Influence of Exercise Intensity on the Decision-Making Performance of Experienced and Inexperienced Soccer Players

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The aim of this study was to examine the decision-making performance of experienced and inexperienced soccer players at four exercise intensities (rest, 40%, 60%, and 80% maximal aerobic power). The decision-making performance of inexperienced players was expected to demonstrate an inverted-U shape with increasing levels of exercise. For the experienced players, decision making was predicted to show no change in performance with increased exercise intensity. Thirty-two adult soccer players (16 experienced, 16 inexperienced) were asked to answer seven decision-making questions as quickly and accurately as possible for each exercise intensity. Results indicated that exercise does not affect the accuracy of decision making; however, the speed of decision making for experienced and inexperienced players improved with increased exercise intensity. These results suggest that physiologically induced arousal only affects speed of decision making.

Keywords: expertise, arousal, exercise, decision making, Yerkes-Dodson hypothesis

Research on expertise that is conducted in settings where exercise intensity does not vary indicates that many elements of the information-processing model including perceptual skills, knowledge base, decision making, and motor skill execution strongly influence sport performance (Abernethy, Wood, & Parks, 1999; McPherson, 1999; McMorris & Beazeley, 1997; Schneider, Bjorklund, & Maier-Bruckner, 1996; Williams & Davids, 1998). However, in sports, players engage in
exercise of various intensities. Although research on the influence of expertise on information processing during sport performance is quite substantial, little research has been conducted under situations in which the participants are exposed to different exercise intensities. Consequently, the purpose of this study was to examine the effect of exercise intensity on the decision-making performance of experienced and inexperienced soccer players.

Research investigating how decision-making performance during the game differs dependent upon level of exercise intensity has drawn upon three competing theories: the Yerkes and Dodson hypothesis, drive theory, and Kahneman’s allocation of resources theory (for a review, see Tomporowski & Ellis, 1986). The Yerkes–Dodson hypothesis (1908) states that cognitive performance shows an inverted-U shape with increased levels of psychological arousal. This hypothesis predicts that as arousal increases, cognitive performance improves up to a point but deteriorates with further increase in arousal.

Whereas explanations based on the Yerkes and Dodson hypothesis focus mostly on the influence of arousal on decision making during game situations, drive theory (Sanders, 1983; Spence & Spence, 1966) predicts that performance is a function of drive and habit. Drive refers to the current level of arousal, whereas habit refers to the level of skill acquisition. Consequently, the effect of arousal on cognitive performance depends on the level of skill acquisition. As arousal increases, cognitive performance is predicted to deteriorate during a novel situation but enhance for well-learned tasks. Another contradiction to the Yerkes–Dodson hypothesis is that the drive theory predicts high levels of arousal impair cognitive performance only for novel tasks. For experienced performers, drive theory predicts high levels of performance with high levels of arousal.

In contrast to the two previous theories, the allocation of resources theory places more emphasis on effort (Kahneman, 1973). This theory presupposes that the attentional capacity of an individual is limited. However, the individual can allocate resources to task-relevant information with such freedom that under conditions in which arousal is not optimal, allocation of resources can offset the effects of arousal, and performance may still be optimal. Consequently, decision-making performance at low levels of arousal can be similar to the optimal level with a more efficient allocation of effort. However, a more efficient allocation of resources is not possible when the demands of the task exceed the available attention capacity, as is the case in very high arousal levels. For such cases, decision-making performance is expected to deteriorate.

In a series of experiments, McMorris and Graydon (1996a, 1996b, 1997) and McMorris et al. (1999) examined the predictive power of these theories for sport-specific information processing. They investigated the decision-making performance of experienced soccer players at three exercise intensities: rest, 70% maximal power output (moderate exercise), and 100% maximal power output (maximum exercise). Inexperienced soccer players were included only in their first experiment (McMorris & Graydon, 1996a). At each stage, two measures were recorded: accuracy and speed of decision making. A common pattern of results is evident throughout these experiments. For experienced players, the accuracy of decision making was not affected by exercise whereas the speed of decision making improved from rest to moderate exercise but no deterioration of performance was found with maximal exercise (exceptions to this pattern are
presented in Note 1, herein). Similar results were achieved for inexperienced players, except that significant improvement in decision-making performance was only noticed in the maximal exercise condition (McMorris & Graydon, 1996a).

The results of the series of experiments by McMorris and Graydon do not clearly support any of the three theories. For example, improvement in the accuracy of decision-making performance from rest to moderate intensity and the deterioration of accuracy and speed of decision-making performance during maximal exercise did not occur as predicted by the Yerkes–Dodson hypothesis. Opposed to claims by drive theory proponents, the accuracy of decision making for experienced players did not improve as exercise intensity increased and the speed of decision making for inexperienced players did not deteriorate at the maximal exercise condition. There was no deterioration of the accuracy and speed of decision making during maximal performance as predicted by allocation of resources theory proponents. In addition, the allocation of resources theory does not explain the dissociation of accuracy and speed of decision making during the rest and moderate exercise conditions. A more efficient allocation of resources during rest could explain the failure of decision making to show less accurate responses, but then it fails to explain the superior speed of decision-making performance during moderate exercise.

