International Journal of
EXERCISE SCIENCE

Original Research

The Impacts of Shoulder Position Sense, Vision, Racket Weight, and Gender on Racket Positioning Accuracy in Tennis Players

KAITLYN COLLINS†, SYDNEY YOUNG†, and YOU-JOU HUNG‡

Department of Physical Therapy, Angelo State University, San Angelo, TX, USA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 13(1): 1086-1097, 2020. Repetitive loading to the shoulder joint can compromise shoulder position sense, which may further contribute to injuries and performance deficits. The first goal of the study was to examine the correlation between shoulder position sense and racket positioning accuracy. The second goal of the study was to examine the impact of visual feedback, racket weight, and gender on racket positioning accuracy in tennis players. Fifty-eight tennis players participated in the study. Active shoulder position sense was examined in 3 abduction (45°, 90°, 135°) and 2 external rotation (45°, 90°) angles. For racket positioning accuracy, participants went through a tennis swing and had the center of the racket touch the ball with full or peripheral vision, and with normal or added (0.6 oz.) racket weight. Low correlation (Pearson's r: from 012 to .381) was found between shoulder position sense and racket positioning accuracy. Shoulder position sense varied among different target angles (p < .001) and the variation was similar between genders (p = .123). Subjects performed better with full vision than with peripheral vision in both racket weight conditions (p < .001). However, racket weight (p = 1.000 for peripheral and p = .362 for full vision) and gender (p = .380) had no impact on racket positioning accuracy. Although the shoulder joint is part of the upper limb kinematic chain, shoulder position sense integrity may not have a direct impact on end-point racket positioning accuracy. Through motor learning, tennis players may have learned to coordinate all upper limb joints and muscles to achieve desired racket positioning accuracy.

KEY WORDS: Kinesthesia, feedback, sex, kinematic chain

INTRODUCTION

Tennis is a popular sport with an estimate of 17.9 million players in the United States alone (29). Due to the nature (repetitive and power driven) of the sport, tennis players often experience a variety of acute and overuse injuries (9, 23, 28). According to Moreno-Pérez et al (2015), shoulder injury is the most common type of upper extremity injury in professional tennis players with the reported incidence between 25% and 47.7% (22). Many factors such as abnormal scapular kinematics (14, 30) and rotator cuff muscle strength imbalance (25, 28) can contribute to shoulder injuries. It is also suggested that proprioception (position sense and movement sense) has a crucial role in controlling shoulder muscles and providing shoulder stability (17). In tennis, overhead movements (such as the cocking phase of the serving motion) can weaken passive shoulder stabilizers (ligaments and joint capsule), therefore compromising shoulder proprioception. Without knowing the precise shoulder position, tennis players may not be able to engage active shoulder stabilizers (such as rotator cuff muscles and deltoids) in a timely fashion to stabilize the shoulder joint and prevent injuries.

From the performance perspective, it is crucial for a tennis player to gather proprioceptive information from the whole upper extremity in order to precisely position the tennis racket at ball contact. Because the shoulder joint is the largest joint in the upper extremity kinematic chain, it is reasonable to hypothesize the acuity of shoulder position sense can have an impact on tennis racket positioning accuracy. Warner et al. (1996) reported that the placement of the hand for upper limb function is partially dependent of joint position and joint motion of the shoulder (34). However, Hung & Darling (2013) found individuals with anterior shoulder instability had similar endpoint reaching accuracy as those with healthy shoulders, suggesting individuals can modify other joints/segments of the kinematic chain to compensate for deficits at the shoulder joint (10). To our knowledge, there is no study that examine the correlation between shoulder position sense and racket positioning accuracy in tennis players.

Vision plays a very important role in daily activities and sports performance (27). Visual information is even more important in sports that demand accuracy in fast movements because proprioceptive feedback may not be fast enough to provide sufficient information for movement correction in those situations (15). Contemori et al (2018) reported that closing a person's eyes significantly reduced static and dynamic shoulder stability in overhead athletes (2). In general, healthy individuals have greater visual sensitivity and shorter response time when the stimulation as presented centrally than peripherally (32). However, peripheral visual information can be processed quickly to detect motion and the visual focus can be directed to other important events in trained athletes (15). For example, tennis players often use peripheral vision to locate the racket but have their visual focus on the other side of the tennis court for their opponent and tennis ball locations. It is unclear if using peripheral vision would greatly hamper racket position accuracy in comparison to using full vision (both central and peripheral vision) for experienced tennis players.

