

Research article

Differences in ball sports athletes speed discrimination skills before and after exercise induced fatigue

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Abstract

Substantial research exists in relation to the effect of fatigue on the cognitive skills of athletes. Very few studies in the sport domain, however, have investigated decision-making time and accuracy in relation to the discrimination of the speed of a moving object following exercise at maximal intensity. The purpose of this study was to examine differences in the pre- and post-fatigue speed discrimination skills of elite ballgame athletes to determine if they prioritize accuracy or speed of decision-making when physically exhausted. The participants in the study were 163 males (M = 21.17, SD = 4.18) Estonian national level soccer (n = 79), basketball (n = 63) and volleyball (n = 21) players. Peak oxygen uptake (VO_{2max}) was assessed during completion of an incremental exercise test on a treadmill. Speed discrimination stimuli were images of red square-shapes on a grey background presented moving along the sagittal axis at four different virtual velocities on a computer (PC) screen. Repeated measures MANOVA revealed a significant main effect for the decision-making time factor. A second MANOVA revealed a significant main effect for the decision-making accuracy factor. The soccer group made a significantly lower number of errors than the basketball group (p = 0.015) in pre- and post-fatigue decision-making accuracy. The results showed that athletes' decision-making time decreased and decision-making errors increased after a maximal aerobic capacity exercise task. A comparison of the pre- and post-fatigue speed discrimination skills of experienced basketball, volleyball and soccer players indicated that the only significant difference was for decision-making accuracy between the soccer and basketball groups. The current findings clearly demonstrated that the athletes made decisions faster at the expense of accuracy when fatigued.

Key words: Decision-making, perception, exhaustion, elite-athletes.

Introduction

Competition and training induced physical fatigue, as an outcome of involvement in sport, has been shown to affect the motor skill execution of athletes (Aune et al., 2008). Fatigue can be considered as a performance constraint that affects not only motor processing but also the perceptual processing that is linked to the execution of skills required in expert level ball game participation (McMorris and Graydon, 1997; Royal et al., 2006). The performance of perceptual skills involving tasks such as choice reaction time typically improve during the completion of exercise tasks of increasing intensities until maximal energy expenditure is reached (Brisswalter et al., 1997; Chmura et al., 2002; Tomporowski, 2003). Many sports require participants to complete physical activities

that involve moderate and maximal exercise intensities and at the same time perform perceptual motor skills that must be completed as quickly and accurately as possible (Chmura et al., 2002; Rendi et al., 2007). Furthermore, variations in the balance of exercise intensity and psychomotor response requirements between ball game sports may lead to the athletes involved demonstrating different perceptual processing attributes to support their physical and motor performance.

Sport oriented studies investigating the influence of the perceptual-cognitive skills related to visual processing, such as anticipation and pattern recognition, are capable of contributing valuable evidence to better understand the psychophysiological attributes of elite level athletes (Jackson et al., 2006; Williams et al., 2006). One aspect of visual processing that requires further investigation in the sport domain is decision-making time and accuracy in relation to discrimination of the speed of a moving object. Previous research in the neuroscience field has provided a more specific descriptor for this process termed 'speed discrimination' (Clifford et al., 1999; Huang et al., 2008; Overney et al., 2008).

Williams and Ford (2008) provided a detailed overview of the adaptations that may occur to perceptual-cognitive skills as a result of on-going involvement in practice and training. They proposed that "improvements in anticipation and decision-making skill are caused by changes in perceptual-cognitive skills, knowledge, and mechanisms that mediate how the brain and nervous system process information and control performance" (p. 10). Overney et al. (2008) used a set of seven visual discrimination tasks that included a measure of speed discrimination to assess differences in perceptual processing between tennis players, triathletes, and non-athletes. They found that time-related skills, such as speed discrimination, were superior in tennis players. In relation to team ball games, Kioumourtzoglou et al. (1998) reported significant differences between samples of elite and novice level volleyball players in the mean estimation time of the speed and direction of a moving object using computer based stimuli. Differences between the groups were not found in relation to the number of correct responses associated with the identification of the speed and direction of the moving objects. As yet no researchers have found a clear pattern of differences in the perceptual-cognitive processing skills of athletes involved in different sports.

