Effects of Prolonged Intermittent Exercise on Perceptual-Cognitive Processes

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ABSTRACT

CASANOVA, F., J. GARGANTA, G. SILVA, A. ALVES, J. OLIVEIRA, and A. M. WILLIAMS. Effects of Prolonged Intermittent Exercise on Perceptual-Cognitive Processes. *Med. Sci. Sports Exerc.*, Vol. 45, No. 8, pp. 1610–1617, 2013. **Purpose**: The visual search behaviors and thought processes underpinning anticipation and how these are influenced by intermittent exercise were examined in high- and low-level soccer players. **Methods**: High-level (n = 8) and low-level (n = 8) players completed a soccer-specific, intermittent exercise protocol that simulated the demands of a match while responding to filmed sequences of offensive play. HR, blood lactate concentrations, anticipation performance, visual search behaviors, and immediate retrospective verbal reports were assessed. **Results**: High-level players demonstrated superior anticipation compared with low-level counterparts, but both groups showed reduced accuracy across the exercise protocol. Mean HR and blood lactate values increased significantly from the beginning to the end of each half of the match ($P < 0.05$). Visual search data revealed significant group–test session interactions for the number of locations ($P < 0.0001$), mean fixation durations ($P = 0.003$), and number of fixations ($P < 0.0001$). When compared with low-level participants, high-level players used more fixations of shorter duration to more locations at the beginning of each half; whereas at the end of the exercise protocol, they used fewer fixations of longer duration to a lower number of locations. There was a significant group–type of statement–test session interaction ($P = 0.001$) for the verbal report data. High-level participants generated a great number of evaluation, prediction (in the beginning of the second half), and deep planning statements (during the first and the last test sessions). In contrast, low-level players used more superficial cognition statements than high-level individuals in both halves. **Conclusion**: The intermittent exercise induced changes in perceptual-cognitive processes in both groups, although high-level players exhibited superior anticipation across test sessions accompanied by more effective search behaviors and elaborate thought processes. **Key Words:** ANTICIPATION, VISION, THOUGHTS, SOCCER

The game of soccer presents a complex and rapidly changing environment that requires players to anticipate the actions of teammates and opponents under varying exercise intensities. Anticipation is critical to high-level performance, and it has been reported that the ability to make such judgments necessitates dynamic interactions between different perceptual-cognitive processes (32). Previous reports involving soccer players suggest that the perceptual-cognitive processes underpinning anticipation differ across skill groups (high- vs low-skill level) as well as across task and situational constraints (1,28,33).

Only a few researchers have collected process-tracing measures such as gaze behavior and verbal reports of thinking simultaneously during performance (15,21). For instance, during open-play situations involving 11 versus 11 players in soccer, skilled players use search strategies involving shorter fixation durations (FD) when compared with less skilled counterparts (e.g., 30,33). Furthermore, skilled players modify gaze behaviors according to their specific functional role in the team with, for instance, different search strategies being used in offensive compared with defensive situations (e.g., 22,23,31) and when participating in micro (e.g., 3 vs 3 players) and macro (e.g., 11 vs 11 players) states of the game (30,31).

Think-aloud retrospective verbal reports have been used to understand how experts use information from the display when making anticipation judgments (14–16,18,21,27). When compared with less skilled counterparts, skilled players anticipate future events and search possible alternatives beyond the next move by more effectively building dynamic situational representations or cognitive models “on the fly” (12,27). In contrast, less skilled participants have impoverished retrieval structures and largely articulate thoughts related to currently available information rather than anticipating future retrieval demands and evaluating alternative courses of action.

Time–motion analyses and physiological measurements during the game show that soccer players cover large distances

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(9–12 km), with a change in intensity and type of displacement every 4–6 s (17). The displacements demanding higher intensities are related to early onset of fatigue (2,17,19,20) and therefore can negatively affect physical and technical performance (11,13,17). As reported by Jinshen et al. (11), most goals are scored toward the end of a soccer match, likely due to physical and mental fatigue and/or changes in strategy and tactics (19). Although there have been attempts to examine how exercise influences the visual search behaviors used in relatively closed skill situations involving an aiming task (cf. Williams et al. [33]), there have been no efforts to examine how the perceptual-cognitive processes used during anticipation in dynamic, open-play situations in team sports such as soccer may be influenced by exercise conditions that attempt to mirror actual match play.