The weight of a tennis racket is another factor that can contribute to sport performance and shoulder injuries. With similar muscle activation, racket weight variation can create different swing torques and outcomes (2). Conversely, to achieve a similar swing torque, the weight of the racket can also have an impact on shoulder muscle activation. Creveaux et al (2013) reported that subjects who used a lighter racket required more muscle activation at the shoulder joint to achieve a similar post-impact tennis ball velocity, which may further lead to muscle fatigue and chronic pain/injuries (4). In addition, the weight of the racket can also have an impact on upper limb proprioception (through varying alpha-gamma co-activation and mechanoreceptor activation) and therefore racket position accuracy. To our knowledge, no study had examine the impact of racket weight on racket position accuracy in tennis players.

Another potential factor that can impact proprioception is gender. Some studies found males performed better on proprioception testing than females in the lower extremity (12, 23, 29). It was suggested that females have smaller anterior cruciate ligaments than males, therefore have less feedback about knee proprioception than males (12, 23, 29). In addition, muscles, tendons, and ligaments have estrogen receptors, and estrogen proliferation has a direct effect on muscle strength and other mechanisms that could have an indirect effect on proprioception (3). On the contrary, other studies found no significant position sense difference between genders (1, 21). It is unclear if gender difference would have an impact on shoulder position sense and racket position accuracy in tennis players.

The purposes of this study were to examine 1) the correlation between shoulder position sense and racket positioning accuracy, 2) to the effects of racket weight on racket positioning accuracy, 3) effects of full versus peripheral vision on racket positioning accuracy, and 4) the effects of gender on shoulder position sense and racket positioning accuracy in tennis players. We hypothesized that there would be a correlation between shoulder position sense and racket positioning accuracy because the shoulder is the largest joint in the upper body kinematic chain. We also hypothesized that racket positioning accuracy would be better with full vision than with peripheral vision due to greater visual sensitivity with full vision. However, there is no convincing evidence to provide strong rationales for the impact of racket weight and gender.

METHODS

Participants

Fifty-eight tennis players (25 males and 33 females, aged 18-71 years) participated in this study. Subjects were recruited from the tennis team of Angelo State University and a tennis club in the local community. To be included for the study, participants had 1) a minimum of 2 years of tennis playing experience, 2) a ranking in the United States Tennis Association or the International Tennis Association, 3) no pain or discomfort moving their examined arm to the target locations, and 4) shoulder range of motion and muscle strength that were within functional limits. Prior to screening and testing procedures, subjects signed the consent form approved by the Institutional Review Board of Angelo State University. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (24).

Protocol

Ascension Technology's trakSTAR electromagnetic tracking system was used to assess shoulder position sense and racket position accuracy. The validity of this system has been well documented (17, 18, 19). Four electromagnetic sensors of the trakSTAR system were secured on the skin over each participant's manubrium, the distal end of the scapular acromion, the lateral epicondyle of the humerus, and the styloid process of the ulna. Additional 2 sensors were secured at the center of the strings of the tennis racket (the ideal contact point) and at the intended targets in space (represented by a tennis ball on a stick). Two tennis rackets (2018 Babolat Pure Drive), with the same strings and tension (55 lbs.) were used for racket position accuracy testing. A 0.6 oz. Tungsten tape was added to the distal end of one racket to increase its weight. The center of the tennis ball and tennis racket were marked with a permanent marker to ensure consistency among testing conditions and subjects.

After giving their consent, all potential participants attended a screening session to ensure that all inclusion criteria were met prior to participation. During the screening, subjects were asked to move their dominant arms to designated target shoulder locations to see if they experienced any pain or discomfort. The target shoulder locations were 45° abduction, 90° abduction, 135° abduction, 90° abduction with 45° external rotation, and 90° abduction with 90° external rotation. Those target locations were chosen because they could be easily comprehended and achieved by the subjects, as well as providing the opportunity to compare data between mid-range and near end-range of motion. To ensure subjects understand the target location, examiners further defined and demonstrated those target angles prior to testing. To avoid motor learning effects, subjects were not allowed to practice in front of a mirror and no feedback was provided to the subjects. Manual muscle testing and range of motion testing for shoulder abductors and internal/external rotators were also performed to see if subjects met the inclusion criteria.

