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Leila Nuri [a], Azadeh Shadmehr [b], Nastaran Ghotbi [a] & Behrouz Attarbashi Moghadam [a]

[a] Sport Physiotherapy Department, School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran

[b] Physiotherapy Department, School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran

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ORIGINAL ARTICLE

Reaction time and anticipatory skill of athletes in open and closed skill-dominated sport

LEILA NURI[1], AZADEH SHADMEHR[2], NASTARAN GHOTBI[1], & BEHROUZ ATTARBASHI MOGHADAM[1]

[1]*Sport Physiotherapy Department, School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran,* [2]*Physiotherapy Department, School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran*

Abstract
In sports, reaction time and anticipatory skill are critical aspects of perceptual abilities. To date, no study has compared reaction time and anticipatory skill of athletes from open and closed skill-dominated sport. Accordingly, the present study investigated whether a difference exists in sensory-cognitive skills between these two different sport domains. Eleven volleyball players and 11 sprinters participated in this experiment. Reaction time and anticipatory skill of both groups were recorded by a custom-made software called SART (speed anticipation and reaction time test). This software consists of six sensory-cognitive tests that evaluate visual choice reaction time, visual complex choice reaction time, auditory choice reaction time, auditory complex choice reaction time, and anticipatory skill of the high speed and low speed of the ball. For each variable, an independent *t*-test was performed. Results suggested that sprinters were better in both auditory reaction times ($P < 0.001$ for both tests) and volleyball players were better in both anticipatory skill tests ($P = 0.007$ and $P = 0.04$ for anticipatory skill of the high speed and low speed of the ball, respectively). However, no significant differences were found in both visual choice reaction time tests ($P > 0.05$ for both visual reaction time tests). It is concluded that athletes have greater sensory-cognitive skills related to their specific sport domain either open or closed.

Keywords: *Reaction time, anticipatory skill, open and closed skill-dominated sport, sensory-cognitive tests*

Introduction

Excellence in sport performance requires not only physical and motor capabilities but also sensory-cognitive skills. Due to high demands of cognitive skills in sports, several studies have ascertained the role of this skill set in sports over recent years (Mann, Williams, Ward, & Janelle, 2007; Williams, 2002). The majority of sports is performed under conditions of stress because of the physical demands, psychological demands, environmental demands, expectations and pressure to perform to a high standard (Gould, Jackson, & Finch, 1993). Under such conditions, athlete's ability to quickly and accurately pick up relevant information will reduce the time of making a decision and will allow more time for preparation of motor behaviour (Savelsbergh, Williams, Van der Kamp, & Ward, 2005; Shim, Carlton, Chow, & Chae, 2005). In sport domains, reaction time (RT) and anticipatory skill are critical aspects of perceptual abilities that have been considered advantageous to the player's successful performance (Mori, Ohtani, & Jmanaka, 2002).

Anticipatory skill plays an important role in successful decision-making (Vaeyens, Lenoir, Williams, & Philippaerts, 2007), particularly in team ball sports such as volleyball, basketball and handball in which players must monitor the activities and positions of multiple players simultaneously. RT has been considered as a key strategy in competitive sports which require fast reactions such as karate (Layton, 1991) and sprint events of athletics (Collet, 1999).

Sports domain classification system is based on the environmental conditions and the task to be

Correspondence: A. Shadmehr, School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran, E-mail: shadmehr@tums.ac.ir

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performed (Knapp, 1963). Sports with a preponderance of closed skills refer to sports in which performance is less dependent on the environment and movements follow set patterns. These skills tend to be self-paced such as in track and field and swimming. Sports with a preponderance of open skill are those that take place in relatively unpredictable and constantly changing environment and movements have to be continually adapted. Various ball games are classified into this group such as volleyball and basketball (Poulton, 1957). In both categories, there is a large range of sporting activities. The degree of environmental stability differs from sport to sport within the same sports category (Gentile, 1987). In open skill-dominated sports, for example, team ball sports like volleyball and basketball are considered more environmentally open than individual open skill-dominated sports like tennis. Consequently, team ball sports players have more relevant information to process simultaneously. In closed skill-dominated sports, sprinting is an example of a sport in which athlete's skills are not much affected by environment.