It is possible that a lack of support for one of the theories may be due to methodological limitations present in the McMorris and Graydon (1996a, 1996b, 1997) and McMorris et al. (1999) studies. Thus, methodological limitations may have masked the results. Methodological limitations in the decision-making instrument and exercise protocol are present in the series of experiments conducted by McMorris and colleagues in comparison with the instruments used in the current study.

The decision-making instrument had two shortcomings: alternate test forms that were nearly identical with poor ecological validity. The alternate forms of the decision-making instrument used by McMorris and Graydon (1996a, 1996b, 1997) and McMorris et al. (1999) displayed soccer decision-making situations that were identical except for placement on the field. The use of test forms with identical situations might explain the lack of support for the hypothesized decision-making performance. It is possible that decision-making accuracy was not affected by exercise intensity because the participants, noticing the situations were the same, chose the same answers. It is also possible that improvements in decision-making speed were due solely to participants repeating answers from one exercise condition to the next. The instrument chosen for this experiment uses alternate test forms with completely different situations. Validity and reliability of the instrument used in the current experiment have been tested extensively (Fontana, 2004).

Second, the decision-making instrument used by McMorris and Graydon (1996a, 1996b, 1997) and McMorris et al. (1999) was not ecologically valid. It consisted of a tachistoscopic presentation of slides of soccer game situations that were made using model soccer players set on a table tennis top. Tachistoscopically presented tests have been criticized for poor ecological validity owing to static presentation in contrast to the dynamic display of the actual game situations (Helsen & Pauwels, 1988). The instrument chosen for the current experiment
improves ecological validity by using videotape segments taken from World Cup
soccer matches. The advantage of video clips over slides is that participants are
able to follow developing plays and therefore are able to observe a greater number
of cues to determine the most appropriate action. The ideal scenario is to use an
instrument in which decision making is measured during game play. In soccer,
however, the number of extraneous variables is so large and the ability to control
the situation across trials so difficult that such an instrument has yet to be
developed.

The exercise protocol used by McMorris and Graydon (1996a, 1996b, 1997)
and McMorris et al. (1999) had one limitation. It exposed participants to a fixed
sequence of exercise intensities from rest to 100% maximal power output. During
soccer matches, the exercise performed by players varies greatly in intensity.
Thus, to better simulate soccer matches, participants in this experiment were
exposed to different exercise intensity sequences. In addition, counterbalancing
exercise intensity assisted in controlling order effects.

Owing to refined decision-making and exercise protocols, it is hypothesized
that exercise will affect the decision-making performance of experienced and
inexperienced players differently. For the inexperienced players, it is predicted
that the accuracy and speed of decision making will demonstrate an inverted-U
shape with increasing levels of exercise. For the experienced players, owing to the
automaticity of information processing, the accuracy and speed of decision
making are predicted to show no change in performance with increased exercise
intensity. It is also hypothesized that experienced soccer players will show faster
and more accurate decision-making performance than inexperienced soccer play-
ers across exercise conditions.

**Methods**

**Participants**

Thirty-two college male soccer players (16 experienced, mean age = 21.13 years,
SD = 1.62; 16 inexperienced, mean age = 19.54 years, SD = 1.14) participated in
the study. Experienced players were selected based on two criteria. They needed
to be members of a college soccer team from a Division-I university, and have
eight or more years of competitive experience. (Division I is the highest level of
intercollegiate competition in the United States.) Experienced players had an
average of 13.78 years (SD = 1.57) including their college and high school soccer
experience. Inexperienced soccer players were selected from among college stu-
dents who did not play soccer for their high school team or play competitive
soccer since leaving high school and had a minimum of one and a maximum of
four years of soccer experience. Inexperienced soccer players had an average of
2.38 years (SD = 1.08) of organized soccer experience, all of which were accrued
before entering high school. It was important that inexperienced players had lim-
ited experience with soccer because individuals without any experience are likely
to answer decision-making problems at random. Choosing answers randomly is
likely to mask the effects of exercise on decision making. Before the start of the
experiment, all participants signed the informed consent form, and their health
was screened with the use of a medical questionnaire.
Procedures

Testing was divided into three phases. During the first phase, the decision-making instrument was developed. In the second phase, the fitness test was conducted followed 3 to 8 days later by the third phase, the decision-making test.

The Fontana–Gallagher Decision-Making Instrument. During the first phase, a methodological design consisting of two stages was adopted to develop a valid and reliable decision-making instrument. The aim of the first stage was to establish the basic format of the test and determine content validity. Three major steps were completed in this stage. The first step referred to the development of the decision-making situations. Decision-making situations consisted of video clips of critical decision-making situations found in soccer matches. Based on an extensive review of the soccer coaching literature, the investigators developed 59 decision-making clips. Video clips were developed using the software Adobe Premiere 6.0 with a speed of 29.97 frames per second. Each clip was 12 s in length. When the decision point is reached, the video freezes and four possible two-word decision sentences are immediately displayed on the screen (e.g., pass right, shoot goal, cross left, and dribble forward).

