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ARTICLE

Effect of Exercise Intensity on Psychomotor Vigilance During an Incremental Endurance Exercise in Under-19 Soccer Players

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The aim of this study was to analyze the acute effects of an incremental resistance test on psychomotor vigilance in 16 soccer players under-19 years old (age 16.42 ± 0.85 years). Borg 15-point subjective perception of effort scale, the psychomotor vigilance task test, and the Yo-Yo intermittent recovery test were used. Four evaluation sessions were conducted with different intensities of efforts (30%–40%, 60%–75%, 80%–90%, and 100%) on different days (counterbalanced order). A repeated-measures analysis of variance was performed in the reaction time of the psychomotor vigilance task. The results showed that participants responded faster during efforts between 80% and 90% of maximal oxygen uptake (501.20 ± 70.77 ms). From that threshold, the players decreased their performance through a longer reaction time (601.23 ± 85.05 ms; *p* value < .001). The main findings were that the reaction time performance was worse at the lowest and highest effort conditions (5 and 17 km/hr, respectively). This fact helps to focus on the importance of designing and proposing training tasks with medium–high efforts to provoke optimal reaction times in young soccer players.

Keywords: football, reaction time, cognitive performance, executive functions

Soccer is a dynamic team sport in which the behavior of players is regulated by contextual factors and an action–perception cycle that ultimately determines

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performance (Mann et al., 2007). Naturally, the way players perceive more information is dependent on a triad of constraints (environmental, task, and organismic/individual) which interact concurrently (McGarry et al., 2013). Among the functional individual constraints, fitness level, technical skills, tactical expertise, or psychological factors can play a critical role in explaining the way a player interacts with the environment and ultimately succeeds in the challenge promoted by the task (Davids et al., 2003). Thus, physical, technical, tactical, and psychological factors contribute to determining individual success in a specific sport and identifying talent (Bergkamp et al., 2019).

A soccer player's skill to control their actions in a game situation is a requirement reflecting fast and accurate tactical decision making, and rapid implementation of a motor task during intermittent game actions (Frýbort et al., 2016). In this sense, soccer players are required to anticipate and respond constantly in an altering, relatively unpredictable situation on the field (Huijgen et al., 2015). Therefore, within the multidimensional nature of soccer talent, there has been a recent interest in psychological characteristics (Murr et al., 2018). Especially, in soccer players, several factors could influence attention moderation such as psychomotor fitness (Chmura et al., 2002; Huijgen et al., 2015). These cognitive skills are essential not only for the assessment of specific game circumstances through fast, precise, and effective cognition (as well as reaction and anticipation of player's own movements and those of his partners and opponents), but also for information processing in the central nervous system and efficient decision making, especially under environments of cumulative fatigue (Chmura et al., 2002).

Several executive functions such as motor inhibition, attention, and visuospatial working memory might be relevant for high performance in team sports that need quick anticipation and adaptation due to the continuous changes of the game (Verburgh et al., 2014). In this regard, open-skill sports, such as soccer, require high levels of visual attention and fast, flexible decision making and action execution (Taddei et al., 2012). Attention can be divided into four categories, such as orienting attention, selective attention, divided attention, and sustained attention (Memmert, 2009). A recent study has shown that attention and the control and capacity functions of working memory interact to predict sport performance (Vaughan & Laborde, 2021). High levels of attention will allow young soccer players with similar training time and at similar competitive levels to show better responses regarding the tactical actions of the game (de Andrade et al., 2020). In this sense, highly talented youth soccer players outperform youth amateur players in suppressing ongoing motor responses and have the ability to achieve and maintain a state of alertness, which could be essential to succeed in soccer (Verburgh et al., 2014). The difference between an attentive player and a distracted player can destabilize the entire team and lead to poor performance (Fetean et al., 2019).