The present study was designed to examine the visual search behaviors and thought processes that underpin anticipation in high- and low-level soccer players and whether these are influenced by the effects of prolonged intermittent exercise. The approach used is novel and combines a soccer-specific, intermittent exercise protocol, realistic film-based simulations of offensive sequences of play, and sensitive process-tracing measures of performance involving the recording of gaze behaviors and verbal reports of thinking. It was hypothesized that high-level players would demonstrate superior anticipation performance when compared with low-level players. Because there have been no previous attempts to examine how gaze behaviors and thought processes may change under conditions that simulate match play in soccer, we refrain from making specific predictions in regard to how the perceptual-cognitive processes used by the two groups of players would differ across the exercise protocol.

METHODS

Participants

Sixteen players were recruited according to their competitive level in soccer. A high-level group composed of eight participants (mean age = 24.6 yr, SD = 3.9 yr) who had played at a semiprofessional or professional level for an average of 5.1 yr (SD = 2.4 yr). A low-level group composed of eight participants (mean age = 26.3 yr, SD = 2.9 yr) who had only played the game at an amateur level for an average of 2.1 yr (SD = 2.4 yr). Participants reported normal or corrected to normal levels of visual function, and written informed consent was provided. The study was carried out with the ethical approval of the lead institution, which conforms to the Helsinki Declaration.

Match Scenarios

Professional players from the Second National League ($N = 22$) in Portugal performed the match scenarios. A panel of four elite-level soccer coaches, who all held the Union of European Football Associations-A license and had at least 10 yr coaching experience, validated the footage. The level of agreement between observers in regard to suitability of the clips was high ($\alpha = 0.889$). The action sequences were filmed from a position behind (15 m) and slightly above (5 m) the goal with a 16:9 ratio camera (Sony DSR 570 DVCAM), such that the entire width of the playing field could be viewed. Altogether, four different test films were created each comprising of ten different offensive sequences. The duration of each clip was approximately 5 s, with an intertrial period of 5 s. A small circle appeared on screen to indicate the initial position of the ball just before the start of each clip. The clips were all occluded 120 ms before the player in possession of the ball was about to make a pass or take a shot at goal or maintain the possession of the ball.

Apparatus

Film clips were projected onto a large screen (2.5 × 2 m). The screen was placed 1.5 m directly in front of participants to ensure the image was representative of real match play. The screen subtended a viewing angle of 44° in the vertical and 46° in the horizontal direction, respectively.

The visual search behaviors were recorded using an Applied Science Laboratories (ASL®) 3000 eye-movement registration system. The apparatus involves a video-based monocular corneal reflection system that records point of gaze with regard to a helmet-mounted scene camera. The system measures the relative position of the pupil and corneal reflection. These features are used to compute point of gaze by superimposing a crosshair onto the scene image captured by the head-mounted camera optics. The participants wore the ASL® system during the entire duration of the exercise protocol. The image was analyzed frame by frame using the Pinnacle Software, Avid Liquid edition 7 (Pinnacle Systems, Inc., Mountain View, CA). System accuracy was ±1° visual angle, with a precision of 1° in both the horizontal and vertical directions.

A lapel microphone, a telemetry radio transmitter (EW3; Sennheiser, High Wycombe, UK), and a telemetry radio receiver (EK 100 G2; Sennheiser) were used to collect verbal reports. Verbal reports were recorded onto a miniDV tape using a digital video camera (Canon Legria FS 200; Canon, Tokyo, Japan), converted into computer audio .wav files, and then transcribed before analysis.

Procedure

Before commencing the task, the test procedure was explained and the eye-movement system fitted onto the participant's head. The ASL® eye-movement system was calibrated using a 9-point reference grid so that the fixation mark corresponded precisely to the participant's point of gaze. A simple eye calibration was performed for each participant to verify point of gaze, and four periodic calibration checks were conducted during the test (cf. Williams and Davids [31]). After calibration, participants were presented with six practice trials in the laboratory task environment to ensure that they were familiar with the test procedure.

Participants practiced giving verbal reports on how to think aloud and provide retrospective verbal reports by solving generic and sport-specific tasks for approximately 30 min (7,26,27). The transcriptions of retrospective verbal reports were segmented using natural speech and other syntactical markers. Participants were presented with six practice trials to ensure familiarization with the experimental setting. Retrospective verbal reports were collected directly at the end of each sequence.

Participants were asked to anticipate which of three possible actions was about to be performed by the player in possession of the ball: pass (i.e., a situation when the player attempted to play the ball to a teammate), shot at goal (i.e., when the player makes an attempt to score a goal), and retain possession (i.e., when the player has ball possession and attempts to move with the ball).