The second step consisted of establishing the content validity of the clips. Content validity was assessed based on the review by three expert soccer players with more than 20 years of soccer experience at the college and professional levels. Players reviewed the clips independently, and subsequently discussed their answers. Decisions were ranked from least to most appropriate. Four points was associated with the most appropriate action, 3 with the second, 2 with the third, and 1 with the least appropriate action. If agreement was not reached by all reviewers, discussion of the play, moderated by the lead investigator, followed. Four clips were eliminated from the study when agreement among reviewers was not reached. A total of 55 plays were left in the pool of clips.

The third step consisted of establishing the basic format of the test. Item discrimination, item-to-total correlation, and item difficulty index were computed on the responses to the clips of 18 inexperienced and 18 college soccer players. The final number of clips required for the final decision-making instrument was 28 separated into four alternate forms with 7 clips each. Twenty-four clips were excluded based on negative item discrimination and item-to-total correlation lower than .2. Discriminating between experienced and inexperienced players was a required function of the items. A final pool of 28 clips was selected and grouped in four equivalent test forms based on the item difficulty index.

With the basic format of the test developed, the second stage was conducted to determine the reliability of the four forms of the test. Thirty-two subjects categorized into four groups—novices (no experience), intermediate novices (up to 4 years of soccer experience), intermediate experts (competitive high school experience), and experts (competitive college experience)—and were subsequently tested during this phase. Alternate-forms reliability was used to show equivalence among the four test forms created in Phase I. Six Pearson product–moment correlations were computed. All correlations were significant at the .01 level and greater than .7, indicating that the four test forms could be used interchangeably. Internally consistent reliability estimated by Cronbach’s alpha was high (α = .92). In addition, based on the results of a 4 × 4 (Level of Experience × Test Forms)
ANOVA with repeated measures on test forms, the main effect for forms was not significant, \( F(3, 84) = .44, p = .73 \), supporting the equivalence among test forms. This analysis also yielded a main effect for groups, \( F(3, 28) = 9.75, p < .01 \). College soccer players were more accurate than any of the other three groups (intermediate experts, intermediate novices, and novices). Discrimination between experts and intermediate novice players provides substantial evidence for the use of this instrument in the current study.

The final video product, the Fontana–Gallagher Soccer Decision-Making Instrument, contains four equivalent test forms. Each alternate test form consists of seven decision-making video clips with two 6-s intervals between Questions 3 and 4, and Questions 5 and 6. To avoid order effects, alternate test forms were counterbalanced among exercise condition sequences.

**Fitness Test.** The purpose of fitness testing was to determine the participants’ fitness level using the Bruce treadmill protocol. In the Bruce protocol, participants walked/ran on a Trackmaster TMX 425C treadmill until they were unable to continue. The Bruce protocol consists of seven stages lasting 3 min each. The speed and incline progressively increase with each stage. During the Bruce protocol test, \( \text{VO}_2 \) and heart rate were recorded every 30 s. Heart rate (bpm) was measured with a Polar Monitoring System (Woodbury, NY). An open-circuit respiratory metabolic system (True Max 2400, Parvo Medics, Salt Lake City, UT) was used to measure maximal aerobic capacity (\( \text{VO}_2 \)). Test termination criteria consisted of any of the following: (a) a change in \( \text{VO}_2 \) of \(<2.1 \text{ mL·kg}^{-1}·\text{min}^{-1}\) with increasing exercise intensity; (b) a respiratory exchange ratio (RER) of \( \geq 1.10 \) (defined as ratio of \( \text{CO}_2/\text{O}_2 \)); or (c) heart rate \( \pm 5 \text{ bpm} \) of the age-predicted maximum at the end of the exercise test. After completion of the test, participants cooled down at 2.0 mph and 0% grade for 3 min or until heart rate decreased to \(<110 \text{ bpm} \).

Once the fitness test was complete and while the participants were remaining on the treadmill, they answered eight decision-making questions similar to the ones they would be answering during the decision-making session. These questions were scenarios excluded during the development of the decision-making instrument. They took approximately 3 min and served the purpose of acquainting the participants with the decision-making instrument as well as clarifying possible difficulties.

The fitness testing phase was necessary for three reasons: to determine target \( \text{VO}_2 \), predict treadmill speed and grade for various exercise intensities, and determine adjustments. The first purpose was used to compute target \( \text{VO}_2 \) values associated with each exercise condition. The target \( \text{VO}_2 \) values consisted of percentages of the maximum \( \text{VO}_2 \) reached by participants during the Bruce protocol. Target \( \text{VO}_2 \) values were used during the decision-making testing session to ensure that participants were at predicted exercise intensity before answering the decision-making instrument.

The data derived from this phase were also used to predict treadmill speed and grade associated with exercise intensities at 40%, 60%, and 80% of \( \text{VO}_{2\text{max}} \). For each subject, separate simple linear regression equations were calculated for treadmill speed and grade. For each analysis, the predictor variable consisted of \( \text{VO}_2 \) values taken in 30-s intervals and the corresponding treadmill speed or grade values were the criterion variables. Once separate regression equations for speed and
grade were obtained, previously calculated target Vo\textsubscript{2} values were substituted with the independent variable \(X\) to compute the dependent variables’ speed and grade.