To our knowledge, over the past 20 years there are a number of studies which have examined the superiority of the skilled athletes over less skilled athletes (Jackson, Warren, & Abernethy, 2006; Williams, Huys, Cañal-Bruland, & Hagemann, 2008). However, no study has directly compared RT and anticipatory skill by athletes from closed skill-dominated and open skill-dominated sports. To investigate if differences in sensory-cognitive skills between these two categories exist, we compared the skills between volleyball players (open skill-dominated sport) and sprinters (closed skill-dominated sport).

Methods

Participants

Eleven volleyball players (in the age range of 20–24) who had played volleyball for a mean of 4.31 years ($SD = 1.45$) and 11 sprinters (in the age range of 20–26) who had played sprinting for a mean of 4.27 years ($SD = 1.47$) participated in this experiment. Before testing, the purpose and procedures were explained to the participants and informed consents were obtained from each person. The study was approved by the ethics committee of the university. All participants were females and right handed, and were currently training in a university club at the collegiate level. They did not have any hearing and visual problems and had normal colour vision and auditory discriminative ability. The exclusion criteria were having a history of previous neuromuscular and musculoskeletal disorders, taking any medication that affects their motor and cognitive performance, drinking any stimulant drinks such as tea, coffee and alcohol before test session, and unwillingness to continue testing.

Apparatus

A high-resolution LCD colour monitor (Samsung syncmaster B243HD 24 inches, Korea), controlled by a laptop computer system (Dell Vostro 1510), was used to display the test. An examiner carried out custom-made RT and anticipatory skill tests from the laptop. The SART software program consists of six sensory-cognitive tests that evaluate visual choice RT, visual complex choice RT, auditory choice RT, auditory complex choice RT, anticipatory skill of the high speed of the ball and anticipatory skill of the low speed of the ball and yields six scores in the areas of visual and auditory RT and anticipatory skill.

Subjects operated a joystick, connected to the laptop, during the sensory-cognitive tests. The software is designed to record the time interval between the appearance of a stimulus on the monitor screen and a response with hand (pressing the button of joystick). The digital chronometer of the software set to the laptop's timer recorded the RT with the accuracy of 1 millisecond.

Inter-rater and test–retest reliability for this custom-made software were assessed. We measured inter-rater reliability using κ and test–retest reliability using intraclass correlation coefficient (ICC). Ten subjects (five sprinters and five volleyball players) were tested. These subjects were not included in the experimental groups. Reliability test sessions consisted of 3 sets of 10 repetitions of each sensory-cognitive test. Measurement of test–retest reliability was taken by an independent sport physiotherapist with no affiliation to the study (time interval 1 week) yielding correlation coefficients ranging from 0.67 to 0.80 (high correlation) for the anticipatory of high speed of ball index, 0.71 to 0.83 (high correlation) for the anticipatory skill of low speed of ball index, 0.52 to 0.69 (moderate correlation) for auditory choice RT index, 0.75 to 0.86 (high correlation) for auditory complex choice RT index, 0.66 to 0.80 (high correlation) for visual complex RT index and 0.53 to 0.69 (moderate correlation) for visual complex choice RT index. The inter-rater reliability was assessed, half an hour apart, by two sport physiotherapists. The inter-rater reliability for visual choice reaction test and visual complex choice RT tests was very good (κ: 0.88 and 0.85, respectively). The inter-rater reliability for the auditory choice RT and auditory complex choice RT tests was good (κ: 0.61 and 0.72, respectively) and for anticipatory skill of the high speed of the ball and anticipatory skill of the low speed of the ball were good and moderate (κ: 0.74 and 0.58, respectively).

Procedure

The measurement was done in a quiet room free from disturbances. Subjects were 2 meters away from the screen with the joystick in the hand. The examiner explained to the subjects how the system and joystick work and made them familiar with joystick's buttons. After being familiarised with the instrument, participants performed several trials of each test. The main test started when the participant was completely familiar with the test procedure. For each participant a new profile was created and each main test was performed in 3 sets of 10 repetitions. The sequence of tests was selected randomly by examiner.