Once the participants were cleared, they proceeded to the official testing. Four electromagnetic sensors were secured to their designated locations with tapes over their dominant arm. For shoulder position sense testing, the starting position was standing with the examined arm resting at their side (0° of abduction) with 90° elbow flexion. The subject was asked to move the dominant arm to the target locations (5 trials per target) in a random order (Figure 1). After staying at a target location for 1 second, the participant returned the examined arm to the starting position. The difference between the target shoulder angles and the actual movement was calculated as active shoulder position errors.

(a) (b)

Figure 1. Final positions for 2 active shoulder position sense testing protocols: (a) target angle of 90° abduction; (b) target angle of 90° external rotation with 90° abduction.

To examine racket position accuracy, the subject was asked to stand in the forehand tennis stance and with the racket in the backswing location as the starting position. The tennis ball (controlled by a stick, Figure 2) was positioned by the examiner in the participant's preferred contact point roughly the height of the iliac crest. After hearing the start signal from the examiner, the subject went through the forehand swing phase with a self-selected speed and positioned the center of the racket to the center of the ball as accurately as possible. After staying at a target location for 1 second, the subject then returned to the starting position. There were 4 conditions for racket position accuracy test: no added weight with full vision, no added weight with peripheral vision, added weight with full vision, added weight with peripheral vision. With the full vision, subjects were asked to turn their heads to face the racket when it made contact with the ball. With the peripheral vision, subjects were asked to look forward (toward the trajectory of the tennis ball) and only use their peripheral vision to align the racket to the ball. With the added weight condition, a 0.6 oz. Tungsten tape was added to the distal end of the racket. Subject performed 5 trials for each condition and the order of the 4 conditions were randomly assigned to each subject. The 3-dimensional (3-D) spatial difference between the sensor on the tennis ball and the sensor on the racket was used for racket position accuracy comparison.

(a) (b)

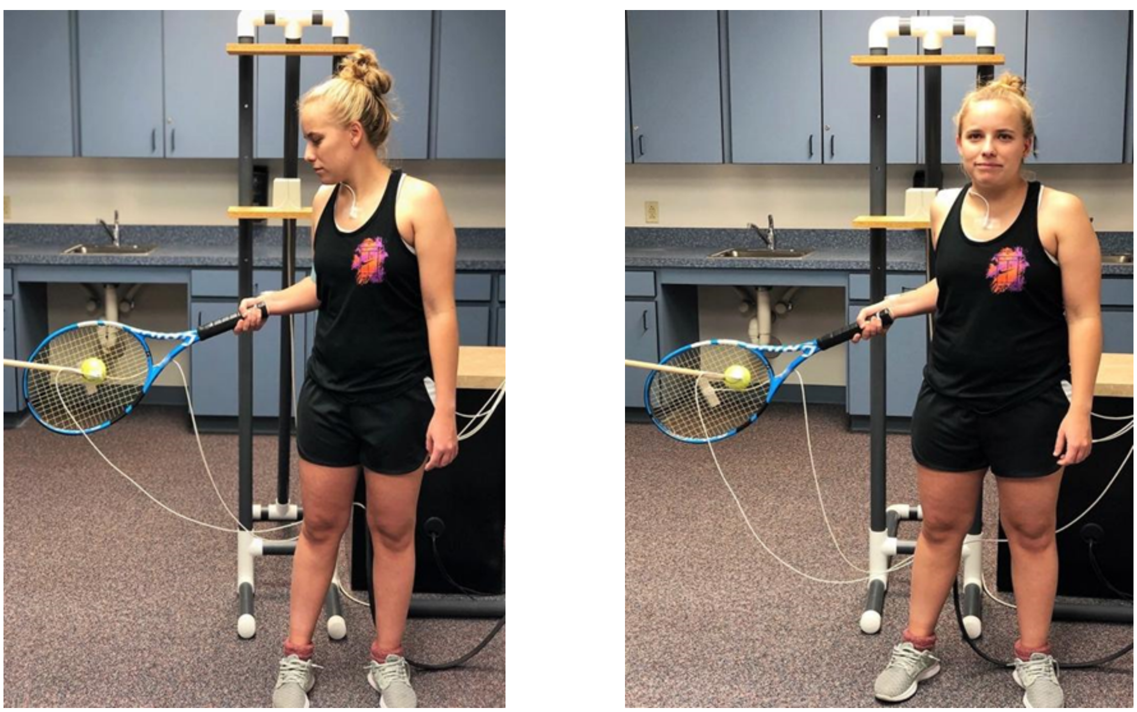

Figure 2. Final positions for 2 tennis racket position accuracy testing protocols: (a) the full vision protocol with the subject turned her head towards the racket; (b) the peripheral vision protocol with the subject looked straight ahead.