In particular, vigilance is the ability to identify infrequent critical events through long periods of time. In tasks of sustained attention across time, it produces a vigilance decrement (Luna et al., 2018). In highly practiced vigilance tasks in which participants show high levels of detection of signals and low levels of false alarms, reaction time (RT) may become the critical measure of performance; therefore, increased RT can be associated with decreased detection rates (Sarter et al., 2001). As a result, there is a functional relationship between attention and RT (Carlson et al., 1983). In particular, RT measures correlate with attention and perceptual speed as well as with general intelligence (Carlson et al., 1983). One of the most investigated factors affecting RT is "arousal" or state of attention (Kosinski, 2008). Especially in soccer players, several factors could influence attention modulation such as the characteristics of motor tasks and internal state (relating to motivation, emotions, and rest–fatigue; Fetean et al., 2019), talent and soccer experience (Lex et al., 2015; Verburgh et al., 2014), muscular tension (Kosinski, 2008), or exercise intensity (Kashihara et al., 2009). In addition, the type of physical activity, intensity, and activity length may have an influence on the acute effect of a physical activity bout on attention (Janssen et al., 2014).

It is noteworthy that exercise intensity is a relevant moderator on cognitive performance. In this regard, the inverted-U hypothesis indicates that moderate-intensity exercise will have the greatest effects while the drive theories suggest that the greatest effects will be observed during high intensity exercise (Chang et al., 2012). Therefore, the relationship between RT and an acute exercise effect has been associated with the intensity of the workloads employed (Huertas et al., 2011). Specifically, acute exercise has a moderate positive effect on cognition speed (Rezaei et al., 2019). More concretely, acute exercise around the anaerobic threshold could improve cognitive functions facilitated by cerebral blood flow and neurotransmitters in the central nervous system, as well as psychological factors (Kashihara et al., 2009). However, the psychophysiological mechanism that causes this phenomenon remains unclear (Kashihara et al., 2009).

Although no significant effect of the level of arousal on the speed of decision making was found among expert female soccer players, the accuracy of decision making was significantly affected by exercise intensity (Rezaei et al., 2019). Conversely, other authors indicated that exercise does not influence the accuracy of decision making; however, the speed of decision making, regardless of the player's experience, improved with increased exercise intensity (Fontana et al., 2009). Unlike previous studies, Paradis et al. (2016) showed that decision-making performance may not be affected by physical effort (Paradis et al., 2016). In addition, researchers noted that the relationship between exercise intensity and attentional breadth is moderated by physical fitness levels (Hüttermann & Memmert, 2014). Therefore, studies on the effects of acute bouts of cardiovascular exercise on cognitive performance show contradictory results due to methodological differences (e.g., exercise intensity, cognitive function assessed, participants' aerobic fitness level; Labelle et al., 2013).

On the other hand, dual-task methodology is a test in which a participant simultaneously performs a cognitive and a motor task (Broglio et al., 2005). A review of the literature reveals that dual-task tests are used to analyze the attention demands of motor tasks or the effects of simultaneous tasks on motor performance; these are influenced by several factors such as age, level of skill, and the nature of the tasks performed (Huang & Mercer, 2001). There are not many studies that dig deeper into this relevant topic. However, the systematic review of Moreira et al. (2021) concludes that dual tasks acutely and chronically impact motor and cognitive performance (working memory and attentional control). Accordingly, for simple cognitive tasks, a reduction of cognitive performance is related to the allocation of attention in a dual-task model. Therefore, with a high physical fitness level, the physiological task constraints are minimal. The attentional requirements related to the control of movement decrease, and the RT performance can be improved (Brisswalter et al., 2002).

To sum up, RT indicates the speed of both cognitive and motor functioning, and is a good marker of performance in several sports (Özdemir et al., 2010). To analyze RT performance under exhaustive conditions can allow us to determine the deterioration of perceptual skills in competitive sport settings (Browne et al., 2017). Therefore, in accordance with Browne et al. (2017), more research is needed to evaluate more cognitive domains, longer durations/types of exercise, and populations trained at high intensities to clarify the relationship between physical exercise and cognition. The purpose of this study was to analyze the acute effects of an incremental endurance exercise on RT in young soccer players.

