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Playing sports to shape attention: enhanced feature-based selective attention in invasion sports players

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A B S T R A C T

Prolonged engagement in sports that place high demands on cognitive functions may result in perceptual and cognitive enhancements. However, empirical evidence on the effect of sport-specific constraints on attentional mechanisms remains limited. Here, we address this gap with two experiments that examine how cognitive demands posed by different sports (invasion and non-invasion) affect two subcomponents of selective attention – feature-based (FBA) and spatial-based (SBA). In Experiment 1, 20 invasion sport athletes and 20 gender-matched controls completed a visual search task and a flanker task to assess FBA and SBA, respectively. Our results showed that invasion sports athletes exhibit enhanced task-specific feature-based attentional skills in the initial stages of the visual search task. Conversely, no group differences emerged in the flanker task, suggesting that invasion sports practice effect is specific to FBA rather than to general selective attention. In Experiment 2, we investigated whether this effect was related to sport type. To do so, we replicated Experiment 1 with 22 non-invasion sport athletes and 23 gender-matched controls. The results did not reveal any group difference in measures of FBA and SBA. These findings indicate that invasion sports practice selectively enhances FBA, suggesting that sport-specific cognitive demands shape and refine cognitive abilities.

1. Introduction

Humans' ability to successfully perform everyday tasks grossly depends on how effectively we can deploy visual attention. Despite the impressive capabilities of the visual system, visual performance is ultimately constrained by the limited amount of cognitive resources (Attwell & Laughlin, 2001; Lennie, 2003). Thus, the available processing capacities must be optimally allocated to behaviorally relevant sensory inputs at the expense of distracting information.

Humans can engage top-down control of attentional processes by selectively directing attention to specific locations (spatial-based attention, SBA) or to relevant features (feature-based attention, FBA). Through spatiotopic maps, SBA prioritizes specific locations in the visual field to be monitored for salient or behaviorally relevant information (Bisley & Goldberg, 2010; Silver & Kastner, 2009). Conversely, FBA involves attending to a particular feature (or set of features) over others, and it appears to be independent of spatial location (Anton-Erxleben & Carrasco, 2013; Ling et al., 2009; Störmer & Alvarez, 2014). Therefore, as SBA and FBA guide an individual's selective attention in everyday life (Moore & Zirnsak, 2017), it is crucial to understand the role these processes play in daily activities and how they benefit from repetitive engagement in tasks that demand the optimal deployment of attentional resources, such as competitive sports (Abernethy, 1990; Davids et al., 2005; Memmert, 2009).

The cognitive component skills approach (Voss et al., 2010) investigates how sports expertise relates to cognitive performance. It offers a comprehensive framework for assessing perceptual-cognitive skills associated with prolonged athletic training and for evaluating domain-specific cognitive adaptations that generalize outside of sports settings (Kida et al., 2005; Krenn et al., 2018; Perrone et al., 2023; Scharfen & Memmert, 2019). Within this context, cognitive functions, such as attention, play a fundamental role in athletes' performance (Memmert, 2009; Furley & Wood, 2016), even resulting in a significant predictor of their success (Vestberg et al., 2012; Cona et al., 2015). An extensive body of literature has demonstrated an association between sport expertise and enhanced perceptual-cognitive abilities, including attention (e.g., Di Russo et al., 2003; Mcauliffe, 2004; Piras et al., 2010; Zwierko et al., 2010; Faubert, 2013; Piras et al., 2014; Roca & Williams, 2016; Meng et al., 2019; Kim et al., 2019; Petilli et al., 2020; for reviews, see Mann et al., 2007; Voss et al., 2010; Scharfen & Memmert, 2019; Brimmell et al., 2022), suggesting that prolonged engagement in sports activities that place high demands on cognitive functions may have

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positive effects on them (Alves et al., 2013; Castiello & Umiltà, 1992; Cowan, 2005; Klatt & Nerb, 2021; Memmert et al., 2009; Posner, 1980). Notably, similar effects have also been observed with video game engagement (Bavelier & Green, 2019; for a comparison between sports and video games, see Petilli et al., 2020). Moreover, such effects on cognitive functioning appear to be supported by structural and physiological changes at the cortical level, suggesting that sports training induces brain adaptations to meet the cognitive demands posed by sports practice (Wang et al., 2020; Wu et al., 2012; Yamashiro et al., 2015; Yarrow et al., 2009).

However, since not all sports have the same requirements and, in turn, produce the same cognitive effects, it is crucial to consider the impact that different sports have on the various cognitive functions. In fact, each sport implies unique and sometimes different characteristics determined by the practice environment – e.g., the playing field, the number of teammates and opponents, the game strategies, and the possibilities and constraints defined by the sports' rules – which in turn result in training-induced, sport-specific adaptations in perceptual and cognitive skills (Mann et al., 2007; Pérez et al., 2014). For instance, previous works have linked enhanced attentional sensitivity to automatic detection of peripheral stimuli in sport-congruent attentional breadth dimensions (Petro et al., 2021), as well as expert superiority in goal-relevant information pick-up across the entire breadth of the visual field (Ryu et al., 2015). Additionally, research has shown that athletes who practice strategic sport types (i.e., sports including multiple teammates, tactical formations, and which require the ability to allocate attention to both the target-projectile and the various players – e.g., rugby, basketball) tend to have enhanced stimulus-driven attention and motor inhibition (Castiello & Umiltà, 1992; Meng et al., 2019; Wang et al., 2020; Yamashiro et al., 2015; Yu & Liu, 2021), while fine sensory-motor skills were reported in athletes in interceptive sports (i.e., sports that require the need for coordination between the players' body and/or sports apparatus – e.g., racquet– and an object – e.g., tennis ball, tennis, volleyball) (Bianco et al., 2017; Wang et al., 2013; Wang & Tu, 2017; Yongtawee et al., 2022). Furthermore, Hüttermann and colleagues (2014) observed systematic modulations in athletes' breadths of attention in relation to the main spatial axis on which a game develops. Specifically, athletes from horizontally dominant sports (e.g., rugby, hockey, soccer) showed horizontally shaped breadths of attention, whereas tendencies for greater vertical developments were observed in athletes coming from vertically dominant sports (e.g., volleyball, basketball, badminton). Accordingly, Umiltà and Castiello (1992) measured the capacity of orienting of attention in volleyball athletes and controls reporting athletes' advantage along sport-relevant spatial locations, namely the lateral axis and the upper portion of the vertical axis.