In testing of both visual and auditory RTs, four different coloured circles (green, blue, yellow and red) appeared on the monitor screen. Four keys of the laptop's keyboard were matched with these circles. The examiner randomly selected one of the circles on the screen by pressing a key, matched with the same circle. In visual choice RT, by selecting each circle, the same visible coloured light appeared in the circle on the monitor screen. The subjects responded to the appearance of the coloured circle as fast as possible as follows: if the green light appeared on the monitor screen, the subject pressed the upper button of the joystick (with the thumb). If the red light appeared on the monitor screen, the subject pressed the lower button of the joystick. If the blue light appeared on the monitor screen, the subject pressed the right button of the joystick. If the yellow light appeared on the monitor screen, the subject pressed the left button of the joystick. In the visual complex choice RT, the only difference with previous test was, after appearing light in each circle, the subject pressed the button of the opposite direction. In auditory choice RT test, each circle represented a particular sound (frequency of the sounds of the green, blue, red and yellow circle were in, respectively, 3000 Hz, 7000 Hz, 500 Hz and 1000 Hz). After hearing the sound, the subject pressed the button, matched with the sound as fast as possible. In auditory complex RT, the only difference with previous test was that the same sounds were played in reverse order with respect to the colours. After completion of the test, the results of RT of each trial and the average RT over 30 repetitions were reported to the subject. For the RT tasks, only RTs for correct responses were used for subsequent analysis (more than 90% of 30 repetitions for each participant). If the subject made more than 3 errors in 30 repetitions of auditory and visual RT tests, the examiner repeated the test. The number of additional sets to obtain this amount of correct responses was considered as error rate of RT. In anticipatory skill tests, a soccer ball appeared on the monitor screen, moving from right to left towards the gate and the last part of the path was hidden from view. Based on the speed of the ball, subjects were asked to estimate the moment the ball would reach the gate by pressing the button. In this test, the ball moved at two different constant speeds (high and low) and examiner selected the modes of the speed randomly throughout the repetitions of this test. The SART software calculated the "Total User Tolerance" (TUT) as the difference between the actual time (A) the ball takes to reach the goal and the estimated time (B), A − B. Test results of each trial, average estimated time and error rate were reported to the subject.

All analyses were conducted using the Statistical Package for the Social Sciences version 19 (SPSS Inc, Chicago, IL, USA). The normality of the distributions was assessed with the Kolmogorow–Smirnov goodness-of-fit test. For each variable (visual choice reaction time, visual complex choice RT, auditory choice RT, auditory complex choice RT, anticipatory skill of the high speed of the ball and anticipatory skill of the low speed of the ball), we performed an independent *t*-test, to investigate differences between sprinters and volleyball players. Significance for all statistical tests was accepted at the 0.05 level of probability.

Results

The means and standard deviations of age, height, weight and years of experience of all subjects are presented in Table I. There were no significant differences between two groups in mean age, height, weight and years of experience ($P > 0.05$, independent *t*-test for each variable). Statistical analysis showed significant differences between sprinters and volleyball players on four sensory-cognitive tests. The volleyball players were significantly slower on auditory choice RT $t\ (20) = -7.346$, $P < 0.001$ and auditory complex choice RT $t\ (20) = -5.549$, $P < 0.001$ compared to sprinters. On the other hand, the analysis revealed that volleyball players were significantly better on the anticipatory skill of

Table I. Mean and standard deviation of basic data of sprinters and volleyball players (mean ± SD).

Variable	Sprinters	Volleyball players
Age, years	22.91 ± 2.16	21.64 ± 1.12
Height, cm	163.91 ± 7.27	166.64 ± 4.22
Weight, kg	56.73 ± 6.24	59.64 ± 9.45
Years of experience	4.27 ± 1.47	4.31 ± 1.45

Note. Sprinters ($n = 11$), volleyball players ($n = 11$), $N = 22$.

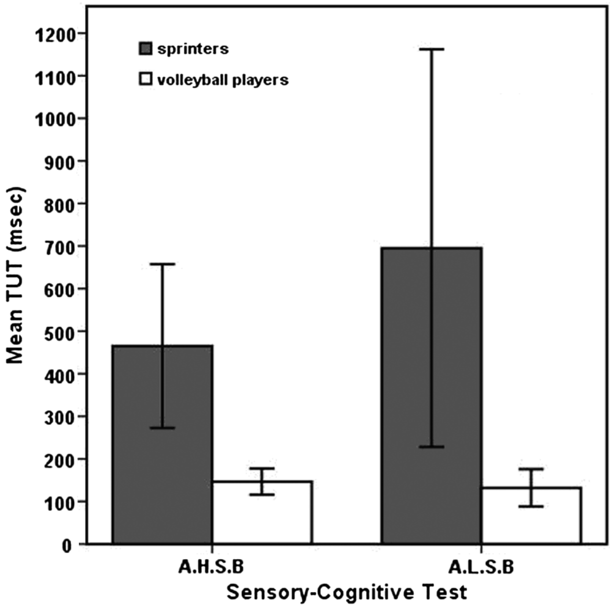

Figure 1. Mean TUT of sprinters and volleyball players for both anticipatory skill tests. A.H.S.B, anticipatory skill of high speed of the ball; A.L.S.B, anticipatory skill of low speed of the ball; msec, milliseconds. Error bars indicate standard errors of mean.