Drust et al. (5) developed a soccer-specific intermittent exercise protocol using a motorized treadmill based on the motion-analysis data reported by Reilly and Thomas (20). The intermittent exercise protocol simulates different exercise activities with varying intensities (e.g., walking, jogging, running, cruising, and sprinting), as observed during match play, and it has been adapted to simulate the physical demands of a soccer game (4,10). Treadmill speeds assigned to each activity category are based on the data of Van Gool et al. (24). Laboratory conditions such as temperature (22°C) and humidity (50%–60%) did not differ across test conditions and trials.

The intermittent exercise protocol lasted 119 min. This activity was divided into two halves with the same duration (52 min), interspersed by a 15-min rest interval. The treadmill (H/P Cosmos, Pulsar, Germany) speeds used for each activity pattern were as follows: walking, 6 $km \cdot h^{-1}$; jogging, 12 $km \cdot h^{-1}$; running, 15 $km \cdot h^{-1}$; cruising, 18 $km \cdot h^{-1}$; and sprinting, 23 $km \cdot h^{-1}$. The protocol included two identical periods of seven blocks (five low-intensity blocks and two high-intensity blocks). The low-intensity phase consisted of five blocks of activity, each one with the following pattern: walking, stopping, jogging, walking, jogging, and running. The total duration of each low-intensity block was 6 min and 24 s, including four repeated cycles of 18 s of walking, 18 s of stopping, 16 s of jogging, 18 s of walking, 14 s of jogging, and 12 s of running. The high-intensity phase consisted of two blocks of activity, with the activity patterns of walking, sprinting, stopping, and cruising. The duration of each high-intensity block was 7 min, involving seven repeated cycles of 13 s of walking, 10 s of sprinting, 15 s of walking, 10 s being stationary, and 12 s of cruising.

The data were collected in four test sessions during which participants viewed 10 clips presented in a counterbalanced order. Two test sessions were completed in each half (after the third and the seventh running blocks of each half). The total duration of the experimental protocol was approximately 210 min. The experimental design is presented in Figure 1.

Analysis Methods

Exertion levels. HR was monitored continuously at 5-s intervals (Polar S610i; Polar Electro Oy, Kempele, Finland). The mean value for each block of the intermittent exercise protocol was calculated. A lactate analyzer (Lactate Pro LT-1710, Kyoto, Japan) was used to collect the blood lactate (La) concentration samples at the left fingertip, immediately after

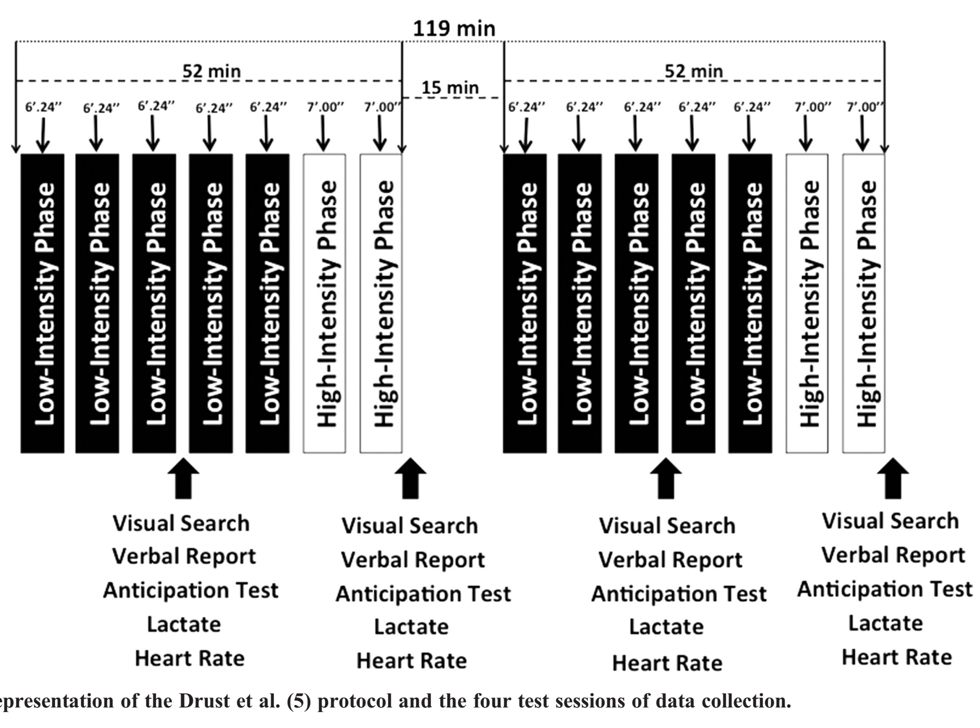

FIGURE 1—The representation of the Drust et al. (5) protocol and the four test sessions of data collection.

the exercise. These measures were obtained immediately after the 3rd, 7th, 10th, and 14th blocks of the intermittent exercise protocol.