Collectively, these findings emphasize the relationship between domain-specific expertise and attentional processing and mastery. However, despite the evidence so far reviewed, investigations that specifically explored whether and which sport-specific constraints selectively influence the two sub-components of selective attention – feature-based and spatial-based attention – is scarce. Arguably, FBA may be considered a fundamental skill in sports requiring the continuous identification and selection of teammates over opponents, which are conventionally distinguished by specific features, such as jersey colors and patterns. However, this aspect is not universal to all sports types, meaning that the relationship between sports and FBA may vary in a sport-specific manner. Consequently, certain sports – and not others – can be hypothesized to selectively influence FBA beyond the natural effects of non-sport daily activities (Hüttermann et al., 2014). Accordingly, the present study examines the relationship between FBA and sports, focusing on invasion and non-invasion sports. Indeed, in invasion sports (e.g., basketball, soccer), teammates and opponents can freely navigate the playing field without spatial restrictions. Thus, in these sports, leveraging FBA is expected to be crucial, as featural differences (e.g., the color of the uniform) are the primary cues for distinguishing players and making quick and appropriate decisions (e.g., when looking for a teammate to pass the ball or monitoring opponent movements). In contrast, in non-invasion sports (e.g., volleyball, dodgeball), players are typically restricted to their own side of the field. Within these scenarios, featural differences, and athletes' FBA, are less critical, as players may be identified solely by their spatial positioning. Following this reasoning, we expect that invasion sports require a greater extent of feature-based selective attention compared to non-invasion sports and that this difference in cognitive demands may lead to sport-specific effects on the selective attention abilities of athletes involved in these different sports.

Thus, in this study, we tested whether athletes from an invasion sport (i.e., basketball) would show enhanced FBA compared to a gender-matched non-athlete group. To this aim, we adopted a visual search task requiring selective focus on a target among distractors differing by visual features and presented in unpredictable locations. To test whether this potential effect was specific to invasion sports, we conducted an analogous experiment comparing a group of athletes from a non-invasion sport (i.e., volleyball) to a gender-matched group of non-athletes. We expected that athletes from invasion sports, but not from non-invasion sports, would show enhanced FBA compared to control non-athletes. Finally, to test whether the effects of invasion and non-invasion sports were specific to the FBA component of selective attention, we compared the same groups in a task not involving FBA but requiring SBA processing, such as spatial selection and distractor suppression. Specifically, we employed the Flanker task, a selective attention paradigm designed to measure the influence of distracting stimuli when the target's location is known in advance. In this case, we did not expect sport-specific effects, anticipating that any potential difference between athletes and controls would not be attributed to the type of sports practiced.

The decision to focus on basketball and volleyball as examples of invasion and non-invasion sports was deliberate. Indeed, these two sports offer an optimal opportunity to experimentally assess the relationships between invasion *vis-à-vis* non-invasion sports and selective attention while keeping relatively constant many external parameters that could potentially have additional effects on selective attention. Accordingly, while basketball and volleyball differ in key characteristics of players' court navigation (FIBA, 2024; FIVB, 2021), they are similar in other relevant in-game aspects such as number of players, court size, eye-to-target demands, vertical attention demands (Allard et al., 1980; Allard & Starkes, 1980; Hüttermann et al., 2014).

2. Experiment 1: invasion sport athletes vs. non-athletes

2.1. Methods

2.1.1. Participants

Statistical analyses were conducted at the item level using linear mixed models. Because our primary interest was in potential differences in feature-based attention, we set a targeted effect size for the key interaction between group and set-size in the visual search task. Given that there are no definitive guidelines for estimating sample size in item-level linear mixed models, we approximated our design using the ANOVA module in G*Power (Faul et al., 2007). For a between-within factor design (Group: Athletes vs. Controls × Set Size: 3 levels), assuming a medium effect size (f = 0.25) based on sport expertise and attentional performance literature (Mann et al., 2007; Scharfen & Memmert, 2019; Voss et al., 2010), an alpha level of .05, and a desired power of .90, the required total sample size was estimated at 36 participants (18 per group). To ensure sufficient power, we ultimately recruited 40 participants (20 per group) in each experiment (Faro et al., 2020; Yu & Liu, 2021). Thus, 20 basketball players (i.e., invasion athlete group) and 20 non-athletes (i.e., controls) were recruited for the study using a convenience sampling procedure. All participants were males.[1] In order to be included in the study, the athletes were required to regularly practice only invasion sports over the past 5 years. In order to be included in the control group, participants were required to have no history of sports practice at a competitive level or regular participation in any team sport over the past 5 years. Specifically, basketball players (age $M = 22.9$ years; $SD = 3.28$) were all trained ($n = 14$; Tier 2) or highly trained ($n = 4$; Tier 3) (based on McKay et al., 2022) individuals who competed at a regional and national level and reported to train a minimum of 3 times a week ($SD = 1.38$) for a total of 6.45 h per week ($SD = 5.32$ h), on average. Participants in the non-athletes group (age $M = 25.3$; $SD = 3.37$) had not competed at either amateur or competitive level in any invasion or non-invasion sport in the last 5 years and were either sedentary ($n = 19$; Tier 0) or recreationally active ($n = 1$; Tier 1) (based on McKay et al., 2022). Athletes and non-athletes did not differ in terms of handedness ($\chi^2_{(3)} = 4.80$, $p = .187$; left-handed = 3) and videogame experience ($t_{(38)} = .950$, $p = .348$).