Finally, the data acquired during this phase were used to determine necessary adjustments to exercise intensity during the next phase of the experiment (decision-making test). Adjustments were only made to treadmill speed. Speed adjustments were based on change-of-speed formulas. Change-of-speed formulas were acquired during pilot studies. The slope of the line\textsuperscript{3} used in these formulas was attained from the speed of the treadmill regression equation. The change-of-speed formulas are described during the decision-making test phase.

**Decision-Making Test.** Three to eight days following fitness testing, a second testing session measured decision making while participants exercised at different intensities. The Fontana–Gallagher Soccer Decision-Making Instrument was projected onto a screen in front of the treadmill using an LCD projector. Projection size was 90 cm in height by 140 cm in width. Projection was located 1.5 m in front of the treadmill and at a height of 1.80 m from the ground. Once the video froze, the participants were asked to select, as quickly and as accurately as possible, the most appropriate option for the player in possession of the ball. The four alternate forms of the decision-making instrument were counterbalanced so that each alternate form was used four times for each predetermined exercise intensity: rest, 40\%, 60\%, and 80\% Vo\textsubscript{2max}.

The rest condition functioned as a control and was always tested first. During rest, participants answered one alternate form of the decision-making instrument while standing on the treadmill. After being tested at rest, treadmill grade and speed were set to match one of the predetermined exercise intensities (40\%, 60\%, or 80\% Vo\textsubscript{2max}). All four predetermined exercise intensities were administered during a testing session. To better simulate level of intensity in soccer and to avoid order effect, six counterbalanced exercise intensity sequences were created. Sequences were randomly assigned to participants.

Between exercise conditions, there was a 10-min rest period. Before another condition was started, the heart rate of the participant had to be below 100 bpm. The same procedure applied to the subsequent two exercise intensities.

Within each exercise condition, a habituation period of 2 min was provided to allow participants to reach the target Vo\textsubscript{2} level. An open-circuit respiratory metabolic system (True Max 2400, Parvo Medics) was used to measure Vo\textsubscript{2} during the first 2-min habituation period. The participant reached target if his Vo\textsubscript{2} at the end of the second minute was within ±3 percentage points of the target scores. For example, during the 40\% condition, for a Vo\textsubscript{2max} of 65.8 mL·kg\textsuperscript{-1}·min\textsuperscript{-1}, Vo\textsubscript{2} scores within the range 24.3 mL·kg\textsuperscript{-1}·min\textsuperscript{-1} (37\% Vo\textsubscript{2max}) to 28.3 (43\% Vo\textsubscript{2max}) were accepted. If the subject was below or above ±3 percentage points of his target Vo\textsubscript{2} at the 2-min mark, an extra 1-min (3rd minute) adjustment period was provided. Slight alterations in speed were made during the adjustment period. At the beginning of the third minute, speed was decreased or increased as necessary based on the following equation: Change in Speed = \(5 \times\) Slope of the Line. Change-in-speed equations were acquired during pilot studies. The slope of the line was based on the regression equation calculated with data from the first session, fitness testing, for the speed of treadmill. If the target Vo\textsubscript{2} was not achieved at the end of the third minute, the exercise condition was terminated. Upon termination, the
participant received a 10-min break. The participant restarted the same condition after a 10-min break if his heart rate was below 100 bpm. An adjustment of the speed was conducted on the change-in-speed equation previously described. However, the adjustment was relative to speed of the treadmill at the end of the adjustment period (3rd minute mark). During the entire research, the test had to be stopped only twice because participants surpassed target exercise intensity; however, target exercise intensity was attained within the habituation period (3rd minute) when the test was restarted.

Upon reaching target \( \text{Vo}_2 \) at the end of the habituation period, the associated heart rate was recorded. Then participants removed the open-circuit respiratory metabolic system by removing the mouth piece and handing it to the researcher as they continued to walk, and the decision-making testing began. The heart rate recorded at the time the participant reached target \( \text{Vo}_2 \) was monitored during the test to ensure a constant intensity during the decision-making test.

As previously described, there were two 6-s intervals in the decision-making instrument. Slight alterations in speed during these intervals were made so that each participant exercised at the predetermined exercise intensity as measured by heart rate throughout the decision-making phase. Alterations were based on heart rate. If heart rate was within \( \pm 5 \) bpm of its initial value, no alterations were made. If heart rate was between \( \pm 5 \) and \( \pm 7 \) bpm, speed was modified based on the equation Change in Speed = \( 3 \times \text{slope of the line} \).\(^3\) If heart rate was above or below \( \pm 7 \) bpm, speed was modified based on the equation Change in Speed = \( 5 \times \text{slope of the line} \).

The speed of decision making, measured in milliseconds, was recorded by a microphone (Blue Snowball Microphone, Model 4911) positioned in front of the treadmill. The microphone was connected to a computer (Power Mac G5). The voice of the participant was recorded by the software Final Cut Express 2. The wavelength of the answers recorded by Final Cut Express 2 was used to determine the speed of decision making, which was based on the difference in time between the moment the video froze (decision point) and the initiation of the response. The most appropriate action was given 4 and the least 1. The accuracy of decision making was measured by the sum of the total number of points associated with the selected decision for each exercise condition. For each clip, points ranged between 1 and 4, with a range of 7–28 possible points for each exercise condition.

