunity for further examination of the neural pathways activated to achieve motion, from basic stereotyped movements to even those that underlie evolutionarily adaptive ones (5).

Locomotion studies in laboratory animals ranging from flies to mice have begun to describe the genetic, neurophysiologic, and biomechanical underpinnings of voluntary movement (6,7). In these studies, animal models lacking proprioception can be studied closely for altered patterns of limb movement, thus demonstrating clearly the importance of this "sixth sense." These frameworks are also useful for modeling injury, such as for amputation or motor neuron degeneration (8).

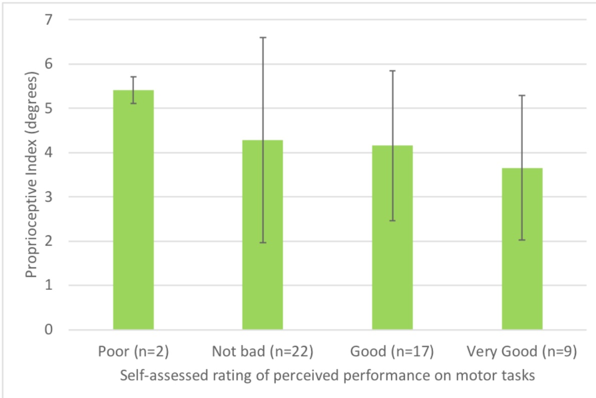
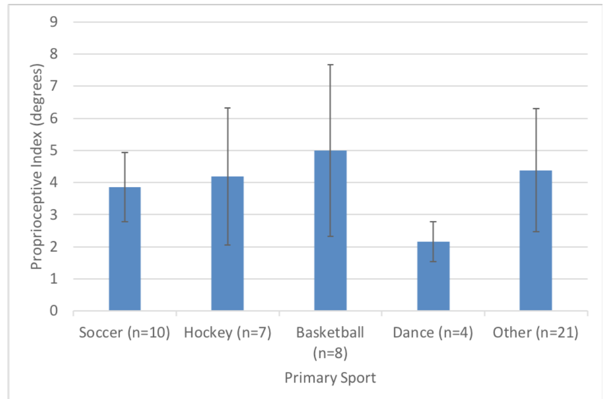


Figure 5. Correlation between proprioceptive index and post-testing performance rating. Following the series of reproduced motor tasks, participants were asked to rate themselves on their own performance to determine whether a test subject's assessment of accuracy matched with the calculated proprioceptive index. A one-way ANOVA concluded there was no significant difference between the means of the groups (p=0.687). Errors bars indicate standard deviation.



Welch's ANOVA	df	F	*p*		Games-Howell test	
between groups	4.0	6.079	0.003454015		SOCCER-HOCKEY	not sig
within groups	16.313				SOCCER-BASKETBALL	not sig
					SOCCER-DANCE	sig
					SOCCER-OTHER	not sig
					HOCKEY-BASKETBALL	not sig
					HOCKEY-DANCE	not sig
					HOCKEY-OTHER	not sig
					BASKETBALL-DANCE	not sig
					BASKETBALL-OTHER	not sig
					DANCE-OTHER	sig

Figure 6. Proprioceptive index as a function of primary sport. Participants were identified by primary sport affiliation. Since there was heterogeneity in variances among the sport groups, the Welch's ANOVA was applied. A significant difference was found between the groups (p=0.00345). Post-hoc analysis using the Games-Howell test for pairwise comparisons further identified a significant difference between dance and soccer, and dance and 'other.' Error bars indicate standard deviation.

In humans, rehabilitation of motor movement following traumatic injury has been an active area of study, along with attempts to apply quantitative metrics to the recovery process (9). These lines of investigation will require a more thorough understanding of proprioception prior to injury.