Anticipation. The response accuracy (RA) scores were calculated based on the participant's responses after viewing each clip (%). An accurate response was recorded if the participant correctly anticipated the decision of the player in possession of the ball compared with what actually happened in the match situation.

Visual search behavior. In each test session, the three most discriminating trials between high- and low-level participants based on group mean scores from the measures of %RA were chosen for visual search analysis (cf. North et al. [18] and Vickers [26]). Visual behaviors were analyzed to obtain the search rate and the percentage of viewing time (%VT) data. The measures of search rate comprised the mean number of visual fixations (NF), the mean FD, and the total number of fixation locations (NFL) per trial. Mean FD was the average of all fixations that occurred during the trial. A fixation was defined as the period (120 ms) when the eye remained stationary within 1.5° of movement tolerance (cf. Williams and Davids [31]). %VT was defined as the proportion of time spent fixating on each area of the display. The display was divided into five fixation locations: ball, teammate, opposition, player in possession of the ball, and undefined. The undefined category was excluded because the %VT in this location was less than 1%. An interobserver agreement formula was used to determine the percentage of agreement for %VT and search rate data, respectively. Altogether, 25% of the data were reanalyzed, resulting in an interobserver agreement value of 99% for these variables.

Verbal reports. Verbal reports were categorically coded based on a structure proposed by Ericsson and Simon (8) and refined by Ward et al. (27,29) to identify statements made about cognitions, evaluations, and planning, which includes predictions and deep planning. Retrospective verbal reports were collected after each trial. In each test session, the three most discriminating trials between groups based on mean scores from the anticipation test were used. An independent investigator reanalyzed all of the data to check reliability; the interobserver agreement was 98%.

Statistical Analysis

The data were analyzed using separate two-way factorial ANOVAs with group as the between-participant factor and test session as the within-participant factor to analyze differences in HR (bpm), La concentration (mmol·L^{-1}), %RA, and search rate data across the intermittent exercise protocol. The %VT data were analyzed using a factorial three-way ANOVA with group as the between-participant factor and fixation location and test session as within-participant factors. A factorial three-way ANOVA was used to analyze verbal reports data with group as the between-participant factor and type of statements and test session as within-participant factors. Partial eta squared (η_p^2) values were provided as a measure of effect size for all main effects and interactions. Bonferroni *post hoc* tests were used to analyze pairwise comparisons between test sessions when appropriate. The alpha level of significance for all tests was set at $P < 0.05$.

RESULTS

The mean values for HR, La concentrations, and anticipation performance (%RA) are presented in Table 1.

Exertion levels. There was a significant difference in HR across test sessions ($F_{2.06,\ 28.86} = 187.66$, $P < 0.0001$, $\eta_p^2 = 0.93$). *Post hoc* analyses showed that HR was significantly higher during the second compared with the first test session in each half ($P < 0.05$). Moreover, HR was significantly lower in the first test session compared with the third test session ($P < 0.05$). There was no significant main effect for group ($F_{1,\ 14} = 0.50$, $P = 0.49$, $\eta_p^2 = 0.04$) or a group–test session interaction ($F_{2.06,\ 28.86} = 0.78$, $P = 0.47$, $\eta_p^2 = 0.05$). There was a significant main effect for La across test session ($F_{1.02,\ 14.33} = 3.33$, $P = 0.03$, $\eta_p^2 = 0.19$). *Post hoc* analyses showed that the La concentration was significantly higher in the fourth test session when compared with the first and third test sessions ($P < 0.05$). There was no significant main effect for group ($F_{1,\ 14} = 0.29$, $P = 0.59$, $\eta_p^2 = 0.02$) and no group–test session interaction ($F_{1.02,\ 14.33} = 1.01$, $P = 0.39$, $\eta_p^2 = 0.07$).

Anticipation. There were significant main effects for group ($F_{1,\ 14} = 18.69$, $P = 0.001$, $\eta_p^2 = 0.57$) and test session ($F_{3,\ 42} = 12.17$, $P < 0.0001$, $\eta_p^2 = 0.47$). The high-level group had higher accuracy scores across all four test sessions. *Post hoc* analyses on the test session main effect showed that players were significantly less accurate in making anticipation judgments in the fourth test session when compared with the first, second, and third test sessions ($P < 0.05$). There was no significant group–test session interaction ($F_{3,\ 42} = 0.24$, $P = 0.80$, $\eta_p^2 = 0.02$).

TABLE 1. Exertion and anticipation data (mean ± SD) per group across the intermittent exercise protocol.