Statistical Analysis

The MotionMonitor® software V. 9 (Innovative Sports Training, Inc, Chicago IL) was used to compute shoulder angles and 3-D spatial locations, and IBM SPSS Statistics 21 (IBM Corp, Armonk NY) was used for all statistical analyses. Two-way Analysis of Variance (ANOVA) with one between-group factor (gender) and one within-group factor (shoulder angle and racket/vision condition) was used to analyze active shoulder position sense and racket position accuracy. Pearson Correlation was used to examine the correlation between shoulder position sense and racket position accuracy. Significance level (*p*-value) was set at 0.05 for all comparisons.

RESULTS

Correlation analyses were performed between the 5 active shoulder position sense testing conditions (45°ABD, 90° ABD, 135° ABD, 45° ER, 90° ER) and 4 racket position accuracy conditions (normal weight full vision, normal weight peripheral vision, added weight full vision, added weight peripheral vision). Pearson's r ranges from .012 to .381 in all paired analyses. The result indicates the strength of all correlations between active shoulder position sense and racket position accuracy is considered low (7).

Active shoulder position sense varied among different target angles (F = 10.135, p <.001) and the variation was similar for both genders, as there was no significant angle x gender interaction effect (F =. 842, p = .457, Figure 3). However, position sense errors were similar between genders (F = 2.453, p = .123). Further analyses showed subjects made significantly greater errors when moving their shoulders to 45° (p = .030) and 135° (p < .001) of abduction than to 90° of abduction. There was no significant difference between the position errors in 45° and 135° of abduction (p = .910). In addition, subjects made significantly greater errors when moving their shoulders to 45° of external rotation than to 90° of external rotation (p < .001).