2.1.2. Procedure

Before data collection, participants answer a series of questions on socio-demographic variables (e.g., age, gender, educational level), handedness, sport-specific data, and videogame experience. The questionnaire was built on Qualtrics software (Qualtrics, Provo, UT) and disseminated via email and word-of-mouth by a weblink. The day of testing, all participants were debriefed on their rights, including the confidentiality of their responses, anonymity, and the option to withdraw from the study at any point. They were then provided with a detailed explanation of the study's objectives. The study was approved by the local Ethics Committee of the University of Milano-Bicocca (Commissione per la Valutazione della Ricerca, Dipartimento di Psicologia) (protocol number: RM-2021-476). The investigation was conducted according to the ethical standards of the Declaration of Helsinki (World Health Organization, 1996). A written informed consent was obtained prior to data gathering.

Participants were comfortably seated at a distance of approximately 60 cm from a 17" laptop screen (Notebook HP Pavilion) with their fingers placed on a supplementary keyboard. Participants completed the two tasks, which aimed to assess their selective attention capabilities. The tasks were implemented and presented using InQuisit software (version 6, Millisecond software, 2015), and the whole experimental session lasted approximately 20 min, including a brief pause between the tasks. The order of presentation of the tasks was counterbalanced, and participants were given practice sessions to familiarize themselves with each task and ask questions in case of doubt. The experimental procedure occurred in a quiet and artificially lit room with no windows, at the University of Milan - Bicocca or the training center.

2.1.3. Selective attention measures

2.1.3.1. Visual search task. The visual search task consisted of a *conjunction search*, with targets defined by a combination of 2 features (i.e., color and shape) among distracting items that share only one of these two features. Specifically, participants were required to identify either a green (or blue) square (i.e., target) amongst blue (or green) squares and green (or blue) diamonds (i.e., distractors) (Fig. 1). The number of distractors varied across 3 set sizes: 5 (4 distractors), 10 (9 distractors), and 20 (19 distractors). In contrast to other search tasks (e.g., feature search, Treisman & Gelade, 1980; Wolfe, 2018), the conjunction search is known to be affected by the number of distractors, offering a measurable way to assess search efficiency.

Each stimulus subtended approximately 0.6° vertically and 0.6° horizontally. The items were arranged randomly on a squared area (15° × 15°) and moved in a straight line following a random direction at a constant speed (2°/sec). Each stimulus contained a small white dot (0.36° × 0.36°), 0.73° to either the right or the left of the stimulus center. Participants were instructed to find the target and to indicate as quickly as possible whether the white dot was located to the left (by pressing "Z") or to the right (by pressing "M") of the target's center. The search array remained on the screen until participants response or up to 10 s. The experiment consisted of 162 trials (54 trials per set size), which were randomized between set sizes, and participants received feedback regarding their accuracy after each trial in the first 12 trials.

2.1.3.2. Flanker task. After a central fixation cross, the stimulus array was presented at the center of the screen and consisted of one target arrow and 6 distractors. Each stimulus array subtends a visual angle of 6.1° x 1.0°. The inter-stimulus interval (ISI) lasted 1000 ms (ms). The task included neutral (i.e., - - - > - - - or - - - < - - -), congruent (i.e., <<<<<<< or >>>>>>>), and incongruent (i.e., <<<><<< or >>><>>>) trials. The stimulus array remained on the screen until the participants' response or up to 600 ms (Fig. 2). Participants were instructed to maintain central fixation and to indicate upon the appearance of the stimulus array whether the target pointed to the left (by pressing "Z") or to the right (by pressing "M"). If the participants pressed either key before the target arrow appeared (i.e., anticipatory response), the message "*Too soon!*" appeared on the screen, invalidating the trial and presenting it again at the end of the experiment. Each session consisted of 166 trials, which were randomized. Participants were presented with feedback on their accuracy during the first 10 trials, after which they only received a late-response feedback (i.e., "*Faster!*") if they took longer than 600 ms to respond.

2.1.3.3. Statistical analyses. Accuracy performance was well above random levels in all participants in both tasks, indicating compliance with task instructions (Flanker task minimum accuracy = 88.55 %; $M = 95.75$, $SD = 2.08$; visual search task minimum accuracy = 92.59 %; $M = 97.86$, $SD = 1.49$). Behavioral performance was evaluated in terms of reaction time (RT). Only correct trials were included in the analyses. Trials with RTs faster than 100 ms (anticipatory responses) or exceeding the third quartile plus 1.5 interquartile ranges (delayed responses) were eliminated (Ratcliff, 1993). Participants' performance on the visual search task was analyzed through a linear mixed model (LMM) with *RT* as the dependent variable and *Group* (2 levels: Invasion Sport, Control), *Set size* (3 levels: 5, 10, 20), and *Trial number* (i.e., the ordinal number of the trials as they are presented throughout the task), and their interactions included as fixed effects. Trial number was entered into the model to evaluate potential changes in participants' performances over the course of the task. *Age* and *years of education* were additionally entered as covariates to keep their potential influence on attention into account. To gain a deeper understanding of how participants' performance changed over time, the task was divided into 3 parts. Thus, a similar LMM was performed, but with the independent variable *Trial number* binned into 3 parts of 54 trials each: initial part, middle part, final part.

Finally, *Participant* was included in the model as random intercepts. Similarly, performance on the Flanker task was analyzed through LMM with *RT* as the dependent variable and *Group* (2 levels: Invasion Sport, Control), *Trial type* (2 levels: congruent, incongruent), and *Trial number* as independent variables. *Age* and *years of education* were entered as covariates, and participants were set as random intercepts. R-squared is

[1] This decision was made for both practical and methodological reasons. Practically, male basketball players are more prevalent and therefore easier to recruit. Methodologically, maintaining a gender-homogeneous group allowed us to control for potential gender effects and avoid unnecessary variability driven by gender-related external factors.