During involvement in the game situation an athlete's cognitive activity is influenced by the level of fatigue. Several theories have been proposed that provide predictions about the effect of physical exertion on cogni-

tive and decision making performance. In particular, Easterbrook's (1959) cue utilisation theory was developed to explain how variations in physical exertion produce changes in attentional processes. At low levels of exertion, cognitive performance may be poor as the individual attends to both relevant and irrelevant cues. As exertion levels increase, attention narrows until it reaches the level when attention is directed toward only task-relevant information. If the physical requirements continue to rise beyond the individual's optimal level, the capacity to focus on task relevant stimuli may be restricted causing cognitive performance to deteriorate. Tomporowski (2003) presented a detailed overview of studies examining the effects of exercise on cognitive function. The major conclusion drawn was that submaximal exercise resulted in an improvement in cognitive tasks such as reaction time and memory, whereas, tasks that involved bouts of exercise leading to voluntary exhaustion did not result in any significant improvement in cognitive performance. Of specific interest was Tomporowski's suggestion that maximal exercise tasks that involved decision-making skills typically resulted in faster response times but no change in the participants' error rates. None of the studies referred to by Tomporowski specifically investigated the effect of fatigue on the performance of speed discrimination tasks.

A number of studies have been completed that focus on fatigue in relation to the cognitive processing of athletes involved in specific sports. McMorris and Graydon (1997) found that the cognitive performance of experienced soccer players while undertaking both moderate and maximal exercise was significantly better than their cognitive performance at rest. The results, however, with respect to the speed-accuracy trade off indicated that the players' improvement in performance was due to quicker decision-making rather than accuracy, which was not significantly affected by exercise. Chmura et al. (2002) reported that improvements occurred in the choice reaction skills of 22 soccer players involved in the Polish Third Division league at each 3 minute assessment point during a progressive workload cycling protocol except for the final assessment at or near the maximum individual exercise workload. Zwierko et al. (2008) used an anaerobic running task, involving 18 Polish Division 2 male handball players, as the physical protocol for the assessment of peripheral perception skills. Players improved in both reaction time and correct reactions after physical effort but also made a higher number of incorrect reactions. These findings highlight that substantial variation exists in the perceptual cognitive responses of athletes following completion of an exercise protocol. In part, this is due to the type of protocol, the level of fatigue induced, and the specific nature of the perceptual cognitive task that the researchers choose to examine athletes' skills.

This study involved the assessment of athletes' de-

cision-making speed and accuracy in relation to the speed of an object moving along the sagittal axis before and after completion of an incremental treadmill test. Specifically, we were evaluating if athletes, following completion of a maximal aerobic capacity exercise task make decisions faster at the expense of accuracy or prioritize accuracy at the expense of speed. A second purpose of this study was to examine differences in the pre- and post-fatigue speed discrimination skills of experienced basketball, volleyball and soccer players.

Methods

Participants

A total of 163 males, aged between 16 and 37 years ($M = 21.17$, $SD = 4.18$) were involved in the study as a component of the routine medical examination associated with their annual registration as a competitor within the Estonian National Sports Championships. The participants in this study were National league soccer ($n = 79$), basketball ($n = 63$) and volleyball ($n = 21$) players in Estonia. All participants consented to be involved in testing in conjunction with the medical assessments. No monetary or other inducements were used to motivate the participants. All participants had normal or corrected to normal vision. The participants were not graded according to their performances within the study and could access their individual results upon request. The permission to undertake the research was given by the Tallinn University ethical committee and the complete data set was available only to the researchers.

Equipment

The participants exercised on a h/p/cosmos pulsar TM 3P 4.0 treadmill (Cosmos Sports & Medical Ltd., Nussdorf-Traunstein, Germany), and a Cosmed Quark CPET pulmonary function analyzer (Cosmed Corporation, Rome, Italy, 2000) was used to measure peak oxygen uptake (VO_{2max}). Speed discrimination stimuli were images of red square-shapes on a grey background presented moving along the sagittal axis at four different virtual velocities on a computer (PC) screen that represented the frontal plane (Table 1). Angular velocity of the stimuli were determined on the basis of the size of the computer screen, the distance the participant is seated from the screen, and by adjusting the maximum exposure time of the image. Participants were seated with a viewing distance of 50 cm from the PC screen. A key element of the simulation involves the square's dimensions changing from 0 pixels through to 130 pixels on each side during the presented stimulus (Thomson, 2001; Stamm et al., 2005). In this experiment, the stimuli were generated using a PC P4 1.6 GHz processor and DELL UltraScan P791 17" flat screen monitor. The screen resolution was set for 640 x 480 pixels and refresh rate to 85 Hz. To

Table 1. The parameters of stimuli.