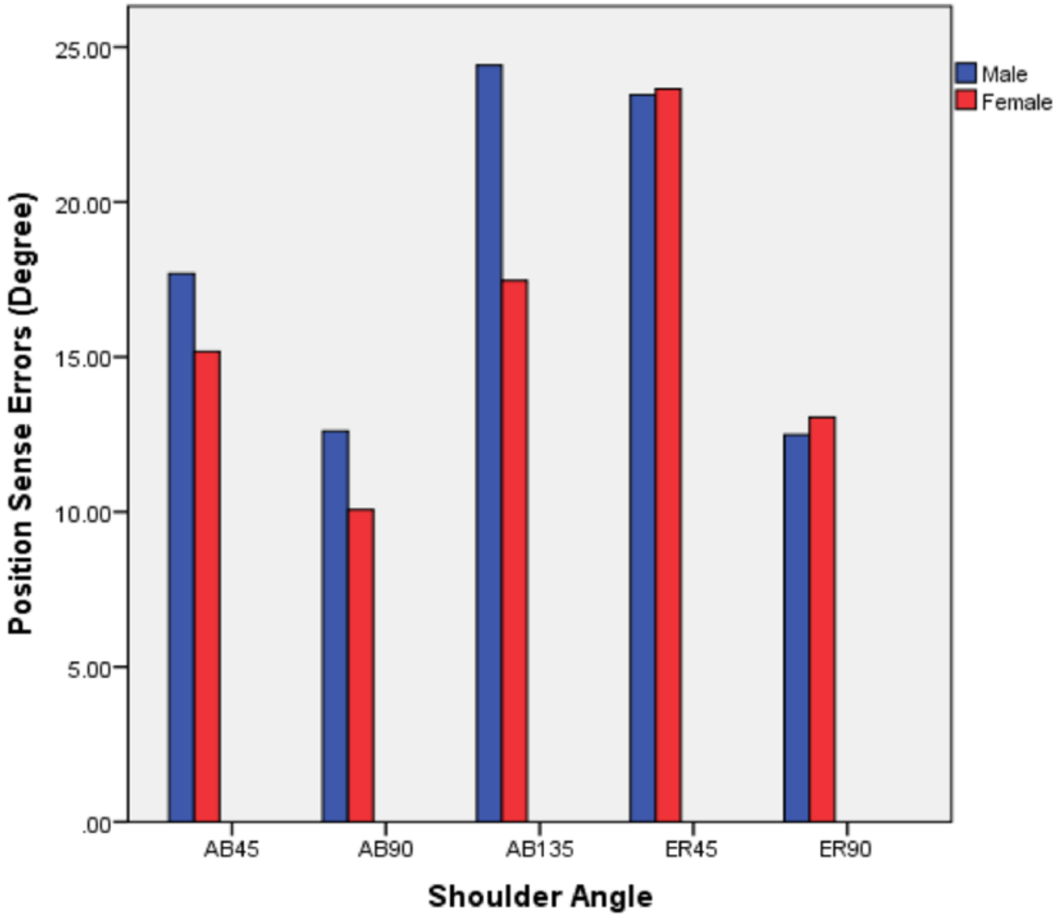

Figure 3. Active shoulder position sense errors (degrees) in male and female tennis players in different target positions and protocols. (ABD45: 45° shoulder abduction; ABD90: 90° shoulder abduction; ABD135: 135° shoulder abduction; ER 45: 45° shoulder external rotation with 90° shoulder abduction; ER90: 90° shoulder external rotation with 90° shoulder abduction)

Racket position accuracy also varied among different testing conditions ($F = 49.099$, $p < .001$) and the variation was similar for both genders, as there was no significant testing x gender interaction effect ($F = 1.037$, $p = .357$, Figure 4). However, racket position accuracy was similar between genders ($F = .782$, $p = .380$). Further analyses showed subjects made significantly greater position errors with peripheral vision than with full vision in both non-weighted ($p < .001$) and weighted ($p < .001$) conditions. In addition, subjects made similar racket position errors between weighted and non-weighted racket conditions with both peripheral ($p = 1.000$) and full ($p = .362$) vision.

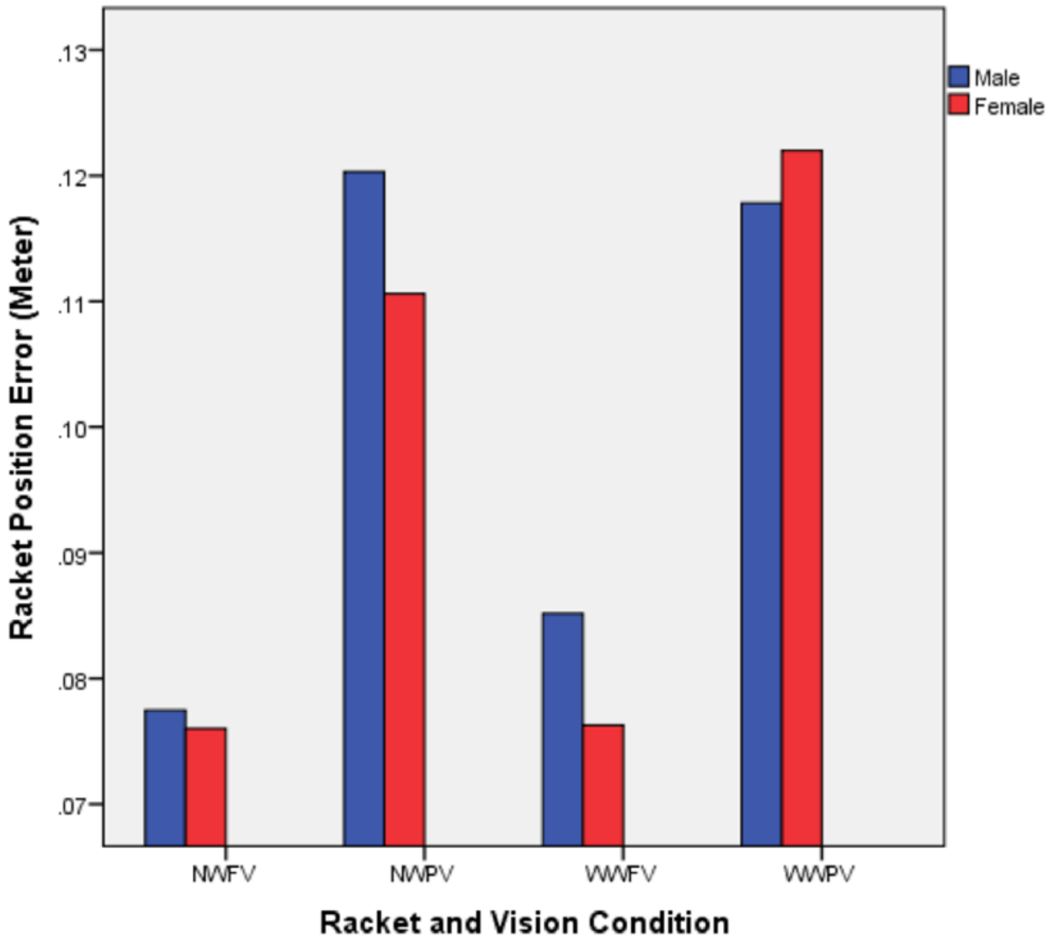

Figure 4. Racket positioning errors (meters) in male and female tennis players with various racket weight and vision protocols. (NWFV: no added weight with full vision; NWPV: no added weight with peripheral vision; WWFV: with added weight with full vision; WWPV: with added weight with peripheral vision)