Materials and Methods

Experimental Approach

This study followed an observational analytic counterbalanced crossover design. Young male soccer players were recruited from a local soccer team. The data collection occurred in August 2021, 5 weeks after the beginning of the preseason. The day of the assessment was preceded by 72 hr of absence from training or matches. The data collection occurred at a gym, adjacent to the soccer field, in an indoor facility with an average temperature of 20–22 °C and 35%–45% relative humidity.

Participants

In total, 16 young male soccer players (age = 16.4 ± 0.85 years, height = 171.9 ± 5.35 cm, weight = 70.7 ± 5.29 kg, body max index = 24.1 ± 1.98 kg/m^2) from one nonprofessional team in the region of Andalucía, Spain (see Table 1 for descriptive information) participated in the present study. Concerning the sample size, the following equation was used: $\textit{Sample Size} = Z2 \times (p) \times (1 - p)/C2$, where Z = confidence level (95%), $p = 0.05$, and C = margin of error 0.05. The assessed players regularly trained twice a week (90 min per session) and played one match a week. The training sessions were based on technical and tactical content development (60% of training time), technical skill improvements (20% of training time), and general improvements in physical condition (20% of training time). Generally, training sessions comprised a warm-up, main part, and cooldown.

The eligibility criteria for selecting the participants were (a) reporting normal vision and no history of any neuropsychological impairments that could affect the results of the experiment, (b) being an active player of the federated team, (c) not presenting any injuries during the last 2 months, (d) giving consent, and (e) participating in all sessions during the study period. Prior to the day of data collection, it was requested that the players not consume any stimulating drink or food, and maintain regular sleep and dietary habits. The participants' parents were provided with information about the main aims of the investigation and signed an informed consent form. All soccer players in this study were treated according to the American Psychological Association guidelines, which ensure the anonymity of participants' responses. The study was conducted in

Table 1 Physiological Parameters in the Experimental Protocol (Mean ± *SD*)

Yo-Yo IR1		
Stage (*n*)	**Distance (m)**	**VO_2max (ml·min^{-1}·kg^{-1})**
17.26 ± 0.64	1,488.57 ± 201.03	48.90 ± 1.69

PVT while running on treadmill			
Effort condition	**HR (bpm)**	**% of HR_{max}**	**Speed (km/hr)**
Trial 1	104.64 ± 4.34	30–40	5
Trial 2	149.43 ± 5.60	60–75	9
Trial 3	180.93 ± 7.31	80–90	14
Trial 4	199.50 ± 4.18	100	17

Note. VO_2max was estimated by the next equation: Yo-Yo IR1 test: VO_2max (in milliliters per minute per kilogram) = IR1 distance (in meters) × 0.0084 + 36.4 (Bangsbo et al., 2008). bpm = beats per minute; HR = heart rate; VO_2max = maximal oxygen uptake; HR_{max} = maximal HR; Yo-Yo IR1 = Yo-Yo intermittent recovery test—Level 1; PVT = psychomotor vigilance task.

accordance with the ethical principles of the Declaration of Helsinki for human research and was approved by the Research Ethics Committee of the Pontifical University of Comillas (Dictamen 2021/74).

Equipment and Materials

A treadmill (X-Trend, Telju) was used to perform the different sessions at different intensities. In addition, a M400 Polar monitor (Polar Electro) was used to monitor and record heart rate (HR) during all sessions.

The maximal oxygen uptake (VO_2max [in milliliters per minute and kilogram]) was estimated after the Yo-Yo intermittent recovery test—Level 1 (Yo-Yo IR1) using the following equation: VO_2max = final distance (in meters) × 0.0084 + 36.4.