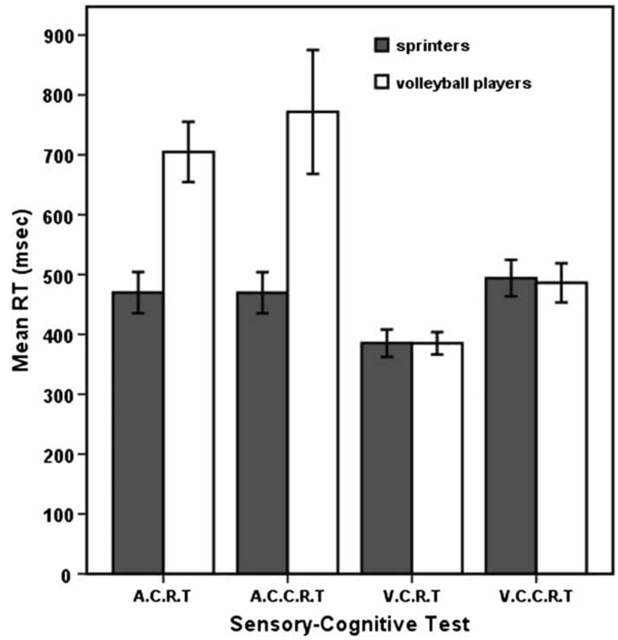

Figure 2. Mean RT of sprinters and volleyball players for different types of sensory-cognitive tests. A.C.R.T, Auditory choice reaction time; A.C.C.R.T, auditory complex choice reaction time; V.C.R.T, visual choice reaction time; V.C.C.R.T, visual complex choice reaction time; msec, milliseconds. Error bars indicate standard errors of mean.

the high speed of the ball t (20) $= 3.36$, $P = 0.007$ and the anticipatory skill of the low speed of the ball t (20) $= 2.35$, $P = 0.04$ than sprinters. Moreover, their TUT scores, yielded by SART in both anticipatory skill tests, were more accurate than sprinters (see Figure 1). Although significant differences were notable in four previous tests between two groups, no significant differences were found in visual choice RT t (20) $= .01$, $P = 0.99$ and visual complex choice RT t (20) $= .36$, $P = 0.72$ between sprinters and volleyball players (see Figure 2). Table II shows all the sensory-cognitive test times for sprinters and volleyball players. Additionally, independent t-test analysis in each group revealed that volleyball players had faster visual RTs than auditory RTs ($P < 0.001$). Similarly, sprinters had faster visual choice RT than both auditory RTs ($P < 0.001$). However, no significant difference was found between visual complex choice RT and both auditory RTs in sprinters ($P > 0.05$). Mean of error rate of both visual RTs for sprinters and volleyball players was 1 ± 0.3; for auditory choice RT and auditory complex choice RT of the sprinters, it was 3 ± 1.2 and 3.5 ± 1.7 and for volleyball players was 1 ± 0.4 and 2 ± 0.7, respectively.

Discussion

Our study was designed to investigate the visual and auditory RT and anticipatory skill of volleyball players (open skill-dominated sport) versus sprinters (closed skill-dominated sport). The number of participants in this experiment was small, 11 sprinters and 11 volleyball players. We compensated the small number of participants by collecting a large number of trials for each participant, 30 responses for each sensory-cognitive test in order to obtain reliable measures of RT and anticipatory skill that would differentiate between the open and closed skill-dominated sport. An important finding in this study was the results of auditory RT, in which volleyball players had significantly slower RT on auditory choice RT and auditory complex choice RT compared to sprinters ($P < 0.001$ for both tests).

Table II. Mean and standard deviation of test times of sprinters and volleyball players (mean ± SD).

Tests	Sprinters	Volleyball players	P-value
Auditory choice RT	474.68 ± 61.74	704.86 ± 83.60	0.000
Auditory complex choice RT	469.68 ± 57.16	771.72 ± 171.25	0.000
Visual choice RT	385.45 ± 37.87	385.27 ± 30.99	0.99
Visual complex choice RT	494.22 ± 50.56	486.18 ± 54.10	0.72
Anticipatory skill of high speed of ball	465.03 ± 318.78	138.24 ± 47.16	0.007
Anticipatory skill of low speed of ball	694.87 ± 774.67	141.48 ± 73.21	0.04

Note. Sprinters ($n = 11$), volleyball players ($n = 11$), $N = 22$. P-value was set at the 0.05 level of probability.