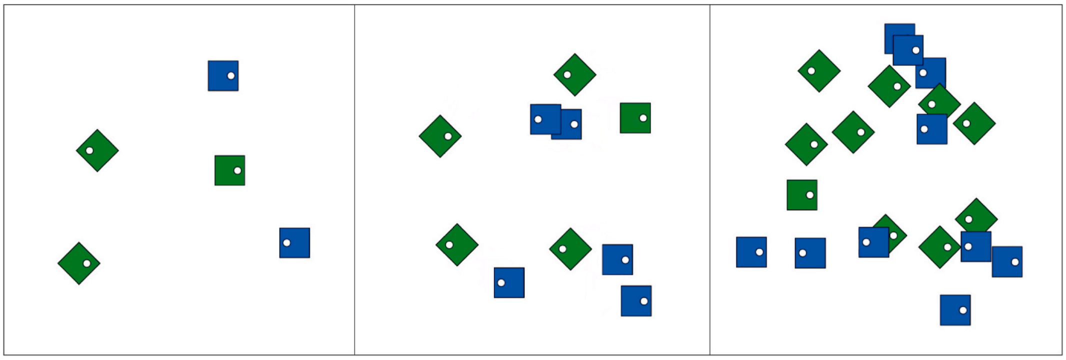

Fig. 1. Example of a frame of the visual search task displaying the 3 set sizes, i.e., 5, 10, and 20, respectively. The target is the green square (e.g., set size 5: center) amongst distractors (blue squares and green diamonds). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

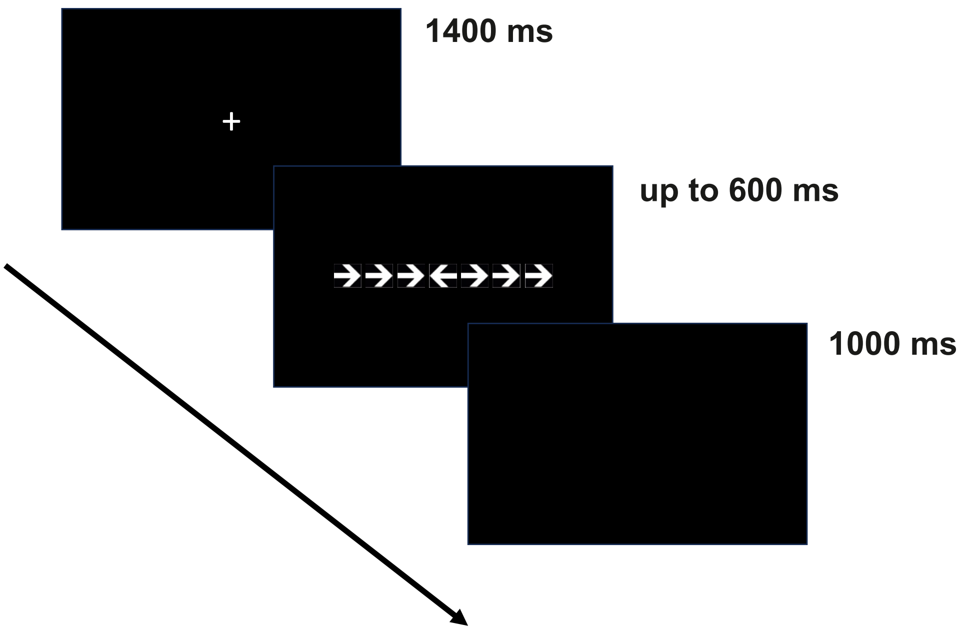

Fig. 2. Example of an incongruent condition of the Flanker task.

reported as a model summary statistic (Nakagawa & Schielzeth, 2013). All statistical analyses were performed on R-Studio (v.4.3, RStudio Team, 2015) via the packages lme4 (Bates et al., 2015) and lme4test (Kuznetsova et al., 2017) for R.

2.2. Results

2.2.1. Visual search task

Participants' performance on the visual search task was analyzed through LMM. The model presented a marginal $R^2 = .312$, and showed a significant effect of *Set size* [$F_{(1,6163.5)} = 875.31$, $p < .001$], as well as a significant 3-way interaction between *Trial number*, *Set size*, and *Group* [$F_{(1,6164.5)} = 8.10$, $p = .004$].

The LMM with *Trial number* binned into 3 parts revealed a significant main effect of *Set size* for all three parts of the task [initial part: $F_{(1, 2002.05)} = 1062.15$, $p < .001$; middle part: $F_{(1, 2056.58)} = 1096.30$, $p < .001$; final part: $F_{(1, 2033.08)} = 914.16$, $p < .001$], whereas a significant interaction of *Set size* by *Group* was found only in the initial part [$F_{(1,2002.40)} = 7.25$, $p = .007$] and not in the middle [$F_{(1,2056.67)} = .96$, $p = .327$] and final part [$F_{(1,2033.62)} = .258$, $p = .612$]. As can be seen in Fig. 3, the typical slowing down produced by increasing set size in the visual search task (Treisman & Gelade, 1980; Wolfe, 2018) was less severe in the Invasion Sport group compared to the *Control* group of non-athletes. However, such an advantage of Invasion over the Control group was lost in the following parts of the task.

A final analysis was conducted to examine the effect of practice on RT separately for each group and set size. In the *Control group*, a significant decrease in RT over trials was observed only at set size 20 [$t_{(6160)} = -5.853$, $p < .001$] (with $p = .218$ at set-size 10 and $p = .399$ at set size 5), highlighting, at the highest level of set size, a reduction of distractor interference with practice. In contrast, the Invasion Sport group did not exhibit a significant improvement in RTs over trials at any set size (all $ps > .734$).

2.2.2. Flanker task

Participants' performance on the Flanker task was analyzed through LMM. The model presented a marginal $R^2 = .117$. The effect of *Trial type* [$F_{(1,6220.1)} = 178.88$, $p < .001$] was significant, indicating that faster responses were given in trials with congruent distractors ($M = 436$, $SD = 53$) than incongruent ones ($M = 474$, $SD = 76$) (Fig. 4). The effect *Trial number* [$F_{(1,6219.9)} = 68.17$, $p < .001$] was also significant, indicating that performance improved as the task progressed. Moreover, we found a significant effect of *Group* [$F_{(1,49.8)} = 4.12$, $p = .048$], indicating that Invasion Sport athletes have faster RTs than the Control Group, overall.