An iPhone 5s (iOS version 12.4.5; Apple) was used to present the stimuli for the psychomotor vigilance task (PVT), control stimulus presentation, and data collection. This device was previously blocked for any other type of notification. The responses of the participants were recorded by pressing the screen of the device that was connected with a video graphics array cable to an Epson Projector EB-501 (215 W, 3,300 LM, Seiko Epson Corporation). The center of the screen was situated 200–250 cm from the participant's head and at eye level. The iPhone is attached to the participants to allow them to run comfortably with the device. See Figure 1, for more information.

Anthropometric Measurements

Body weight (to the nearest 0.1 kg) was measured without shoes using a bioelectrical impedance analysis device (Tanita BC-730, Tanita). Height (to the

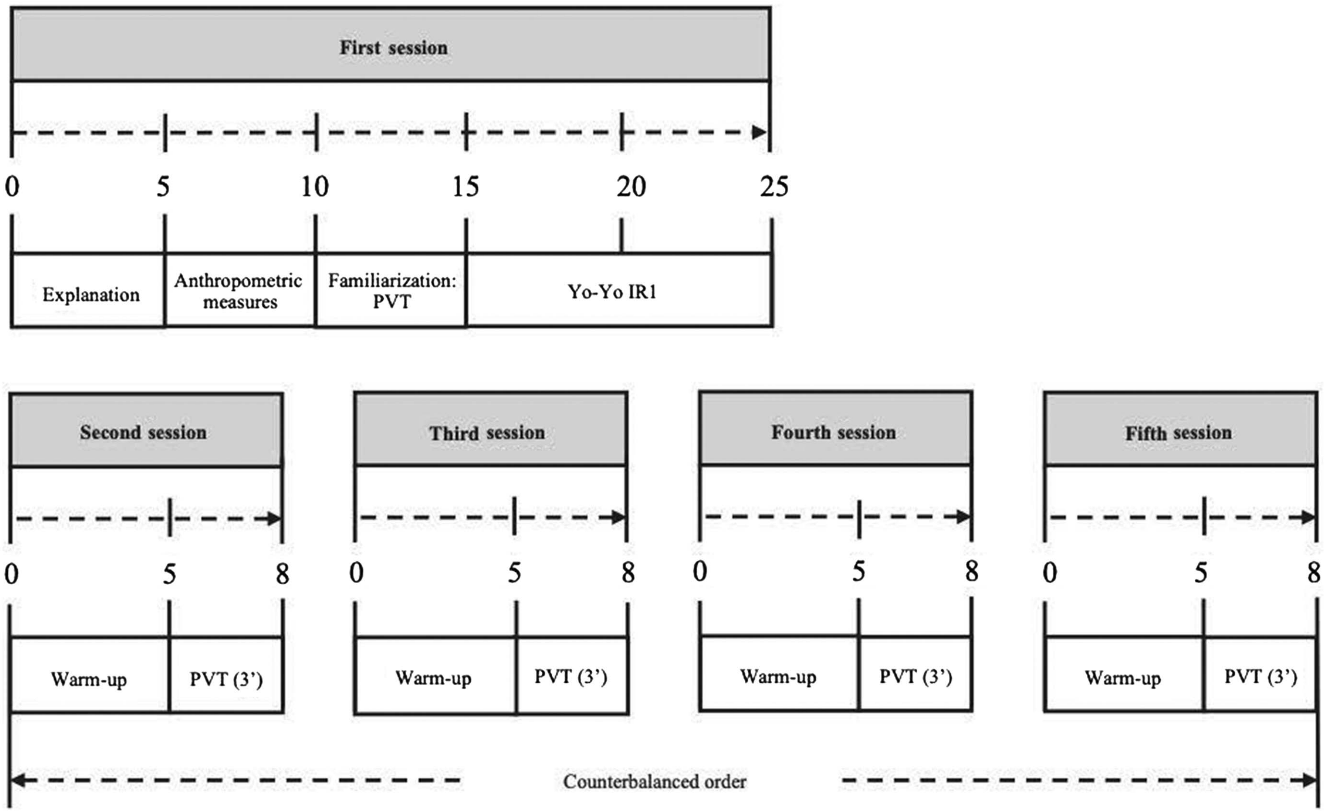


Figure 1 — Experimental set. Soccer player performing PVT while running on treadmill (see text for full description). PVT = psychomotor vigilance task; Yo-Yo IR1 = Yo-Yo Intermittent Recovery Test Level 1.

nearest 0.1 cm) was measured using a stadiometer (Type SECA 225, SECA). Body mass index was also calculated.

Yo-Yo Intermittent Recovery Test—Level 1

The Yo-Yo IR1 test consisted of repeated 20-m runs back and forth between two markers with a progressive increase in speed, regulated by an audio player. Between each 40-m run, the athlete recovered with 10 s of jogging (shuttle runs of 2×5 m). Yo-Yo Level 1 starts at 10 km/hr and Level 2 at 13 km/hr, with both levels progressively increasing in speed throughout the test. The test was completed when the athlete reached voluntary exhaustion or failed to maintain their running pace in synchrony with the audio recording. The number of completed levels and shuttles, and the total distance covered were recorded at the end of the test. The total distance (in meters) was extracted as the outcome.

Cognitive Measurement Using the Psychomotor Vigilance Task

The PVT consisted of presenting a gray screen with a chronometer that appeared at the center of the screen and was used to control the presentation of stimuli and the collection of data. The data began to be completed at the speed of a real stopwatch and was presented on the screen after a random time interval that ranged between 2.000 and 10.000 ms. The participants had to press the center of the device as quickly as possible when the circle began completing. Verbal and written instructions were given prior to the start of the PVT in every