	Group	First	Second	Third	Fourth
HR	High-level	116.8 ± 9.3	155.9 ± 12.1	126.3 ± 19.7	163.1 ± 10.2
	Low-level	123.6 ± 12.4	158.4 ± 12.7	132.1 ± 13.7	164.3 ± 8.6
La	High-level	1.4 ± 0.3	3.9 ± 1.3	1.5 ± 0.5	5.9 ± 1.1
	Low-level	1.8 ± 0.7	3.8 ± 1.8	1.8 ± 0.7	4.7 ± 1.8
%RA	High-level	56.3 ± 9.2	51.3 ± 9.9	50.0 ± 0.0	41.3 ± 13.6
	Low-level	40.0 ± 14.1	37.5 ± 10.4	36.3 ± 7.4	23.7 ± 5.2

HR, heart rate in beats per minute; La, blood lactate concentrations; %RA, percentage of response accuracy.

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TABLE 2. Visual search rate data (mean ± SD) across trials during the intermittent exercise protocol.

	Group	First	Second	Third	Fourth
FD (ms)	High-level	267.9 ± 66.5[a]	289.8 ± 78.2	285.0 ± 81.5[a]	334.4 ± 98.2
	Low-level	362.9 ± 98.4	309.8 ± 74.6	387.8 ± 92.5	312.9 ± 83.8
NF	High-level	16.4 ± 2.2[a,b]	14.3 ± 1.8	15.1 ± 2.2[a,c]	14.1 ± 2.8
	Low-level	12.9 ± 2.7[b]	14.8 ± 3.3	12.1 ± 1.6[c]	14.6 ± 2.7
NFL	High-level	3.3 ± 0.4[d]	2.9 ± 0.4	3.0 ± 0.4	2.8 ± 0.5
	Low-level	2.6 ± 0.5[e]	2.9 ± 0.6	2.4 ± 0.3[e]	2.9 ± 0.5

FD, fixation duration; NF, number of fixations; NFL, number of fixations per location.
[a]Significant difference between high-level and low-level groups ($P < 0.05$).
[b]Significant difference within high-level and low-level groups from the first to the second test session ($P < 0.05$).
[c]Significant difference within high-level and low-level groups from the third to the fourth test session ($P < 0.05$).
[d]Significant difference within high-level group for the first to the second and fourth test sessions ($P < 0.05$).
[e]Significant difference within low-level group from the first to the second test session and from the third to the fourth test session ($P < 0.05$).

Visual search behavior. The visual search rate variables are presented in Table 2. There were no significant main effects for group ($F_{1, 14} = 1.81$, $P = 0.2$, $\eta_p^2 = 0.11$) or test session ($F_{3, 42} = 1.46$, $P = 0.24$, $\eta_p^2 = 0.09$) on the FD variable. However, there was a significant group–test session interaction ($F_{3, 42} = 5.58$, $P = 0.003$, $\eta_p^2 = 0.29$). *Post hoc* analyses showed that the low-level participants used significantly longer fixations at the start of each half (the first and the third test sessions) compared with later in the half (the second and the fourth test sessions), whereas the average duration of fixation for the high-level participants did not differ across the four test sessions ($P < 0.05$). Moreover, participants in the low-level group increased their FD from the second to the third test session ($P < 0.05$).

There were no significant main effects for group ($F_{1, 14} = 1.69$, $P = 0.21$, $\eta_p^2 = 0.11$) or test session on the NF per trial ($F_{3, 42} = 1.44$, $P = 0.24$, $\eta_p^2 = 0.09$). However, there was a significant group–test session interaction ($F_{3, 42} = 8.45$, $P < 0.0001$, $\eta_p^2 = 0.38$). The low-level participants used more fixations in the second compared with the first test session in each half, whereas the high-level participants decreased the number of fixations from the first to the second test session in each half (both $P < 0.05$).

There were no significant main effects for group ($F_{1, 14} = 1.69$, $P = 0.21$, $\eta_p^2 = 0.11$) or test session ($F_{3, 42} = 1.44$, $P = 0.24$, $\eta_p^2 = 0.09$) in regard to the NFL per trial. The group–test session interaction was significant ($F_{3, 42} = 8.45$, $P < 0.0001$, $\eta_p^2 = 0.38$). The high-level participants fixated on more locations in the first compared with the second and fourth test sessions ($P < 0.05$). In contrast, the low-level participants fixated on more locations during the last test session compared with the first session in each half ($P < 0.05$).