**Design and Data Analysis**

**Effectiveness of Methodological Procedures Analyses**

**Exercise Intensity.** A \( 2 \times 4 \) (Experience Level \( \times \) Exercise Intensity) ANOVA with repeated measures on the last factor was computed to determine if the heart rate varied with exercise conditions (rest, 40\%, 60\%, 80\% \( \text{Vo}_{2\text{max}} \)). In addition, descriptive statistics for heart rate including means and standard deviations were used to show that participants maintained target exercise intensities for each exercise condition. Means and standard deviations were computed based on average deviation scores. Deviation scores were based on the difference between target and actual heart rate. Then they were averaged within each exercise condition.
Deviations scores close to zero and small standard deviations would suggest participants maintained exercise intensity within each exercise condition. For all analyses probability level was set at .05.

**Fitness Level.** A one-way ANOVA with experience level as the independent variable (experienced and inexperienced players) was computed on the dependent variable maximal aerobic capacity (\(V_{O2max}\)) to determine whether the fitness level of inexperienced players differed from that of experienced players.

**Carry-Over Effect.** To test whether decision-making performance for one exercise condition was affected by the conditions that preceded it, the data for accuracy and speed of decision making were analyzed using a \(2 \times 3\) (Experience Level \(\times\) Exercise Condition) MANOVA with repeated measures on exercise condition. For this analysis, the exercise condition variable was organized based on the order presented to the participants, so that whichever exercise intensity was presented first to the participant was considered Exercise Condition 1; the second, Exercise Condition 2; and the third, Exercise Condition 3. Each condition included all levels of exercise intensity with the exception of rest. The rest condition was not included in the analysis because it was a control condition that was always introduced first to the participants, and, during rest, participants were not exposed to physiological stress. The purpose of this analysis was to evaluate whether early exercise conditions influenced decision-making performance on later conditions. Order effects were not examined because they were controlled by counterbalancing both the exercise conditions and the alternate forms of the decision-making instrument.

**Decision-Making Analyses**

The independent variables for this experiment were experience level (experienced, inexperienced) and exercise intensity level (rest, 40%, 60%, 80%). The dependent variables were accuracy and speed of soccer decision making.

Speed and accuracy data were analyzed using a \(2 \times 4\) (Experience Level \(\times\) Exercise Intensity Level) MANOVA with repeated measures on exercise intensity. Follow-up ANOVAs were calculated where appropriate. Effect sizes were calculated using the \(\eta^2\) statistic.

**Results**

The results are organized into two sections. The first section evaluates the effectiveness of the methodological procedures used in this experiment, and the second measures the effects of exercise on decision making in soccer.

**Effectiveness of Methodological Procedures**

**Exercise Intensity.** The results revealed a significant main effect for exercise intensity, \(F(1, 30) = 693.80, p < .01, \eta^2 = .96\). The main effect for experience level was not significant, \(F(1, 30) = .86, p = .36\). Least square difference post hoc analysis showed that heart rates at rest \((M = 81 \text{ bpm}; SD = 10.30)\), 40\% \((M = 126 \text{ bpm}; SD = 11.70)\), 60\% \((M = 152 \text{ bpm}; SD = 11.52)\), and 80\% \(V_{O2max} \ (M = 175 \text{ bpm}; SD = 8.91)\) were all significantly different \((p < .01)\). The interaction between
exercise intensity and level of experience was not significant, $F(1, 90) = .43, p = .85$. In addition, the mean of the deviation scores between target and actual heart rate showed that experienced and inexperienced players maintained predetermined exercise intensities throughout each exercise condition. Average deviations at the 80% $\text{Vo}_{2\text{max}}$ intensity were slightly larger, although alterations in treadmill speed were used to keep the participants at the predetermined intensities. This was expected because participants were exercising above the anaerobic threshold.

**Fitness Level.** Results indicated that the fitness level of inexperienced players was not significantly different from the fitness level of experienced players, $F(1, 31) = 3.93, p = .06$. The mean fitness levels for experienced and inexperienced players were 62.62 mL·kg$^{-1}$·min$^{-1}$ ($SD = 7.63$) and 55.14 mL·kg$^{-1}$·min$^{-1}$ ($SD = 13.12$) respectively.

**Carry-Over Effect.** Based on the MANOVA with repeated measures on exercise condition, the interaction between experience level and exercise condition, $F(4, 27) = 1.94, p = .13$, and the main effect for exercise condition, $F(4, 27) = 1.23, p = .30$, were not significant. The main effect for experience level was significant $F(2, 29) = 18.42, p < .05$. Lack of significance for the interaction and for the exercise condition main effect indicated that carry-over effects were not present in this experiment. Decision-making performance during an exercise condition was not affected by the condition that preceded it.

**Decision Making**

Based on the Group $\times$ Intensity MANOVA with repeated measures on the last factor with the dependent variables accuracy and speed of decision making, the interaction between exercise intensity and level of experience was not significant, $F(6, 25) = .43, p = .85$. The construct of decision making (speed and accuracy) was significantly affected by level of experience, $F(2, 29) = 14.70, p < .01$, $\eta^2 = .50$, and exercise intensity, $F(6, 25) = 3.72, p < .01$, $\eta^2 = .47$. These results suggest that both level of experience (experienced and inexperienced) and exercise intensity (rest, 40% $\text{Vo}_{2\text{max}}$, 60% $\text{Vo}_{2\text{max}}$, 80% $\text{Vo}_{2\text{max}}$) have an effect on the ability of participants to make decisions. Follow-up univariate analyses were separately computed on accuracy and speed of decision making.