DISCUSSION

The shoulder joint is the largest joint of the upper extremity and it is reasonable to consider shoulder position sense may play a role in upper extremity kinematics, reaching accuracy, or tennis racket position accuracy. However, results of the present study shows only low correlation between any of the 5 shoulder position sense testing conditions and any of the 4 racket positioning accuracy testing conditions. Considering there are many joints (eg, shoulder, elbow, and wrist) in the upper extremity kinematic chain, it is possible that an individual can use other joints to compensate for a joint's deficit or choose a different movement strategy to accomplish the same goal. For example, Hung & Darling (2013) reported that individuals with anterior shoulder instability can achieve similar endpoint reaching accuracy as those with healthy shoulders but with a different strategy (10). Similarly, tennis players who have shoulder instability or shoulder position sense deficit may not exhibit deficits in racket positioning accuracy or sport performance. Further studies are needed to examine the correlation between shoulder position sense and tennis racket positioning accuracy in a more functional setting with a higher racket swinging velocity.

Tennis players exhibited larger shoulder position sense errors when asked to actively abduct their shoulders to 45° and 135°, compared to 90°. This result is in agreement with Hung & Darling (2012), who used a similar active positioning protocol and found lesser position sense errors at 90° than at 45° and 135° of abduction in both healthy subjects and those with anterior shoulder instability (11). One explanation is that subjects were more familiar with 90° abduction and were used to aligning their arms to horizontal references (such as doing dumbbell lateral raises) than other target angles (5, 6). Another potential explanation is that the arm generates the greatest gravitational torque near 90° abduction. Stronger muscle contractions can enable mechanoreceptors (such as muscle spindles and joint receptors) to provide better information about joint position. The present study also finds tennis players exhibited larger active position sense errors at 45° ER than at 90° ER. This result contradicts what Hung & Darling (2012) found in individuals with anterior shoulder instability (11). One possible explanation is that subjects of the present study are healthy tennis players (overhead athletes) who rotate their shoulders to 90° ER and beyond frequently. Ninety degrees of shoulder external rotation is closer to the end-range than 45° ER, therefore shoulder position sense could be better due to enhanced mechanoreceptors in the joint capsule and ligaments. On the contrary, individuals with anterior shoulder instability could exhibit larger shoulder position sense errors at 90° ER than at 45° ER because the fear of shoulder re-dislocation (or apprehension) could worsen the accuracy of moving the injured shoulder to a vulnerable position (11).

Tennis players exhibited significantly better racket positioning accuracy with full vision (central and peripheral) than with peripheral vision. The results are consistent with other studies that address the importance of utilizing full vision in other functional activities (2, 4). Using full vision can enhance motor control through obtaining a better spatial representation of the target (better extrinsic feedback) as well as providing additional reference of our body/limb position. Moreover, it was established that healthy individuals have greater visual sensitivity and shorter response time when the stimulation as presented centrally than peripherally (32). For the group with full vision, subjects were able to face and tennis ball and racket directly and utilize the central vision component to achieve better racket position accuracy, as well as utilize the peripheral vision component to provide better spatial reference and balance control. In addition to enhancing tennis performance, better racket-ball positioning accuracy may cause less kinematic changes over the forearm (2), thus reduce the repetitive stress to upper limb joints.