session, requiring that participants focus on the center of the screen, try not to move their eyes, and respond as quickly as possible (while avoiding anticipation errors) as soon as the chronometer started. The task included a single block lasting 3 min. The exact number of trials of each participant depended on the latency of the individual's response. This protocol is found in the study of González-Fernández et al. (2022). Participants completed a familiarization task as a control measure to verify that they had understood the operation of the PVT. All subjects completed the same number of PVTs (see information provided in the "Procedure" section).

Procedure

Researchers visited the field on one day and the laboratory on four different days to (a) collect anthropometrical data and familiarize themselves with the Yo-Yo IR1 and PVT; (b) conduct Trial 1; (c) Trial 2; (d) Trial 3; and (e) Trial 4, in counterbalanced order. Soccer players were analyzed at the same time of day (4:30–8:00 p.m.) and all visits were at least 48 hr but no more than 72 hr apart. Environmental conditions (space, temperature, and humidity) were controlled during the experimental protocol sessions. The Polar HR monitor was attached around the chest of the participant upon arrival at the laboratory. Each participant completed five experimental sessions. Before the start of the sessions, all participants were instructed to wear comfortable sports clothes and running shoes, as this was vital for the appropriate administration of the battery and experimental sessions (Figure 2).

First Session

First, we ensured that each participant signed the informed consent form detailing the possible benefits and risks of participating. In order to ensure accurate and reliable data recording (especially for the physical fitness assessments), one main researcher controlled every task and test. During the first session, the order of assessment was (a) anthropometry (height and body weight), (b) PVT for 3 min, and (c) Yo-Yo IR1.

Second, Third, Fourth, and Fifth Sessions

The young soccer players completed four experimental sessions on separate days and in a counterbalanced order. In each session, after a 3′ warm-up, participants performed the PVT for 3′ while running either at 40% of the VO_2max, 60% of the VO_2max, 80% of the VO_2max, or 100% of the VO_2max. The participant's HR was monitored throughout the effort sessions to ensure the maintenance of the proper intensity, and the ergometer resistance in steps of 0.01 km/hr was reduced or increased as necessary.