The data for %VT are presented in Table 3. There was no significant main effect for group ($F_{1, 14} = 2.40$, $P = 0.144$, $\eta_p^2 = 0.146$) or test session ($F_{3, 42} = 0.88$, $P = 0.459$, $\eta_p^2 = 0.059$). However, there was a significant main effect for fixation location ($F_{3, 42} = 122.59$, $P < 0.0001$, $\eta_p^2 = 0.898$). Participants spent significantly more time fixating the player in possession of the ball compared with other locations ($P < 0.05$). In addition, participants spent significantly less time fixating the ball compared with all other locations coded ($P < 0.05$).

There was a significant test session–fixation location interaction ($F_{9, 126} = 1.98$, $P = 0.046$, $\eta_p^2 = 0.124$). There was a significant difference between the first and the third test sessions in the time spent fixating the player in possession of the ball ($P < 0.05$). Although not statistically significant ($P = 0.073$), participants tended to decrease the time spent fixating the opposition between the first and the fourth test sessions.

There were no significant group–test session ($F_{3, 42} = 1.59$, $P = 0.204$, $\eta_p^2 = 0.102$), group–fixation location ($F_{3, 42} = 2.01$, $P = 0.128$, $\eta_p^2 = 0.125$), and group–fixation location – test session interactions ($F_{9, 126} = 1.59$, $P = 0.204$, $\eta_p^2 = 0.102$) for the %VT variable.

Verbal reports. The verbal report data are presented in Table 4. There was a significant main effect for type of verbal statement ($F_{2.19, 30.62} = 41.56$, $P < 0.0001$, $\eta_p^2 = 0.748$). Participants made significantly more verbal statements coded as cognitions than evaluations, predictions, and deep planning ($P < 0.05$). Moreover, significantly more evaluation

TABLE 3. %VT per location (mean ± SD) across trials during the intermittent exercise protocol.

%VT	Group	First	Second	Third	Fourth
Ball	High-level	0.9 ± 1.7	3.6 ± 5.1	1.4 ± 2.7	1.6 ± 2.5
	Low-level	3.8 ± 4.5	5.5 ± 6.1	3.9 ± 7.9	4.5 ± 3.3
Teammate	High-level	19.8 ± 11.2	19.8 ± 7.1	18.9 ± 8.8	18.2 ± 10.4
	Low-level	19.4 ± 10.2	18.6 ± 11.3	12.5 ± 5.2	18.7 ± 9.4
Opposition	High-level	38.9 ± 7.9	30.9 ± 8.8	34.3 ± 8.9	28.6 ± 10.8
	Low-level	33.2 ± 13.6	27.8 ± 9.5	21.3 ± 10.3	29.1 ± 8.9
Player in possession of the ball	High-level	39.7 ± 11.9[a]	45.5 ± 13.5	42.9 ± 12.3	50.7 ± 11.8
	Low-level	43.6 ± 14.7[a]	47.6 ± 13.5	62.1 ± 12.3	47.7 ± 11.8

%VT, percentage of viewing time.
[a]Significant difference on the player in possession of the ball from the first to the third test session in both groups ($P < 0.05$).

TABLE 4. Verbal report statements percentage data (mean ± SD) per group across trials during the intermittent exercise protocol.

	Group	First	Second	Third	Fourth
Cognition	High-level	43.2 ± 13.4[a]	44.1 ± 17.3	39.5 ± 16.3	46.7 ± 16.7[d]
	Low-level	66.7 ± 14.7[c,f]	54.9 ± 15.1	75.6 ± 21.8	70.9 ± 21.2
Evaluation	High-level	30.6 ± 10.0	32.9 ± 16.5	42.3 ± 11.3[d]	31.1 ± 10.3
	Low-level	24.3 ± 15.8	30.6 ± 15.3[g]	13.6 ± 10.5	24.9 ± 16.5
Prediction	High-level	11.4 ± 15.5	16.9 ± 22.4	11.6 ± 17.9[d]	15.9 ± 12.7
	Low-level	9.0 ± 15.7	12.6 ± 14.9	7.9 ± 10.7	4.2 ± 7.9
Deep planning	High-level	14.8 ± 12.3[a,b]	6.1 ± 8.1	6.7 ± 10.2	6.2 ± 7.9
	Low-level	0.0 ± 0.0[e]	1.9 ± 5.3	2.9 ± 8.4	v0.0 ± 0.0[e]

[a]Significant difference between high-level and low-level groups across test sessions ($P < 0.05$).
[b]Significant difference within high-level from the first to the second and fourth test sessions ($P < 0.05$).
[c]Significant difference between low-level and high-level groups during the first, third, and fourth test sessions ($P < 0.05$).
[d]Significant difference between high-level and low-level groups on evaluation and prediction ($P < 0.05$).
[e]Significant difference between low-level and high-level groups during the first and the fourth test sessions ($P < 0.05$).
[f]Significant difference within low-level from the first to the second test session and from the third to the fourth test session ($P < 0.05$).
[g]Significant difference within low-level from the second to the third test session ($P < 0.05$).

statements were verbalized compared with those coded as prediction and deep planning ($P < 0.05$).