Results of the present study shows adding 4 oz. of weight to the distal end of the tennis racket did not have an impact on racket positioning accuracy. Although Creveaux et al (2013) reported a significant difference in upper limb kinetics while using rackets with different weights, their subjects' racket swinging velocity was different as the result of different racket weights (4). Different racket swinging velocity could contribute to varying upper limb kinetics and reaching/position accuracy due to speed-accuracy trade off. For the present study, subjects were asked to move both regular and weighted rackets with a self-selected comfortable speed, which may dampen the true effect of adding weight to the tennis racket. In addition, adding a small amount of weight during a short period of time in the present study (5 trials per condition) may yield less impact than during a longer duration. Tennis matches generally last from over an hour up to five hours (8). Although this duration is not completely taken up by swinging, the rest time is minimal between swings and muscles can quickly reach the fatigue state. With added weight, upper limb muscles may reach the fatigue state earlier, therefore compromising sport performance and/or racket positioning accuracy. On the other hand, prior to the fatigue state, adding weight to the racket may generate greater muscle activation and enhance upper limb proprioception. Moreover, adding weight to the racket may increase the swinging torques and performance. Further studies are needed to examine the impact of additional racket weight at various swinging velocity and muscle fatigue states.

No gender difference was found in all shoulder active position sense testing and racket position accuracy testing protocols. This result is consistent with previous findings that both genders of asymptomatic adults exhibited similar shoulder joint position sense with an active reproduction of active positioning test (21) and with a passive reproduction of passive positioning test (33). In addition, Warner et al (1996) also used an active reproduction test to compare shoulder position sense between genders (34). Despite the direction error differed between genders (females are more likely to overshoot the targets than males), no significant position error difference was found between genders (34). Moreover, the lack of gender difference for shoulder position sense can further explain the lack of gender difference in racket position accuracy because the racket is the distal end of the same upper extremity kinematic chain.

There are a few limitations of the study. Subjects in the present study were asked to move their shoulders to certain target locations and swing the tennis racket with a self-selected comfortable speed. It is not clear whether increasing the movement speed to a competition level would have an impact on the results of both tests, as well as the correlation between their test results. In addition, the tennis ball presented to the subject was fixed to a stick in a stationary position. Tennis racket position accuracy may differ if the racket travels at a speed that is similar to a speed during a match. Considering the functional significance for the sport, it will be beneficial for future studies to examine shoulder position sense with various movement speed, as well as to examine the racket positioning accuracy with a speed that is similar to those during a match with a proper follow-through.

Results of the present study indicate low correlation between shoulder position sense and racket positioning accuracy. Although the shoulder joint is part of the upper limb kinematic chain, shoulder position sense integrity may not have a direct impact on end-point racket positioning accuracy. Clinicians should be aware of that devoting too much resources to enhance shoulder position sense may not provide proportional benefits in end-point positioning accuracy and sport performance. Moreover, racket positioning accuracy was much superior with full vision than with peripheral vision. Clinicians (such as sports physical therapists) should encourage their tennis player patients to use full vision instead of peripheral vision when playing tennis. Using full vision can promote a better racket-ball contact position, therefore provide better kinematics and reduce repetitive stresses over upper body joints.

REFERENCES

1. Artz N, Adams M, Dolan P. Sensorimotor function of the cervical spine in healthy volunteers. Clin Biomech 30(3): 260-268, 2015.

2. Contemori S, Biscarini A, Botti F, Busti D, Panich, R, Pettorossi V. Sensorimotor control of the shoulder in professional volleyball players with isolated infraspinatus muscle atrophy. J Sport Rehabil 27(4): 371-379, 2018.

3. Contreras M, Martínez-Molina A, Santacreu J. Do the sex differences play such an important role in explaining performance in spatial tasks? Pers Individ Differ 52(6): 659-663, 2012.

4. Creveaux T, Dumas R, Chèze L, Macé P, Rogowski I. Influence of racket polar moment on joint loads during tennis forehand drive. Comput Methods Biomech Biomed Engin 16(sup1): 99–101, 2013.

5. Darling WG, Hondzinski JM. Kinesthetic perceptions of earth- and body-fixed axes. Exp Brain Res 126(3): 417–430, 1999.

6. Darling WG, Miller G. Perception of arm orientation in three-dimensional space. Exp Brain Res 102(3): 495-502, 1995.

7. Domholdt, E. Physical therapy research, principles and applications. Philadelphia: WB Saunders; 1993.

8. Fernandez J, Mendez-Villaneuva A, Pluim BM. Intensity of tennis match play. Br J Sports Med. 40(5): 387–391, 2006.

9. Fu MC, Ellenbecker TS, Renstrom PA, Windler GS, Dines DM. Epidemiology of injuries in tennis players. Curr Rev Musculoskelet Med 11(1): 1–5, 2018.

10. Hung Y, Darling WG. Kinesthetically guided reaching accuracy in individuals with a history of traumatic anterior shoulder instability. Orthop Res Rev 5: 43-49, 2013.