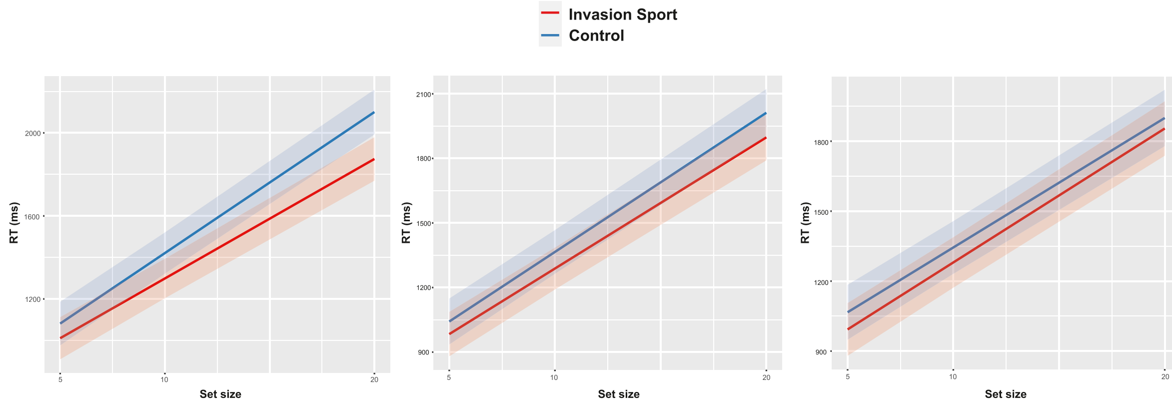

Fig. 3. Graphical output of the Visual Search task displaying the RTs (in milliseconds) as a function of set size in the first (left), second (middle), and third (right) parts of the task. The graph indicates that the Control group (blue line) exhibits worse search efficiency (as indicated by the steeper slope of RT as a function of set size) compared to the Invasion Sport group (red line) only in the first part of the task and especially at larger set sizes. Conversely, search efficiency in the second and third parts of the task did not differ between the two groups. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

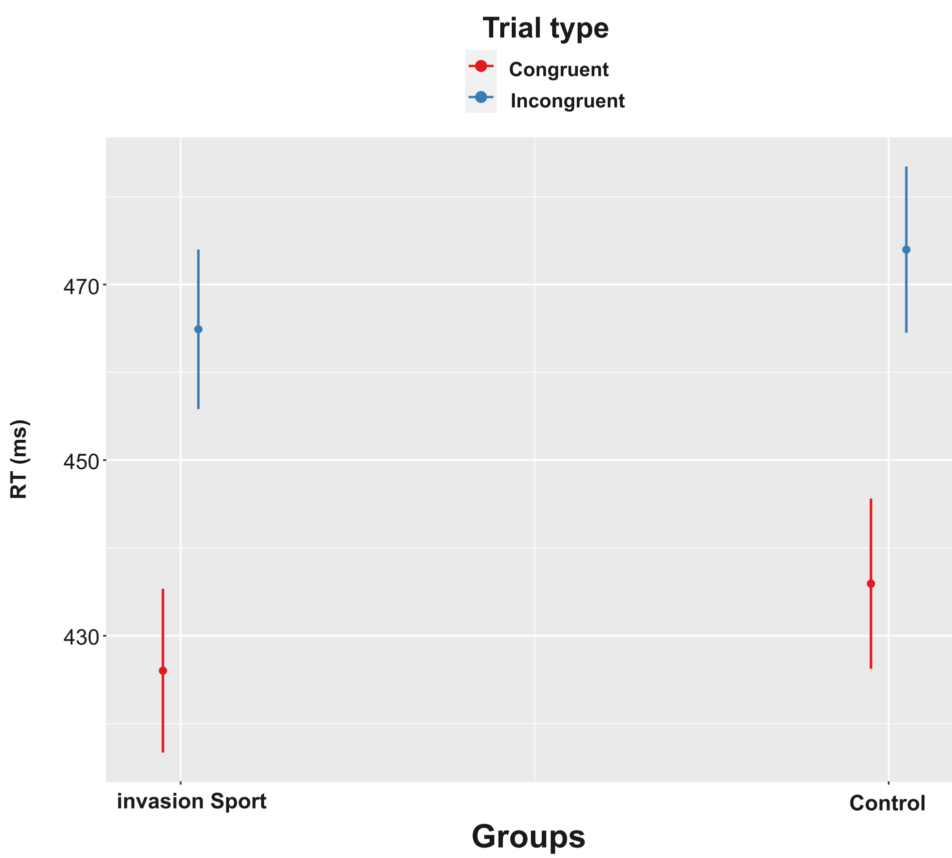

Fig. 4. Graphical output of the Flanker task reporting the participants' reaction times in trials with congruent (red) and incongruent (blue) distractors. Both groups showed faster reactions when distractors were congruent to the target, compared to when they were not. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

However, we did not find any significant interaction between *Group* and *Trial type* [$F_{(1,6220.1)} = .01$, $p = .901$], suggesting that Invasion Sport athletes do not have a significant attentional advantage in relation to the distractors' interference effect, despite their general speeded performance compared to the Control group. Finally, all remaining interactions were not significant (all $ps > .097$).

3. Experiment 2: non-invasion sport athletes vs. non-athletes

3.1. Methods

3.1.1. Participants

A total of 22 volleyball players (i.e., non-invasion athlete group) and 23 non-athletes (i.e., controls) were recruited using a convenience sampling procedure. All participants were females. Inclusion criteria were the same as those in Experiment 1, except for the athlete group, which included only athletes who had regularly practiced only non-invasion sports in the past 5 years.

Specifically, volleyball players[2] (age $M = 24.6$ years; $SD = 4.06$) were all trained ($n = 17$) or highly trained ($n = 5$; Tier 3; McKay et al., 2022) athletes who competed at regional and national level, and reported to train a minimum of 3 times a week ($SD = .09$) for a total of 7.09 h per week ($SD = 3.79$ h), on average. Participants in the control group (age $M = 22.9$ [$SD = 3.25$]) had no history of sports practice at a competitive level or regular participation in any team sport over the past 5 years and were either categorized as sedentary ($n = 22$; Tier 0) or recreationally active ($n = 1$; Tier 1). Athletes and non-athletes did not differ in terms of handedness ($X^2_{(3)} = 1.45$, $p = .694$; left-handed = 3) or videogame experience ($t_{(43)} = .052$, $p = .959$).