Statistical Analysis

For data processing, we used adequate statistical methods to calculate percentages, and central and dispersion parameters (arithmetic mean and *SD*). Descriptive statistics were calculated for each variable (Table 1). Before any parametric statistical analyses were performed, the assumption of normality was tested with the Kolmogorov–Smirnov test on each variable. A repeated-measures analysis of variance (ANOVA) test with the effort condition (40%, 60%, 80%, and 100% of the VO_2max) and time-on-task (3 min) was performed. This 3-min duration of the PVT was divided into blocks of 1 min to investigate the time course of the RT. The experiment trials with RT below 100 ms were assumed to represent anticipation error and were discarded from the analysis. The final extracted outcomes were the mean RT of each player for each condition. Furthermore, a repeated measures ANOVA was used to analyze the RT and HR data. Statistically significant effects were further analyzed by paired samples *t* tests corrected with a Holm–Bonferroni for multiple comparisons. Effect size is indicated with Cohen *d* for *t* tests and partial eta-squared for *F*s. The Greenhouse–Geisser correction was applied when sphericity was violated. Statistical analyses were performed using SPSS (version 26) for Mac. For all analyses, significance was accepted at $p < .05$.

Results

Heart Rate

A repeated measures ANOVA with participants' mean HR data from the experiment (Table 1) revealed a significant main effect of effort condition, $F(3, 39) = 1{,}141.6$, $p < .001$, $\eta_p^2 = .99$. Paired samples *t* tests showed significant differences between all conditions, all ps $< .001$. In Trial 4, HR was the highest value (199.5 beats per minute) in 17 km/hr on treadmill, and the lowest value was in Trial 1 in 5 km/hr.

Psychomotor Vigilance Task

A repeated measures ANOVA, with participants' mean RT, revealed a significant main effect of effort condition, $F(3, 45) = 19.452$, $p < .001$, $\eta_p^2 = .56$; Figure 1. As shown in Figure 3, participants responded faster at 80% VO_2max effort (501.20 ± 70.77 ms) followed by 60% VO_2max effort (522.97 ± 53.39 ms), 40% VO_2max effort (542.57 ± 65.66 ms). The lowest performance was found in the 100% VO_2max effort condition (601.23 ± 85.05 ms). The main effect of time-on-task, and interaction between effort condition and time-on-task was marginally significant, $F(6, 90) = 2.05$, $p < .06$, $\eta_p^2 = .12$.

Pairwise comparisons showed significant differences in RT between the 80% VO_2max effort and the 100%, 60%, and 40% VO_2max effort conditions, $t(15) = -6.85$, $p < .001$, $d = -1.60$; $t(15) = -6.85$, $p < .01$, $d = -0.40$; and $t(15) = 3.00$, $p < .008$, $d = -0.69$, respectively. Comparisons between the 60% VO_2max trial and the 100% VO_2max trial showed $t(15) = -5.40$, $p < .001$, $d = -1.45$. In addition, comparison between the 40% VO_2max effort condition and 100% VO_2max trial was significant, $t(15) = -3.17$, $p < .006$, $d = -0.98$. However, the comparison between

Figure 2 — Schematic representation of the experiment (see text for full description).

40% VO_2max trial and 60% VO_2max trial, $t(15) = 1.75$, $p < .09$, $d = 0.38$ failed to reach statistical significance. Figure 4 shows the differences between trials at 1, 2, and 3 min of exercise. From Minute 2, significant differences in RT were observed between Trial 4 with Trials 2 and 3.