There was a significant group–type of statement interaction ($F_{2.19,\ 30.62} = 5.17$, $P = 0.01$, $\eta_p^2 = 0.269$). The low-level participants made significantly more statements coded as cognitions compared with the high-level participants, whereas the high-level participants provided more deep planning statements compared with their low-level counterparts (both $P < 0.05$).

The type of statement–test session interaction ($F_{9,\ 126} = 1.95$, $P = 0.05$, $\eta_p^2 = 0.122$) was sufficiently close to being significant to warrant discussion (Table 4). *Post hoc* analysis showed that the deep planning statements decreased significantly from the first to the second and fourth test sessions ($P < 0.05$).

There was a significant group–type of statement–test session interaction ($F_{4.96,\ 69.39} = 4.88$, $P = 0.001$, $\eta_p^2 = 0.259$). The low-level participants verbalized significantly more cognition statements during the first, third, and fourth test sessions compared with high-level participants. When compared with their low-level counterparts, the high-level participants verbalized significantly more evaluation and prediction statements in the beginning of the second half (the third test session) and deep planning statements during the first and the fourth test sessions ($P < 0.05$). Moreover, the high-level group made significantly fewer deep planning statements in the second and fourth test sessions compared with the first test session ($P < 0.05$). In contrast, the low-level participants decreased the number of cognition statements at the end of each half as well as evaluation statements between the second and the third test sessions ($P < 0.05$; see Fig. 2).

DISCUSSION

This study was designed to examine differences in anticipation between high- and low-level soccer players and how intermittent exercise influences the perceptual-cognitive processes underpinning such judgments. A novel method was used, requiring participants to make anticipation judgments in response to realistic filmed sequences of offensive play from the perspective of a central defender, while simultaneously recording gaze behaviors and verbal reports of thinking. The main finding was that intermittent exercise leads to a significant decrement in anticipation accuracy in both high- and low-level soccer players. However, high-level players demonstrated superior anticipation performance when compared with their low-level counterparts across the test sessions, with this superiority being underpinned by differences in gaze behaviors and thought processes.

An intermittent, soccer-specific exercise protocol was used to simulate the physiological demands of a match. This

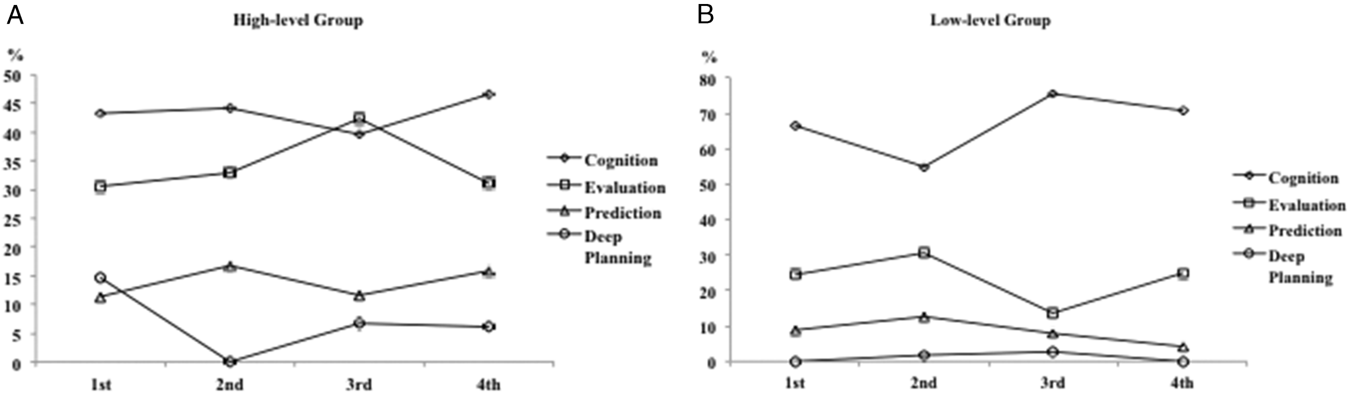

FIGURE 2—Mean type of statements values (%) for (A) high-level and (B) low-level groups across the intermittent exercise protocol.