3.1.2. Procedure

Experiment 2 replicated the design and procedures of Experiment 1.

3.1.3. Statistical analyses

Accuracy performance was well above random levels in all participants in both tasks, indicating compliance with task instructions (Flanker task minimum accuracy = 84.94 %; $M = 95.14$, $SD = 3.10$; visual search task minimum accuracy = 86.41 %; $M = 96.98$, $SD = 2.53$). Experiment 2 performed the same statistical analyses as Experiment 1.

3.2. Results

3.2.1. Visual search task

The model presented a marginal $R^2 = .313$, and revealed a significant main effect of *Set size* [$F_{(1,6536)} = 968.14$, $p < .001$] and an interaction between *Set size* and *Trial number* [$F_{(1,6536.9)} = 11.71$, $p = .003$] (Fig. 5). However, there was no significant main effect of *Group* [$F_{(1,143.6)} = .11$, $p = .745$], nor any interaction between *Group* and other variables (all *ps* $> .253$), thus indicating that Non-invasion Sport group and Control group did not significantly differ in visual search performance.

Finally, as for Experiment 1, we examined the effect of practice on RT separately for each group and set size. In both groups, only at set size 20, RTs decreased over trials (*ps* $< .007$), highlighting a reduction of distractor interference with practice.

3.2.2. Flanker task

The model had a marginal $R^2 = .074$. Significant main effects of *Trial type* [$F_{(1,6649.6)} = 181.14$, $p < .001$] and *Trial number* [$F_{(1,6649.3)} = 32.25$, $p < .001$] were revealed, once again indicating that participants performance was faster for congruent trials ($M = 453$, $SD = 65$) than incongruent ones ($M = 489$, $SD = 76$) (Fig. 6), and, that it improved through the task. There was no significant main effect of *Group* ($p = .712$). Among the tested interactions, only *Group* x *Trial number* approached the conventional threshold of significance [$F_{(1,6649.3)} = 3.21$, $p = .073$]. In this case, this reflected a descriptively steeper improvement in the Control group (slope $= -0.1098$) compared to the Non-invasion Sport group (slope $= -0.0571$), with the between-group contrast yielding an effect estimate of -0.0527 ($SE = 0.0294$), $t = -1.793$, $p = .0731$. All the other interactions were far from significance (all *ps* $> .69$). Overall, these results indicate that the Non-invasion Sport and Control group did not differ in performance in the Flanker task.

4. Discussion

In the present study, we hypothesized that invasion sports, due to their specific characteristics, enhance the feature-based component of selective attention of athletes. Indeed, FBA represents a crucial skill, especially in invasion sports, as it contributes to players' performance by enabling the efficient focus on critical aspects of the game. In particular, invasion sports require athletes to focus on distinctive features – such as jersey colors and patterns – that allow them to track and monitor the positions of teammates and of a target projectile amongst numerous moving opponents. In line with our hypothesis, our results show that only athletes involved in invasion sports exhibit superior task-specific feature-based attentional skills in the visual search task compared to controls, a performance gap that appears to be bridged only over time due to training on the search task. Conversely, this pattern was not observed in the Flanker task, indicating that the effects of invasion sports on attention are specific to feature-based levels rather than on selective attention in general.

These findings indicate that invasion sports training may be associated with an enhanced feature-based component of selective attention, rather than with broad enhancement of closely related yet distinct cognitive abilities. This result suggests that the cognitive skills developed through sports practice might be highly specialized and tailored to the specific demands of each sport. Nevertheless, such sport-induced selective effects appear to generalize to no sports-related contexts, as measured in our visual search laboratory task. This aligns with the broad transfer hypothesis (Voss et al., 2010), which posits that prolonged engagement in a particular activity produces adaptations in basic cognitive abilities that, in turn, transfer to domains beyond the original field of experience on which the cognitive function was trained (Voss et al., 2010; Vestberg et al., 2012; Alves et al., 2013; Qiu et al., 2019; see also Furley & Memmert, 2011).

A large body of evidence supports a link between sport expertise and superior visual attention, suggesting that domain-specific constraints and demands could influence attentional processing specificity (Faubert, 2013; Guo et al., 2017; Jin et al., 2023; Krenn et al., 2018; Natsuhara et al., 2020; Piras et al., 2014; Shim et al., 2005; Wang et al., 2023; Zhang et al., 2021). Previous research has suggested that expertise might modulate task-related neural networks in ways that allow expert athletes to adopt more automated and, therefore, more efficient processes than more effortful ones (Furley et al., 2015). For instance, superior tracking performance in basketball players was associated with bidirectional reductions in activation and deactivation in regions supporting task execution and processing of irrelevant information, respectively. These effects were interpreted as an increased task-specific neural efficiency of attention systems (Qiu et al., 2019). Practice might influence athletes' attentional strategies in ways in which they favor task-dependent automatic and less effortful approaches in support of effective performance (Kerick et al., 2004; Zhu et al., 2019). Hence, in line with the evidence suggesting that these modulations are task-specific, the lack of differences in measures of FBA between non-invasion athletes and controls may be attributed to volleyball not being a sport soliciting sufficient levels of FBA to result in detectable cognitive enhancement of this function in its players.

Additionally, our results indicate that the sport-specific advantage in FBA was statistically significant only in the early phase of the task. At first glance, this might suggest that the athletes' advantage vanishes over time. However, we are cautious in drawing such a conclusion, as the observed pattern more likely reflects inherent characteristics of the task, which may lack the range or sensitivity needed to detect group differences once high performance is reached by participants. Indeed, invasion sports athletes performed close to the ceiling of their search efficiency from the very beginning of the visual search task, with trivial further improvement. Conversely, non-invasion athletes and controls improved their performance over the course of the trials – specifically at the highest level of set-size – suggesting a learning effect as the task progressed, until performance stabilised and converged on equivalent levels across all groups. This indicates that, while volleyball players and non-athletes required task-specific training to reach such a high efficiency level, the invasion sport athletes exhibited FBA performances that

[2] Basketball players did not differ significantly from volleyball players in terms of training experience [$t_{(36.058)} = .289$, $p = .774$], competitive experience [$t_{(36.486)} = .775$, $p = .443$], training frequency [$t_{(33.713)} = -.249$, $p = .805$], or hours of training per week [$t_{(34.036)} = -.446$, $p = .658$].