Expected Keyboard Response	Max exposure time (s)	Angular velocities (rad/s)
Right shift key (Fast)	.65	.39
Left shift key (Slow 1)	1.04	0.24
Left shift key (Slow 2)	1.55	0.16
Left shift key (Slow 3)	2.06	0.12

Table 2. Means (standard deviations) and F-values for the total sample pre and post-fatigue.

Variables	Pre-fatigue	Post-fatigue	F-value (p)
Decision-making time (s)	.59 (.09)	.56 (.08)	29.931 (<.001)
Decision-making accuracy (errors)	1.10 (1.07)	1.80 (1.30)	45.498 (<.001)

prevent motion after-effects of the viewed stimuli, it is necessary to have an interstimulus interval of at least 1000 ms (Lakshminarayanan et al., 2005). In the present experiment, the interstimulus interval varied randomly between 1000 to 3000 ms.

Procedure

The treadmill test: The treadmill test started with a 10-minute warm-up run at a speed of 2m/s. The gradient for the treadmill test was set a zero degrees. Each interval period was 3 min and the speed was increased by 0.5 m/s (from a commencement speed of 2.5 m/s). The session lasted until the participant is exhausted. Exhaustion was demonstrated by either a plateau in the participants' VO_{2max} even though there was an increase in the workload, a respiratory exchange ratio of greater than 1.15, or when the participant reported they were unable to continue with the test. The average time to reach exhaustion for the incremental exercise test for the entire sample was 26:50 min, 29:34 min for the soccer group, 24:14 min for the basketball group, and 24:24 min for the volleyball group.

Speed discrimination: Speed discrimination ability was assessed 1 min before and after the treadmill test. Participants were seated and asked to commence the speed discrimination demonstration module before commencing the assessment module. During the demonstration module, participants were shown three examples of each of the four velocities. Each velocity was presented in random order and in the demonstration module the participants were given exact information regarding which is the correct "Shift" key on the PC keyboard to push (left shift – slow speeds; right shift – fast speed) for the current stimulus (Table 1). Response to the four velocities, which includes three different velocities categorized as slow and only one as fast, is made on the basis that simplifying the response requirements in using only two keys better addressed the aim of the test in assessing perceptual performance rather than the memorial skills associated with the encoding and retrieval of task requirement information. In the assessment module participants completed the task using the same stimulus presentation and response methods as the demonstration module but without feed-back pertaining to correct answers. Participants were asked to identify the stimulus speeds as quickly and accurately as possible and to push the "Shift" key that corresponds to their decision. During the presentation of stimulus phase, the subsequent stimulus did not present until

the participant provides a keyboard response for the current stimulus. Two non-scored practice trials were completed to provide participants with an adequate opportunity to become familiar with the task, so that the third, and only scored presentation of the assessment module, evaluated speed discrimination skill rather than learning. Decision-making time was calculated as the average response time to identify the stimuli. Decision-making accuracy was reported as the total number of errors made in identifying the stimuli.

Statistical analysis

All statistical procedures were completed using SPSS (Version 16.0, SPSS Inc. Headquarters, Chicago, IL). Means and standard deviations were calculated as descriptive statistics for all dependent variables and groups. A repeated measures multivariate analysis of variance (MANOVA) was used to analyze both the overall and between sport groups differences for the pre-fatigue and post-fatigue decision-making time and accuracy scores. A preset alpha level of $\alpha = 0.05$ was used for all statistical procedures. Significant main effects were further analyzed using the Bonferroni corrected level of significance for the Post Hoc between sport group comparisons.