Discussion

The purpose of this study was to analyze the acute effects of incremental endurance exercise on psychomotor vigilance in young soccer players. Similar to previous studies (Frýbort et al., 2016; Chang et al., 2012), the major findings of this study were that exercise intensity is a moderator of RT, but had the inverted-U shaped curve (from low-intensity to high-intensity exercise). At an intensity of 80%–90% of maximal HR, the best RT responses were obtained. Therefore, increased arousal during moderate-intensity exercise resulted in a faster speed of processing (McMorris & Hale, 2012). Most researchers who have analyzed the effect of physical exercise on cognitive performance have shown that psychomotor performance improves with exercise-induced activation of the central nervous system and deteriorates after exceeding a certain work intensity according to an inverted-U relationship (Pesce et al., 2007). A relationship between RT and plasma catecholamines fits the U-shape curve (Chmura et al., 1994). The effect of faster RT under physical load indicates that submaximal workloads have a facilitation effect on reaction speed in tasks which require cognitive effort (Pesce et al., 2007).

This result may be explained by the fact that moderate aerobic exercise modulates the functioning of phasic alertness by increasing the general state of tonic vigilance (Huertas et al., 2011). In addition, during moderate- and high-intensity exercise conditions, the cognitive workload required to perform at such velocity on a treadmill is very high. Thus, when comparing the resting condition with the exercise conditions, there is an effect of exercise and a strong dual-task effect (Smith et al., 2016). The positive effects of physical exercise on RT increase to an optimal point that may be associated with the lactate threshold (Kashihara et al., 2009), or other parameters such as VO_2 max and HR.

Several previous studies demonstrated that the speed of a motor response is dependent on physiological fatigue manifestation and exercise intensity (Chmura et al., 2002; Klatt & Smeeton, 2021; Kokštejn et al., 2016). A similar study showed that under a rest condition as well as under physical exercise conditions of 70% (moderate load) and 90% (high load) of their HR reserve, soccer-related decision-making, and perceptual and attentional capabilities remained constant in the moderate-load condition and deteriorated in the high-load condition compared with the rest condition (Klatt & Smeeton, 2021). In addition, in elite young soccer players, high-intensity exercise has a negative effect on visual-motor response time in comparison with moderate-intensity exercise (Kokštejn et al., 2016). Similarly, a previous study performed with young soccer players showed that a highest psychomotor response, recorded by choice RT during an incremental cycling exercise, was recorded at 76% $\dot{V}O_2$ max ($HR = 164 \pm 4.7$ beats per minute; Chmura et al., 2002). Moreover, fitness and soccer experience could be moderators of this relationship (Chang et al., 2012; Kokštejn et al., 2016; Labelle et al., 2013).