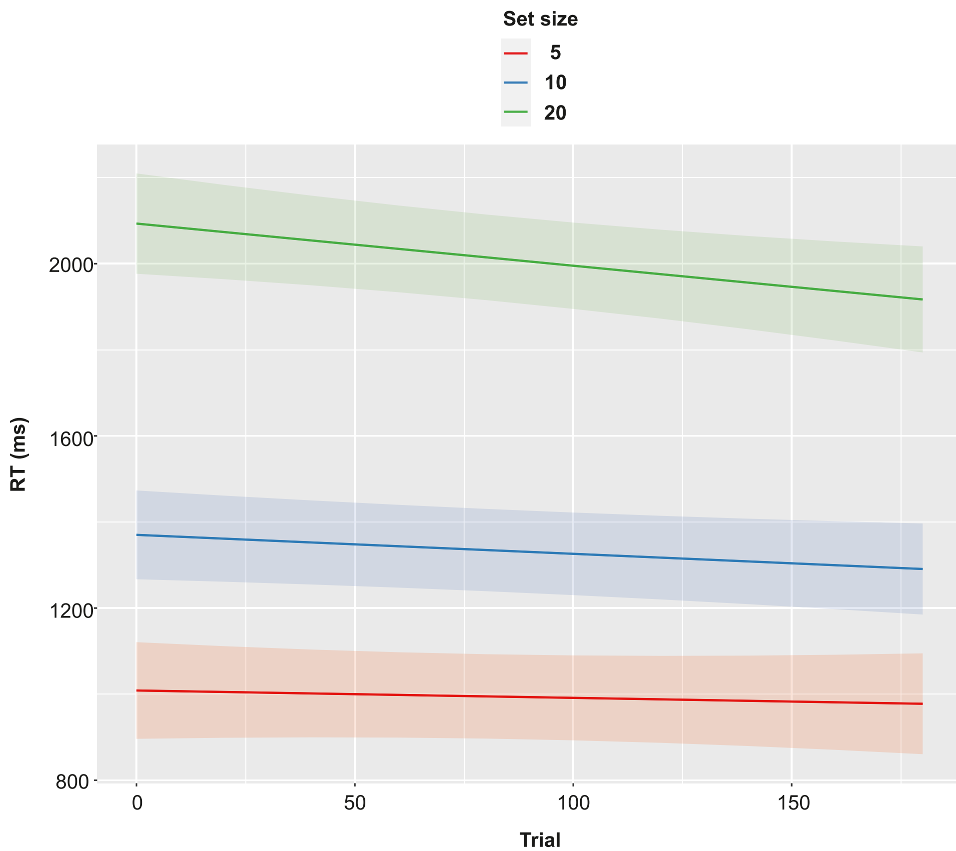

Fig. 5. The graph shows participants' reaction times (in milliseconds) plotted against the number of the trials in the Visual Search task. Participants in both groups performed better at smaller set sizes and as time-on-task progressed.

were at the ceiling from the very beginning of the task. These findings suggest that particular sport expertise is linked to more readily available and efficient attentional resources, while less can be inferred about the persistence of this effect over time. Future research employing more demanding visual search tasks — specifically designed to engage performance beyond the range captured by the current paradigm — will be helpful in further elucidating the persistence of such attentional advantages in invasion sports.

The results obtained in the Flanker task were somewhat puzzling, and support only in part previous findings. Based on the literature suggesting positive effects of sports expertise on visual attention and processing speed (Krenn et al., 2018; Rahimi et al., 2022; Voss et al., 2010), one could expect lower interference produced by distractors in athletes compared to controls. Nevertheless, the absence of any significant interaction between *Group* and *Trial type* corroborates previous works indicating that strategic sports do not necessarily confer advantages in inhibitory control (Alves et al., 2013; Meng et al., 2019; Simonet et al., 2022; Wylie et al., 2018). Instead, the overall faster reaction times observed in invasion sport athletes relative to controls may reflect broader enhancements in processing speed, superior visuomotor integration, or more efficient allocation of attentional resources (Brimmell et al., 2022; Li & Smith, 2021; Voss et al., 2010). In addition, sport-related advantages in attentional spatial selection and distractor suppression may be present at a neural level even without behavioral enhancements (Yao et al., 2024). If so, the present Flanker task may not have been sensitive enough to detect subtle differences in spatial-based attentional skills associated with strategic sports. Alternatively, the absence of differences at the behavioral level may be related to task specificity. In particular, ecologically valid tasks that closely mimic sport-specific cognitive demands (e.g., complex field dynamics and rapid sport-relevant decision-making) may offer a more adequate way to explore sport-specific perceptual-cognitive advantages that might be elusive to classical laboratory-based reaction times measures (Ericsson, 2003, pp. 371–402; Kalén et al., 2021). However, while this approach is appropriate when investigating sport-specific cognition, it might be less suitable for the assessment of cognitive skills outside of sport settings (Voss et al., 2010).

Notably, the Flanker task mainly assesses the spatial selection and distractor suppression processes of SBA, while it does not fully isolate attentional orienting mechanisms (Ridderinkhof et al., 2021). Therefore, future research should consider incorporating cueing paradigms – or composite measures such as the Attention Network Test (Fan et al., 2002) – to comprehensively disentangle orienting, executive control, and filtering processes of SBA.