**Accuracy of Decision.** The interaction between exercise intensity and level of experience for accuracy, $F(3, 90) = .49, p = .69$, was not significant. Experienced soccer players were significantly more accurate, $F(1, 30) = 16.60, p < .01$, $\eta^2 = .36$, than their less experienced counterparts (Table 1). Accuracy, however, did not vary across exercise intensities, $F(3, 90) = 1.32, p = .27$.

**Speed of Decision.** The interaction between exercise intensity and level of experience for speed of decision making, $F(3, 90) = .63, p = .60$, was not significant. However, experienced soccer players made significantly faster decisions, $F(1, 30) = 6.50, p = .02$, $\eta^2 = .18$, than their less experienced counterparts (Table 1). Speed of decision making was affected by exercise intensity $F(3, 90) = 7.12, p < .01$, $\eta^2 = .19$. Least square difference post hoc analysis indicated that speed of decision making was significantly faster at 60% and 80% maximal aerobic capacity compared with rest for both groups (Table 1).
Table 1: Values for Accuracy and Speed of Decision Making Across Experience Level and Exercise Intensity

<table>
<thead>
<tr>
<th>Group:</th>
<th>Rest</th>
<th>40% Vo₂</th>
<th>60% Vo₂</th>
<th>80% Vo₂</th>
<th>Collapsed across exercise intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Accuracy</td>
<td>Speed</td>
<td>Accuracy</td>
<td>Speed</td>
<td>Accuracy</td>
</tr>
<tr>
<td>Inexperienced</td>
<td>22.3</td>
<td>1950</td>
<td>22.6</td>
<td>1726</td>
<td>21.9</td>
</tr>
<tr>
<td></td>
<td>(2.8)</td>
<td>(472)</td>
<td>(2.6)</td>
<td>(702)</td>
<td>(1.8)</td>
</tr>
<tr>
<td>Experienced</td>
<td>23.8</td>
<td>1430</td>
<td>24.9</td>
<td>1307</td>
<td>24.4</td>
</tr>
<tr>
<td></td>
<td>(2.5)</td>
<td>(692)</td>
<td>(1.5)</td>
<td>(486)</td>
<td>(2.1)</td>
</tr>
<tr>
<td>Collapsed across experience level</td>
<td>23</td>
<td>1689</td>
<td>23.1</td>
<td>1516</td>
<td>23.6</td>
</tr>
<tr>
<td></td>
<td>(2.7)</td>
<td>(640)</td>
<td>(2.3)</td>
<td>(631)</td>
<td>(2.6)</td>
</tr>
</tbody>
</table>

Note. Speed of decision values are given in milliseconds. Values in parenthesis represent standard deviations.

a$p < .05$ (accuracy and speed of decision making across experience level).
b$p < .05$ (speed of decision making compared with rest condition).
Discussion

Expertise has a major influence on sport performance. However, only a few studies on expertise have been conducted under conditions of physiological stress, most of which were conducted by McMorris and Graydon (1996a, 1996b, 1997) and McMorris et al. (1999). To our knowledge, only two other articles investigating the effect of exercise on decision-making performance in sports have been published (Marriott, Reilly, & Miles, 1993; Tenenbaum et al., 1993) and were criticized by McMorris and Graydon (1996a) for lacking reliability scores, not examining possible learning effects, and not testing speed of decision making. The studies by McMorris and Graydon (1996a, 1996b, 1997) and McMorris et al. (1999) also have methodological limitations. The decision-making instrument consisted of nearly identical test forms and the exercise protocol exposed subjects to a fixed exercise intensity sequence.

Because of the criticisms of previous experiments, it becomes imperative to discuss the effectiveness of the methodological procedures used in this experiment. The validity and reliability of the decision-making instruments were extensively reported. The decision-making instrument used in this experiment included four different but equivalent test forms.

Manipulation of exercise intensity produced four exercise conditions (rest, 40%, 60%, and 80% \( \text{Vo}_{2\text{max}} \)) that were different from each other. In addition, it was documented that participants exercised at the predicted exercise intensities throughout each exercise condition. There was a small deviation from target intensity for the 80% \( \text{Vo}_{2\text{max}} \) condition, which was expected since participants at this intensity are using anaerobic metabolism. Finally, a lack of carry-over effects indicated that accuracy and speed of decision-making performance on one exercise condition were not affected by the previous exercise conditions.

The fitness level of the participants was also not likely to have interfered with any of the results of this experiment. The fitness level of participants was controlled by requiring them to exercise at percentages of their own aerobic capacity. In addition, the groups of experienced and inexperienced players were similarly fit. The aerobic fitness level of experienced players was not significantly different from that of inexperienced players. This was likely due to the recruitment of inexperienced players by signs posted in university fitness centers. Thus, the methodological procedures used in this experiment were effective.