Results

Means and standards deviations for each dependent variable are presented for the total sample (Table 2) and for each sport group (Table 3). A repeated measures MANOVA revealed a significant main effect for the decision-making time factor, Wilks' $\Lambda = 0.84$, $F(1, 160) = 29.931$, $p < 0.000$, $\eta^2 = 0.16$. A second MANOVA revealed a significant main effect for the decision-making accuracy factor, Wilks' $\Lambda = 0.78$, $F(1, 160) = 45.498$, $p < 0.000$, $\eta^2 = 0.22$. Analysis of variance (ANOVA) was conducted on each dependent variable as a follow-up test to the MANOVA and results showed only a significant between group difference for decision-making accuracy. Using a traditional Bonferroni procedure, to control for type 1 error, each follow-up ANOVA was tested at the 0.017 level (.05 divided by the number of groups). Post hoc analyses to the ANOVAs consisted of conducting pairwise comparisons to find differences between the ball game sport groups in decision-making accuracy. The soccer group participants reported a significantly lower number of errors than the basketball group ($p = 0.015$) in pre- and post-fatigue decision-making accuracy.

Table 3. Means (standard deviations) and ANOVA results for sport groups pre and post-fatigue.

Variable	Sport Group			ANOVA	
	Soccer (n = 79)	Basketball (n = 63)	Volleyball (n = 21)	F-value	p
Decision-making time (Pre) (s)	.58 (.09)	.60 (0.09)	.59 (.10)	1.300	.275
Decision-making time (Post) (s)	.55 (.08)	.57 (.09)	.55 (.07)		
Decision-making accuracy, (Pre) (errors)	1.10 (1.10)	1.3 (1.05)	0.90 (0.96)	4.297	.015
Decision-making accuracy (Post) (errors)	1.50 (1.20)	2.2 (1.30)	1.8 (1.53)		

Discussion

In the present study, we investigated the effect of fatigue, induced using an incremental exercise test, on the speed discrimination skills of elite level ball games athletes. Speed discrimination was assessed on the basis of decision-making time and error rate in relation to the speed of a computer generated image of a square moving along the sagittal axis. The results showed that athletes' decision-making time decreased and decision-making errors increased after a maximal aerobic capacity exercise task. A comparison of the pre and post-fatigue speed discrimination skills of experienced basketball, volleyball and soccer players indicated that the only significant difference was for decision-making accuracy between the soccer and basketball groups.

The current findings clearly demonstrated that the athletes made decisions faster at the expense of accuracy when fatigued. Only one of the previous studies reviewed, involving athletes completing endurance tasks to exhaustion, reported an increase in choice reaction errors, and an accompanying increase in reaction time. Decrements in the psychomotor performance of the sample of soccer players occurred only during the very final phase of the maximal endurance task (Chmura et al., 2002). Zwierko et al. (2008) also found an increase in errors at exhaustion by handball players, however, there was also an accompanying increase in correct reactions and improvement in response speed. These findings are in contrast to the results of McMorris and Graydon (1997) who found that soccer players' speed of decision-making improved at maximal exercise intensity, with no corresponding deterioration in accuracy. The reviews of Brisswalter et al. (2002) and Tomporowski (2003) support the proposition that following engagement in moderate levels of aerobic, steady state exercise, cognitive response speeds increase and error rates are unchanged, however, they concluded the pattern is less clear at maximal exercise intensities. Additionally, Royal et al. (2006) highlighted that task specificity may affect the accuracy of responses. Tasks that have a greater meaning to an athlete, rather than those representative of general information processing, may provide a basis for better attentional focus or arousal control in cognitive performance at the highest levels of physical exertion. In the current study, the speed-discrimination task was not sport-related and novel to the participants. Consequently, at the maximal level of aerobic output athletes may have been able to complete the task rapidly but were unable to demonstrate the processing resources required to answer the items with improved accuracy. This result is also in line with the cue utilization theory (Easterbrook, 1959), whereby, the athletes in the highly fatigued state were able to complete the speed discrimination task quickly but were unable to successfully attend to the relevant cues necessary to make decisions as accurately as in the non-fatigued state.

Results of the comparison of the speed discrimination skills of the ballgame athletes, showed only the number of decision-making errors of the soccer and volleyball groups differed significantly following the incremental exercise test. As yet, no investigations appear to have

contrasted the cognitive skills of elite level athletes grouped according to their sport before and after a maximal exhaustion test. Several sport group studies have, however, undertaken perceptual-cognitive comparisons without using exercise protocols. Kioumourtzoglou et al. (1998) reported differences in the choice reaction time skills of expert ball games athletes, with volleyball players reacting fastest and basketball players recording the highest number of correct responses. Overney et al. (2008) found that tennis players had better speed discrimination skills than triathletes. Although both these studies demonstrated that differences in the perceptual cognitive skills of athletes from different sports exist, no specific conclusions as to the basis for the observed variations were generated. In relation to the current findings, one possible reason for the fewer errors made by the soccer players post-fatigue may be that physical performance requirements of soccer may be most closely aligned to the physical requirements of the exercise protocol. Following completion of the exhaustion protocol, soccer players may recover more quickly and therefore were able to retain sufficient cognitive processing to complete the speed discrimination task with fewer errors. This is in line with the suggestion of Covassin et al. (2007) that following maximal exercise differences in recovery rates may lead to differences in neurocognitive performance by individuals in the fatigued state.