The correlational nature of the study design prevents us from establishing a clear directionality of the effects between sports practice and attentional abilities. On the one hand, it's been previously suggested that prolonged sports practice may induce experience-dependent brain adaptations to meet the sport-specific cognitive (Mann et al., 2007; Scharfen & Memmert, 2019; Voss et al., 2010). On the other hand, it is also plausible that individuals who naturally possess attentional skills required in a given sport might be facilitated and encouraged by their achievements to continue practicing that sport, as well as genetic and socioeconomic factors likely influence cognitive performance (Scharfen & Memmert, 2019). Nonetheless, it is reasonable to hypothesize a bidirectional relationship between attention and sport: cognitive and/or neural predispositions may lead athletes to practice sports that align with their cognitive strength, while sport-specific constraints might, in turn, further train sport-related cognitive skills (Ericsson & Lehmann, 1996; Hüttermann et al., 2014; Newell & Rosenbloom, 1981). Longitudinal studies investigating the short- and long-term effects of sport-specific training provide a robust alternative, enabling causal inferences that would warrant further investigations in future research (Scharfen & Memmert, 2019; Kalén et al., 2021). Additionally, as both

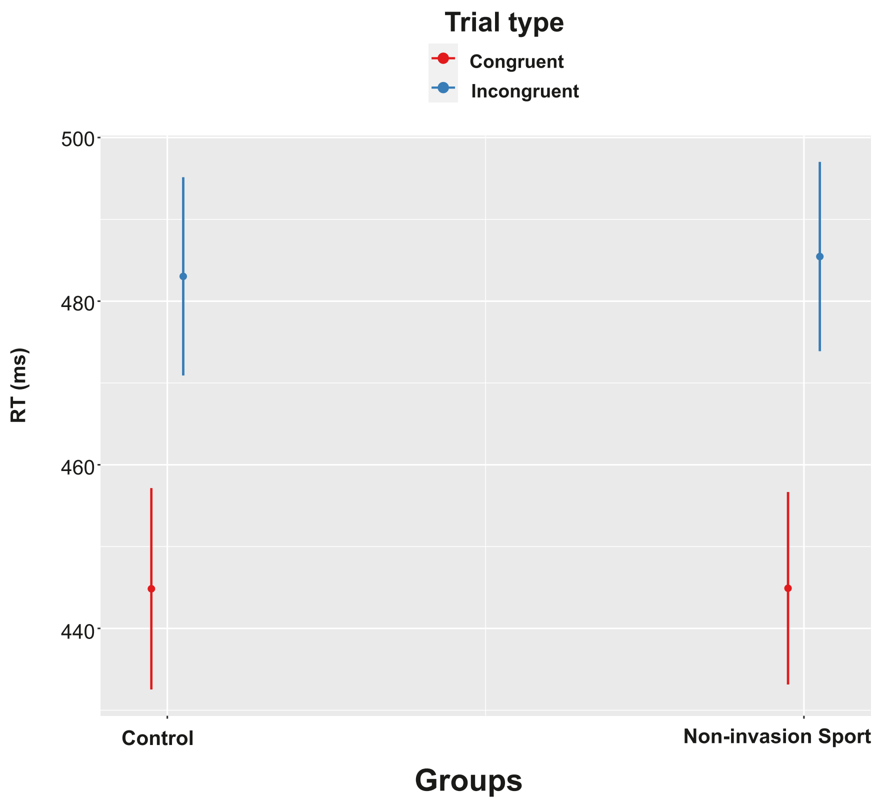

Fig. 6. Graphical output of the Flanker task displaying participants' reaction times in trials with congruent (red) and incongruent (blue) distractors. Both groups showed faster reactions when distractors were congruent to the target, compared to when they were not. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

the invasion and non-invasion sports samples in our study were composed of athletes from a single discipline (i.e., basketball and volleyball), the generalizability of our findings to the broader categories of invasion and non-invasion sports should be interpreted with caution, and more research is needed to extend the present findings to other sports.

Finally, it is important to address a limitation concerning gender composition. To ensure perfect gender matching within the athlete–control comparisons, we recruited only male participants for Experiment 1 and only female participants for Experiment 2, a decision driven by practical recruitment considerations. This design effectively eliminated gender as a confounding variable in the within-experiment comparisons (athletes vs. gender-matched controls), allowing us to conclude that our main findings—the positive effect of basketball and the null effect of volleyball on FBA—stem from sport-specific practice, not from overall gender differences. However, this design precludes us from definitively ruling out gender as a potential intervening factor in explaining differences observed comparing sport type between experiments, given that gender and sport type varied simultaneously. Given existing literature suggesting gender influences attentional processes (Jin, Ge, & Fan, 2023; Legault & Faubert, 2024), future studies employing full factorial designs (i.e., including more than one gender within each experiment) are needed to comprehensively highlight potential interaction effects between gender and sport type on FBA as well as SBA.

In conclusion, the current study is among the firsts to provide a direct empirical test of sport-related differences in FBA and SBA, using behavioral tasks designed to isolate each component of selective attention. While it's true that very few (if any) studies have explicitly dissociated FBA and SBA in this way, previous work—e.g., Alves et al. (2013), Krenn et al. (2018), and others—has examined sport-related differences in attentional control more broadly, often touching on mechanisms that may be closely related to FBA or SBA. By doing so, the present study suggests that invasion sports are associated with enhanced and more readily available FBA skills. These findings have implications for both the sporting perspective – highlighting the key role of this attentional component in invasion sports – and the psychological perspective – suggesting the beneficial effects that sports practice has on attentional abilities. In particular, these results enhance our understanding of the specific effects that sports practice may have on various components of attention, demonstrating how diverging constraints within different sports might influence cognitive skills in a sport-specific manner. Future studies should expand the analysis to sport-specific demands across sport types that might account for variability in the results (e.g., in-game attentional axes, sport apparatus, court size or type, etc.). Moreover, a more systematic evaluation of factors that account for athletes' perceptual-cognitive abilities would allow practitioners to develop ever more effective training protocols.

CRediT authorship contribution statement

Luca Bovolon: Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation, Formal analysis, Data curation. **Simona Perrone:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis. **Carlotta Lega:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Luisa Girelli:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization. **Simone Mattavelli:** Writing – review & editing, Software, Methodology. **Marco A. Petilli:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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