11. Hung Y, Darling W. Shoulder position sense during passive matching and active positioning tasks in individuals with anterior shoulder instability. Phys Ther 92(4): 563-573, 2012.

12. Karkousha R. Sex differences of knee joint repositioning accuracy in healthy adolescents. Bull Fac Phys Ther 21(1): 56-60, 2016.

13. Kibler WB. The role of the scapula in athletic shoulder function. Am J Sports Med 26(2): 325–337, 1998.

14. King M, Hau A, Blenkinsop G. The effect of ball impact location on racket and forearm joint angle changes for one-handed tennis backhand groundstrokes. J Sports Sci 35(13): 1231–1238, 2016.

15. Knudson D, Kluka DA. The impact of vision and vision training on sport performance. J Phys Educ Recreat Dance 68(4): 17–24, 1997.

16. Lephart SM, Pincivero DM, Giraido JL, Fu FH. The role of proprioception in the management and rehabilitation of athletic injuries. Am J Sports Med 25(1): 130–137, 1997.

17. Meskers C, Fraterman H, Van Der Helm F, Vermeulen H, Rozing P. Calibration of the "Flock of Birds" electromagnetic tracking device and its application in shoulder motion studies. J Biomech 32: 629 -633, 1999.

18. Meskers C, Vermeulen H, De Groot J, Van Der Helm F, Rozing P. 3D shoulder position measurements using a six-degree- of-freedom electromagnetic tracking device. Clin Biomech (Bristol, Avon) 13(4-5): 280-292, 1998.

19. Milne A, Chess D, Johnson J, King G. Accuracy of an electromagnetic tracking device: a study of the optimal range and metal interference. J Biomech 29: 791 -793, 1996.

20. Mille S. Modern tennis rackets, balls, and surfaces. Br J Sports Med 40(5): 401–405, 2006.

21. Minn S, Côté J. Gender differences in sensorimotor characteristics associated with the performance of a manual dexterity task at shoulder height. J Electromyogr Kinesiol 42: 143-150, 2018.

22. Moreno-Pérez V, Moreside J, Barbado D, Vera-Garcia F. Comparison of shoulder rotation range of motion in professional tennis players with and without history of shoulder pain. Man Ther 20(2): 313-318, 2015.

23. Nagai T, Sell T, Abt J, Lephart S. Reliability, precision, and gender differences in knee internal/external rotation proprioception measurements. Phys Ther Sport 13(4): 233-237, 2012.

24. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1-8, 2019.

25. Niederbracht Y, Shim A, Sloniger M, Paternostro-Bayles M, Short TH. Effects of a shoulder injury prevention strength training program on eccentric external rotator muscle strength and glenohumeral joint imbalance in female overhead activity athletes. J Strength Cond Res 22: 140-145, 2008.

26. Pluim B. Tennis injuries: occurrence, aetiology, and prevention. Br J Sports Med 40(5): 415-423, 2006.

27. Proteau L, Elliott D. Vision and motor control. Amsterdam: North-Holland; 1992.

28. Saccol M, Gracitelli G, da Silva R, Laurino C, Fleury A, Andrade M, da Silva A. Shoulder functional ratio in elite junior tennis players. Phys Ther Sport 11(1): 8-11, 2010.

29. Schmidt L, Depper L, Kerkhoff G. Effects of age, sex and arm on the precision of arm position sense—left-arm superiority in healthy right-handers. Front Hum Neurosci 7: 915, 2013.

30. Struyf J, Nijs J, De Graeve J, Mottram S, Meeusen R. Scapular positioning in overhead athletes with and without shoulder pain: a case–control study. Scand J Med Sci Sports 21(6): 809-818, 2011.

31. Tennis Industry Association. Tennis participation in the US grows to 17.9 million players. Available at: http://www.tennisindustry.org/cms/index.cfm/news/tennis-participation-in-the-us-grows-to-179-million-players/; 2019.

32. Thibaut M, Tran T, Szaffarczyk S, Boucart M. The contribution of central and peripheral vision in scene categorization: a study on people with central vision loss. Vision Res 98: 46-53, 2014.

33. Vafadar A, Côté J, Archambault P. Sex differences in the shoulder joint position sense acuity: a cross-sectional study. BMC Musculoskelet Disord 16: 273, 2015.

34. Warner J, Lephart S, Fu F. Role of proprioception in pathoetiology of shoulder instability. Clin Orthop Relat Res 330: 35-39, 1996.