Overall, the pattern of results found in this study reflect the possibility that as the physiological requirements of a physical task increase to the maximal capacities of the individual, then the ability to maintain optimal attentional focus on a cognitive activity being performed simultaneously is diminished (Brisswalter et al., 1997). Furthermore, the better post-fatigue speed discrimination skills of the soccer group may demonstrate an adaptation to the requirements of maintaining attentional focus on the cognitive elements of their sport while engaging in physical workloads greater than either the basketball or volleyball groups. This is in line with the general ideas of Williams and Ford (2008) who propose that as result of long-term engagement in training and practice athletes adapt to the specific constraints of the performance environment. In the case of our findings, it could be suggested that the soccer group, as an outcome of the perceptual-cognitive and physical requirements of their sport demonstrated an adaptation that was advantageous in the completion of the speed discrimination task at maximal exercise intensity.

The present study was limited as an outcome of the restricted access to participants. The data collection phase was completed in conjunction with the overall medical assessment of the athletes' associated with their player registration and it was not possible to organize post-test assessments (e.g., 15 min or 30 min after completion). A more comparative data set could also have been achieved by the use of a control group and the assessment of speed discrimination skills at several points during the exercise protocol (e.g., 25%, 50% and 75% of maximal workload). Finally, the analysis of speed discrimination skill differences between sport groups may have benefitted from contrasts on the basis of the actual duration time of

athletes in reaching maximal exercise intensity.

Future research should be undertaken that involves athletes from different sports that have similar aerobic or anaerobic requirements. The use of a multilevel investigation of the speed discrimination skills of athletes at varying levels of workload intensity that incorporates a control group, several groups from highly aerobic sports, and several groups from highly anaerobic sports would serve to provide a more thorough analysis of the contrasts and similarities of the decision-making speed and accuracy of elite level athletes during exercise. The resultant information may provide a useful insight for coaches and trainers to consider in relation to both competition and training settings as to the manner in which players respond to the cognitive requirements of their sport during periods of high physical workload.

Conclusion

These findings showed that in the case of elite level ballgames athletes that decision-making speed and accuracy of a computer based perceptual-cognitive task deteriorated following maximal intensity exercise. Previous studies involving similar cognition related activities have typically reported improvements in decision-making speed but no changes in accuracy at submaximal workload intensities but the findings are less clear when the testing incorporated a VO_{2max} protocol. Furthermore, significant post-fatigue differences between national level players participating in soccer, basketball, and volleyball were found only in relation to decision-making accuracy. Continuing investigation of the speed discrimination skills of athletes at varying exercise intensities will serve to assist in the clarification of the exact pattern of the cognitive responses of athletes as they experience fatigue. Coaches and trainers involved in ballgame sports may benefit from this knowledge as they endeavor to manage the workload levels of athletes to optimize both physical and cognitive performance.

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Key points

- The purpose of this study was to examine differences in the pre- and post-fatigue speed discrimination skills of elite ballgames athletes to determine if they prioritize accuracy or speed of decision-making when physically exhausted.
- Speed discrimination stimuli were images of red square-shapes on a grey background presented moving along the sagittal axis at four different virtual velocities on a computer (PC) screen that represented the frontal plane.
- The participants exercised on a treadmill to level of 100% of peak oxygen uptake (VO_{2max}).
- Repeated measures MANOVA revealed significant main effects for both the decision-making time and accuracy factors. The current findings clearly demonstrated that the athletes made decisions faster but with greater errors when fatigued
- Post hoc analyses of the differences between the ball game sport groups indicated that soccer group participants reported a significantly lower number of errors than the basketball group ($p = .015$) in pre- and post-fatigue decision-making accuracy.
- Further investigations are required to clarify the equivocal set of previous findings regarding the relationship between the cognitive function of athletes at varying physical workload intensities.

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