In sprinting, the sound of the starter's gun indicates the start of the race. A fast RT to auditory stimuli is important in sprinting; a longer RT in the period between the firing of the gun and the initiation of movement could change the overall result of sprinting in the competition. During the auditory RT test of SART, examiner's instruction for the subjects in both groups was as follows: after hearing the sound, discriminate it and then respond to it as fast as possible. In response to this instruction, although sprinters responded fast in comparison to volleyball players, their error rate in discrimination of the sound was more than volleyball players and made the examiner to repeat the auditory RT tests several times. For the sprinters, achieving fast RT was more important than answering correctly compared to volleyball players who spent more time for discrimination of the sound to respond correctly. A reason for this could be that sprinters are conditioned to start on some auditory stimuli. During training and competition the start is triggered by, for example, a whistle blow. Since the penalty of auditory RT test of SART against a false response (redoing the test) was not equal to potential disqualification as in real sprinting events, they preferred to make more errors rather than achieving longer RT.

According to the results of the anticipatory skill test in which the value of differences between user RT and average of correct RT was analysed (for both anticipatory skill tests, $P < 0.05$), it is clear that volleyball players anticipated the ball speed better in comparison to sprinters. Volleyball players have been trained in a team ball game in a quite dynamic environment in which they have to continuously predict where the ball is going to be. Thus, their ability in prediction and estimation of ball speed has been trained. Sprinters do not need to predict and estimate the ball speed. Thus, they performed lesser than the volleyball players. Moreover, throughout the anticipatory skill test, most of the volleyball players used different gaze strategies for anticipating the exact moment the ball will reach the gate. They moved their head and eyes, but we could not see any visible strategy by sprinters. Unfortunately, in our study, no eye or head movement measurement was taken. This issue needs to be addressed in future research by employing some advanced technologies like electronic goggles and head movement controller, to clarify the difference of eye and head movement strategy between two groups. Our result was consistent with the nature of the sport, closed skill-dominated sport in which the environment is almost predictable and open skill-dominated in which the unpredictability of the environment forces the athletes to anticipate impending events accurately.

Although we have not found any studies investigating the difference of anticipatory skill between closed and open skill-dominated sport, several studies have investigated the impact of sport-specific practice and development of expert decision-making in team ball sport (Baker, Côté, & Abernethy, 2003a, 2003b). In these studies, researchers found that not only do experts spend more time overall in practice, but they also devote more time in participating in game activities to improve their anticipatory skill and decision-making. This training could explain the specific sensory-cognitive traits exhibited by our subjects.

Furthermore, the results of visual RT test indicated that there were no significant differences between two groups (for both visual RT test, $P > 0.05$). Although volleyball players need to survey their environment by visual search (Wilkinson, 1992) and research has demonstrated that when vision affects performance and decision-making, there are at least three visual perceptual skills that form the foundation of the athlete's capacity for such decision-making: visual search, selective attention and anticipation (Kluka, 1999). In both visual tests in SART the aim was finding their RT to visual stimuli and not their perceptual skill. On the other hand, visual RT may be a skill acquired by athletes over years' practice in a wide range of different sports (Côté, Baker, & Abernethy, 2001; Côté & Hay, 2002), and these skills are fundamental and transferable across sports (closed and open skill-dominated). Another issue is that volleyball players and sprinters had significant faster visual choice RT compared to auditory RT tests. Since the aim of both the RT tests of SART was discrimination of stimulus and then making a response, it could be assumed that discrimination of appearance of the light in coloured circle is easier than discrimination of the sounds with different frequencies. Therefore, the lack of significant differences in visual RT tests between two groups might be due to the lack of difference in visual-cognitive skill of athletes in both domains.

Conclusion

In conclusion, the present study showed that athletes have greater sensory-cognitive skills in their particular domains either open or closed. Volleyball players can anticipate the ball timing task better than sprinters. However, sprinters have faster RT to auditory stimuli in this reaction task.

An important area for future consideration is whether sensory-cognitive skills of athletes from open and closed skill-dominated sports can be improved through these sensory-cognitive tests to facilitate effective transfer of this acquired skill set to both sport domains.

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