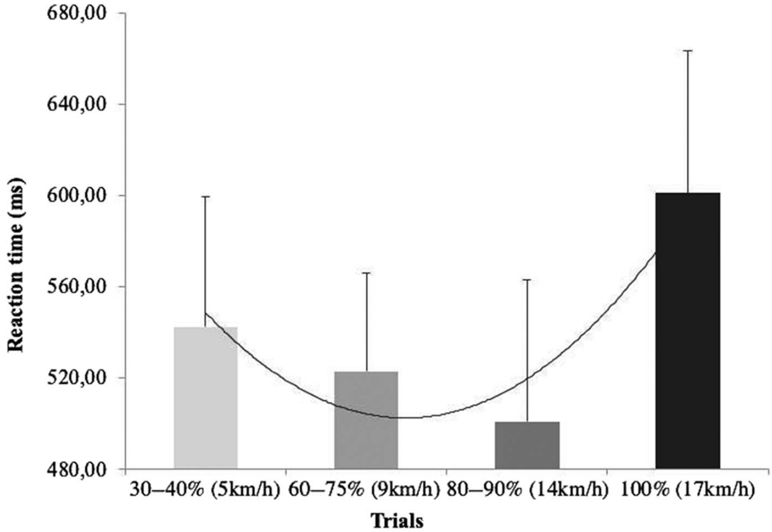
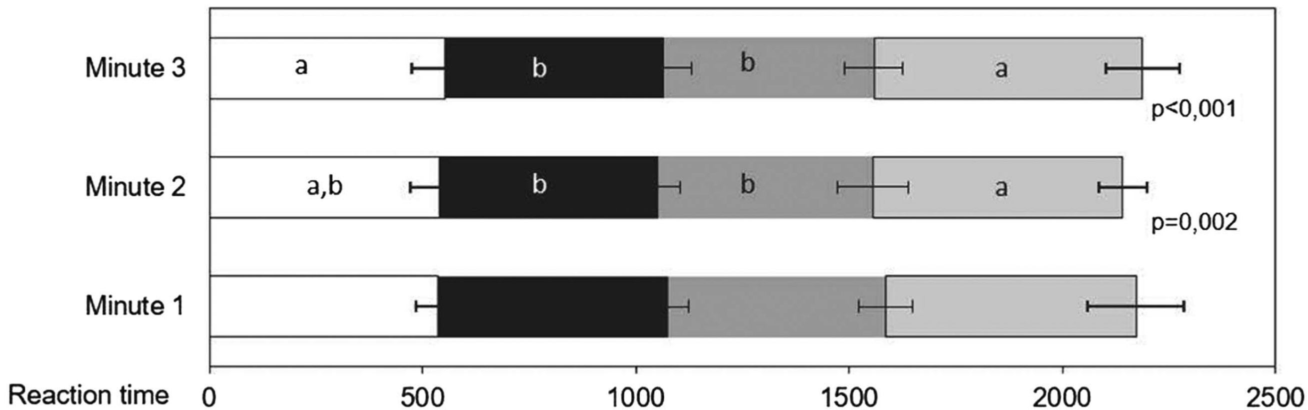


Figure 3 — Psychomotor vigilance task. Participants' mean reaction time (±*SE*) as a function of exercise intensity.

However, in the current study, physical fitness did not influence RT performance. The effect of acute high-intensity exercise on cognitive performance in trained individuals is dependent on the specific cognitive domain being assessed (Browne et al., 2017). From a practical point of view, visual attentional training should be incorporated into the cognitive training paradigm in soccer players.

Strengths and Limitations

The rigorous effort conditions and the methodological design are the strengths of this study. Thus, confidence in the results can be ensured. Stimulant effort conditions improved RTs in psychomotor vigilance in soccer players under 19 years of age in the last stage of training. u One possible limitation of the current study could be its ecological validity due to the use of laboratory testing conditions; in addition, the precision of tasks, such as errors in decision making, as well as other complex tasks, were not assessed. It has been suggested that some soccer players, for example, started with Trial 4 and others with Trial 2, which could affect subsequent training sessions. We could not control this variable, thus it was common for all study participants. Possibly, it could be understood as a strength since the results obtained show large sizes. Considering practical applications, this study provides relevant information that ensures positive effects at the vigilance level, a very important cognitive concept in soccer during resistance exercises with an intensity greater than 60% and less than 90%. The relevance in the knowledge of thresholds in soccer workloads is known; this study contributes in an unprecedented way to the effect this has on the soccer player's vigilance.



	Minute 1	Minute 2	Minute 3
Trial 1	535,086875	540,48625	552,14375
Trial 2	540,216875	513,45	515,24625
Trial 3	511,456875	501,288125	490,875625
Trial 4	586,0625	587,3975	630,240625

Figure 4 — Differences in RT between trials at 1, 2, and 3 min of exercise. Different subscript letters indicate significant differences ($p < .01$). RT = reaction time.

Conclusion

Psychomotor vigilance during an incremental endurance exercise in young soccer players was influenced by exercise intensity, achieving the best performance at an intensity of 80%–90% of maximal HR. Moreover, the profile of RT performance had a U-shaped curve. In addition, the lowest efforts caused long RTs. These facts offer great practical utility to focus on the importance of designing and programming tasks at medium–high thresholds that cause optimal performance of psychomotor vigilance with low RTs.

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