This study examined motor precision in healthy subjects and found a lower proprioception index, and therefore better performance, for individuals who are active in dance. Further assessment employing various kinds of routine dance positions would evaluate whether the proprioceptive index correlates along a spectrum of easy to difficult movements. One limitation of the novel assessment of proprioception presented here was that it was restricted to shoulder-arm rotation that could be mathematically modeled using simple geometry. Although performance in competitive sports is not limited to a fixed number of basic maneuvers, reproducible actions are especially important when different environmental conditions are factored in, such as the wind, cold temperatures, and the speed of a ball at play. Extensive mathematical models for skilled motor tasks prevalent in many sports—throwing, for instance— have incorporated variables such as launch angle and speed of throw (10). If a proprioceptive index could be determined for critical variables related to agility and performance, then these measurements may be indicators of the athlete's future success, or serve as guideposts at different stages of the athlete's training.

Methods

Clock-face position task and extended arm placement task using a pulley apparatus

A pulley apparatus was designed to consist of a tape measure glued to a wooden plank, with a piece of felt attached to act as a pulley. For the baseline measurements i) the length of the participant's extended arm from hand to shoulder (defined as 'x') and ii) the vertical distance between the board on the ground and the participant's shoulder height (defined as 'y') were measured. The extended length of the tape was measured for each task (defined as 'z').

For the clock-face position task, the participant was shown the following three target positions prior to re-creating them: three o'clock (90 degrees), two o'clock (120 degrees), and four o'clock (60 degrees). The participant executed each specified position starting with their arms at their side (zero degrees). The z-values were recorded from the measuring tape for each movement.

For the extended arm placement task, the arm was fully extended out to the side at shoulder height to establish an imaginary horizontal axis; the horizontal line was defined as 90 degrees and resting position as 0 degrees. First, the participant chose an arbitrary position, which would serve as the reference point, below the horizontal axis. The participant was asked to re-create this target position starting from resting position. A second shoulder movement was executed, but this time using an arbitrary position above the horizontal as the targeted reference point. The z-values were recorded from the measuring tape for each task.

Calculation of the proprioceptive index for shoulder-arm rotational movement

The x, y, and z dimensions measured generated a triangle shape. The angle θ, the angle generated by each arm movement, was calculated based on the dimensions of the triangle using the law of cosines:

$$z^2 = x^2 + y^2 - 2xy\cos(\theta)$$

$$\cos(\theta) = (x^2 + y^2 - z^2) / 2xy$$

The angle generated by the subject was compared to the specified target angle. The magnitude of error was calculated as the difference between the two angles; the absolute value was applied in order to work with all positive numbers. The average error on the clock-position test was determined using the fixed target angles of 60, 90 and 120 degrees:

$$\text{clock-face position average error (degrees)} = |(60 - \theta_{60})| + |(90 - \theta_{90})| + |(120 - \theta_{120})| / 3$$

The average error on the extended arm placement test was calculated from two arbitrary reference angles (below and above the horizontal axis) determined by the subject; hence, the reference angles themselves were computed using the law of cosines from the measured z-value set by the subject.

$$\text{extended arm placement average error (degrees)} = |(\theta_{below} - \theta_{re\text{-}created})| + |(\theta_{above} - \theta_{re\text{-}created})| / 2$$

Taken together, the two motor tasks were similar enough to justify a combined average, yet different enough to provide five unique data points to contribute toward the proprioceptive index. So finally, the average error for the two motor tasks were equally weighted to yield the overall average, which was designated the proprioceptive index.

Statistical Analysis

Pairwise comparisons of the means between two groups were done by the Student's *t*-test. Where more than two groups were compared a one-way ANOVA was utilized. In the comparison by primary sport, due to the limitation of unequal sample size and variance, a Welch's one-way analysis of variance was conducted. Then to determine where the differences occurred between the groups, the Games-Howell post-hoc test was applied to each group pairing to determine significance (11).

Participant Survey

All participants were asked to fill out a brief survey where they i) self-rated their athleticism on a scale of 1-5 (5 being most athletic), ii) listed their primary sport based on degree of personal interest and commitment, iii) indicated participation at a varsity level in any of their competitive sports, and iv) self-reported on their accuracy in carrying out the motor tasks for this study (from 'very good' to 'poor' accuracy).

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