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protocol has activity patterns with durations similar to those observed in real match play (4,5,10,24). Moreover, the exertion levels achieved during exercise in this study, as assessed by the HR and La concentrations, were comparable with those observed in other laboratory-based studies (4,10) and during real soccer matches (2,13). Participants were exposed to an increased circulatory strain, especially during the last test session in each half (4,17). The involvement of anaerobic glycolysis, assessed by the La concentrations, increased significantly at the end of each half, with mean La concentrations in the range observed by Bangsbo (2) and Krustrup et al. (13) during soccer games (3–6 $mmol \cdot L^{-1}$). However, there are limitations to the approach. The protocol did not include activity changes or soccer-specific actions involving the ball or physical contact and challenges that are characteristic of match play (4). The exercise was performed on a motorized treadmill using cyclic sequences of categorical activity patterns defined by locomotion speeds, which is somewhat different from real soccer match play where sequences of activity patterns are not predictable and players are required to make decisions that are specific to the unique task, situation, and context evident during each match. Finally, the intensity of activity patterns in the exercise protocol is defined by the external load (speed), which does not take into account differences in mechanical efficiency in the transition across adjacent activity categories and the possible energy savings (9).

The high-level participants used a different gaze strategy (FD, NF, NFL, and amount of time fixating in specific locations) when compared with their low-level counterparts, albeit the nature of the search behaviors changed across the exercise protocol for both groups of players. At the beginning of each half, the high-level participants fixated on significantly more locations in the visual display and used more fixations of shorter duration across all conditions compared with the low-level players. These skill-based differences in search behaviors mirror those previously reported and are presumed to reflect more efficient use of processing resources (21–23,25,30). For example, Williams and Davids (31) reported that a search strategy involving more fixations of shorter duration is an advantage, particularly during dynamic open-play situations involving 11 versus 11 players. Such a search strategy likely enhances the player's awareness of more pertinent or relevant information (e.g., positions and movements of teammates and opponents and areas of free space that may be exploited or exposed). At the end of each half, as the physical demands increased considerably, high-level participants used significantly less fixations of longer duration to fewer locations (see Table 2), and this was accompanied by a decline in anticipation accuracy. However, the high-level players still fixated on a greater number of locations compared with low-level players across the intermittent exercise protocol (see Table 3), which likely contributed to their ability to maintain superior performance when compared with the low-level players as the physical demands increased.

The low-level players also showed distinct changes in their gaze behaviors across the exercise protocol; notably, these participants used significantly more fixations of shorter duration to a larger range of visual locations at the end of the intermittent exercise compared with early in each half. However, these changes in gaze behaviors were not accompanied by any improvements in performance with these participants recording extremely low scores at the end of the second half (i.e., the fourth test session; see Table 1). It seems that these changes in gaze behavior resulted in search strategies that were more akin to those used by high-level players, yet these changes did not translate into any meaningful improvement in performance, and the very low accuracy scores suggest that the nature of the information extracted is more important than the underlying gaze behaviors used by low-level players.

When compared with low-level participants, high-level players showed differences in the manner in which information was processed across the intermittent exercise protocol. The high-level participants generated a great number of verbal statements coded as evaluation and prediction (at the beginning of the second half) and deep planning statements (during the first and the fourth test sessions). In contrast, low-level players made a greater proportion of statements that merely recalled current actions or descriptions of current events during the intermittent exercise protocol. These data suggest that high-level participants activate more elaborate domain-specific memory representations when compared with low-level players, leading to engagement of higher-level thought processes that enable events and potential outcomes to be considered, assessed, and predicted rather than merely monitored in their present state (8,14,21,27). Moreover, to deal with the increasing demands placed on them by the intermittent exercise protocol, the high-level players are more likely than their low-level counterparts to allocate resources more efficiently, engaging more higher-level thought processes that enable them to better predict and plan for future events rather than dealing with current events (3,6).

In conclusion, novel data are reported, which illustrate how prolonged intermittent exercise resulted in adaptive changes in gaze behavior and thought processes in high- and low-level soccer players. Although performance was negatively affected by prolonged intermittent exercise across both groups of players, the changes in search behaviors and thought processes resulted in less marked decrements in anticipation performance in high-level players when compared with low-level counterparts. The low-level players were more negatively affected by the intermittent exercise conditions, particularly in the fourth test session, resulting in marked decrements in performance accuracy. Prolonged intermittent exercise significantly influences the perceptual-cognitive processes underpinning anticipation and can negatively influence the accuracy of judgments. These findings highlight the need to design training programs that better insulate players from the negative effects of incremental exercise on performance as well as to enhance the perceptual-cognitive skills that underpin superior anticipation in soccer.

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