Two hypotheses were tested in this experiment. One of the hypotheses tested concerned the effects of expertise on decision-making performance. The results indicated that experience is the major factor in players’ decision making. Experienced players made more accurate and faster decisions than inexperienced players. When viewed as a construct, the effect size for decision making was moderately high (MANOVA), suggesting that differences between inexperienced and experience players in decision making are meaningful in sport situations. However, when viewed separately, the effect size was moderate for accuracy but only small for speed of decision making (ANOVAs). In soccer though, even the small effect size for speed of decision making is likely to represent meaningful differences between inexperienced and experienced players. In this experiment, inexperienced players were on average approximately 400 ms slower in making decisions; in a fast-action game like soccer, this has the potential for a player to lose the ball.
or modify a decision to execute the more appropriate play. These results agree with findings from research that tested differences in decision-making performance between experienced and inexperienced players (Kioumourtzoglou et al., 1998; McMorris & Beazeley, 1997; McPherson, 1999; Nielsen & McPherson, 2001). A new finding is that this difference in decision-making performance is independent of the intensity of the exercise performed. Experienced players performed better than inexperienced players during rest, moderate exercise, and highly intense exercise.

Although the hypothesis concerning the effects of expertise on decision-making performance was supported, the results of this experiment did not support the hypothesis that exercise level would affect the decision-making performance of experienced and inexperienced players differently. In fact, results for experienced and inexperienced players are parallel. Independent of experience level, the accuracy of decision making did not vary as a function of exercise intensity (\(M_{\text{rest}} = 23, SD = 2.7; M_{40\% VO_2} = 23.1, SD = 2.3; M_{60\% VO_2} = 23.6, SD = 2.6; M_{80\% VO_2} = 24, SD = 2.2\)); however, decision making of both groups was affected by exercise intensity (\(M_{\text{rest}} = 1689 \text{ ms, } SD = 640; M_{40\% VO_2} = 1516 \text{ ms, } SD = 631; M_{60\% VO_2} = 1440 \text{ ms, } SD = 449; M_{80\% VO_2} = 1364 \text{ ms, } SD = 456\)). The effect size for exercise intensity was small, but a difference of 325 ms between rest and 80% \(\text{VO}_{2\text{max}}\) is meaningful in sports like soccer where the environment is constantly changing. Improvement in speed of decision making was evident at 60% and 80% \(\text{VO}_{2\text{max}}\) exercise intensities compared with rest. Expertise research has consistently demonstrated different use of strategies by individuals with different levels of experience (Vickers 1996; Williams, Singer, & Frehlich, 2002); however, in this experiment, the patterns for accuracy and speed of decision-making patterns were the same for experienced and inexperienced players with the experienced players performing at a higher level.

The results of the current study replicate the results of McMorris and Graydon (1996a, 1996b, 1997) and McMorris et al. (1999) studies despite several methodological improvements made to the decision-making instrument and exercise protocol used in this experiment. Improvements to the decision-making instrument included designing equivalent test forms consisting of different decision-making situations and using video clips in the place of slides. Improvements to the exercise protocol included randomizing exercise conditions to control for order effects and to better simulate exercise performed during soccer matches. In addition, as previously discussed, participants in this experiment exercised at intended exercise intensities, and there was no carry-over effect or difference in the fitness level of inexperienced and experienced players. Even with the methodological improvements made to this experiment, results from McMorris and Graydon (1996a, 1996b, 1997) and McMorris et al. (1999) stand. Agreement among the results suggests that the results of this experiment are robust.

As with the studies conducted by McMorris and Graydon (1996a, 1996b, 1997) and McMorris et al. (1999), results of this study do not adequately support the Yerkes–Dodson hypothesis, drive theory, or the allocation of resources theory. Lack of deterioration of accuracy and speed of decision making during exercise performed at 80\% \(\text{VO}_{2\text{max}}\) exercise intensity and lack of improvement in accuracy of decision making from rest to 60\% \(\text{VO}_{2\text{max}}\) exercise intensity do not support the inverted-U performance as claimed by Yerkes–Dodson hypothesis.
Results also fail to support the claims of drive theory. Although improvements were expected, performance for experienced players for accuracy of decision making was constant across exercise conditions. Failure of highly intense exercise (80% $\text{Vo}_{2\max}$) to impair accuracy and speed of decision making of inexperienced players also disagrees with the drive theory claims. Finally, the drive theory predicts that experienced and inexperienced players will demonstrate different performance patterns for accuracy and speed of decision making. The patterns for experienced and inexperienced players were similar to each other.

Although in the latter study, McMorris et al. (1999) used the allocation of resources theory to explain the results, the dissociation of accuracy and speed of decision-making results during rest and 60% $\text{Vo}_{2\max}$ exercise intensity cannot be explained by the allocation of resources theory. If a more efficient allocation of resources is used to explain the failure of experienced and inexperienced players to demonstrate less accurate decision making during rest compared with 60% $\text{Vo}_{2\max}$ exercise intensity, then a more efficient allocation of resources during rest fails to explain the superior speed of decision making during the 60% $\text{Vo}_{2\max}$ exercise intensity. Proponents of the allocation of resources theory would also have expected a deterioration of accuracy and speed of decision making during the 80% $\text{Vo}_{2\max}$ exercise intensity.

It is critical to mention that when manipulating exercise intensity, McMorris et al. (1999) used the adrenaline threshold owing to its potentially more accurate measure of central nervous system arousal (Cooper, 1973; Chmura et al., 1994). Based on the results of their study, McMorris et al. suggested that only exercise above the adrenaline threshold elicits optimal arousal. In the current study, the adrenaline threshold was not measured. However, participants were not likely to have surpassed their adrenaline threshold at the intensity of 60% $\text{Vo}_{2\max}$, but speed of decision-making performance still improved compared with rest. In fact, even the speed of decision making at the 40% $\text{Vo}_{2\max}$ exercise intensity was better, although not significant, than the rest condition. The results of the current study suggest that improvement in speed of decision making possibly occurs before the adrenaline threshold. More studies need to be conducted before recognizing the effectiveness of the adrenaline threshold as a maker of central nervous system arousal.

Although our results do not fully support any of the three theories, it is important to recognize that maximal exercise intensity was not investigated in this study and decision-making measurements were taken during game play. It is possible that deterioration in decision-making performance would occur at higher exercise intensities than the ones used in this experiment. McMorris and Graydon did not find decrements in decision-making performance at maximal exercise intensity. However, this contention cannot be fully discarded at the moment due to the limitations in McMorris and Graydon (1996a, 1996b, 1997) and McMorris et al. (1999) studies.

It is also possible that different results would have been achieved if the decision-making measurements were taken during game play. Critical decision-making situations in actual soccer games tend to have a much larger number of options. In addition, opposed to the two-dimensional test presented to the participants in this experiment, actions in soccer games occur on the side and behind players. Therefore, with the demands of actual soccer games, the relationship between exercise
intensity and decision making could be different. Future research conducted during game play is strongly recommended.

Owing to improvements in speed and lack of improvement in accuracy of decision making, an alternative explanation to the results is that they are due to the effects of exercise on one of the elements of the information-processing sequence that occurs before decision making (i.e., perception). McMorris and Graydon (1997) investigated this hypothesis by measuring the speed of decision making using a visual search task. Visual search was not affected by exercise. The visual search task, however, was simple and only required the participants to state whether a ball was present or not in the display. Visual search during sport-related decision-making situations is much more complex. In decision-making situations in soccer, visual search involves more elements, and participants must extract a massive amount of information, such as the direction the player is running or how far from the goal he or she is located before making a decision. Future research is necessary to clarify what causes exercise to affect only speed of decision making.

Finally, another possible explanation to the results is that physiologically induced arousal produces different effects on cognitive performance than does psychologically induced arousal. McMorris et al. (1999) stated that exercise may not produce the same effects as emotional arousal because the physiological changes associated with exercise are used to keep the body in homeostasis, whereas physiological changes produced by emotional arousal disturb homeostasis. Moreover, none of the theories—the Yerkes–Dodson hypothesis, drive theory, or the allocation of resources theory—were specifically designed to explain the response to the effects of arousal produced by physiological manipulations. Based on speculations that the effects of arousal physiologically and psychologically induced on decision-making performance differ, a new paradigm emerges. Based on this new paradigm, accuracy of decision making is unaffected by variations in exercise intensity, whereas speed of decision making improves as exercise intensity increases from rest to moderate levels, with no further improvement as exercise intensity increases. More evidence needs to be collected to further validate this new paradigm.

Notes

1. Improvement in the speed of decision making during moderate and maximal exercise compared with rest was present across studies, but significant differences were not found between moderate and rest in the second study by McMorris and Graydon (1996b). In this study, one group of experienced players was asked to answer the decision-making problems as fast as possible whereas the other group was told that the speed of decision making was not a critical factor. Similarly, no significant differences were found in the first experiment of the 1997 study. In this experiment, experienced players had to state as quickly and accurately as possible if the ball was present or absent in each situation.

2. A separate regression equation was computed for each participant based on their fitness data using simple linear regression analysis procedures. An example of a regression equation used to determine treadmill speed during decision-making test is Speed = .949 + .058 (X). For a participant with a \( V_{O_2} \max \) of 73.5 mL·kg\(^{-1}\)·min\(^{-1}\), the target \( V_{O_2} \) value for the 60% exercise condition equals 44.1 mL·kg\(^{-1}\)·min\(^{-1}\). Once X in the regression equation is substituted by 44.1 mL·kg\(^{-1}\)·min\(^{-1}\), a speed 3.5 mph is reached. This is the value used to elicit the target 60% exercise intensity for this participant.
3. During the decision-making test phase, minor adjustments in the speed of the treadmill were made to elicit target exercise intensity. Adjustments were based on change-in-speed formulas. Adjustments of exercise intensity were made only to speed. The “slope of the line” used in these formulas was attained from the regression equation for treadmill speed. From the example provided in Note 2, the slope of the line is equal to .058. If the heart rate of this participant was above 7 bpm, the speed of the treadmill was adjusted by the formula Change in Speed = 5 × (.058) = .3 mph. The slope of the line represents the change in speed made for every unit change in VO2.

References


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