

RESEARCH ARTICLE

Anticipatory and pre-planned actions: A comparison between young soccer players and swimmers

Francesca Nardello, Matteo Bertucco , Paola Cesari *

Department of Neurosciences, Biomedicine and Movement Sciences, University of Verona, Verona, Italy

* paola.cesari@univr.it OPEN ACCESS

Citation: Nardello F, Bertucco M, Cesari P (2021) Anticipatory and pre-planned actions: A comparison between young soccer players and swimmers. PLoS ONE 16(4): e0249635. <https://doi.org/10.1371/journal.pone.0249635>

Editor: Cosimo Urgesi, Università degli Studi di Udine, ITALY

Received: November 20, 2020

Accepted: March 23, 2021

Published: April 7, 2021

Peer Review History: PLOS recognizes the benefits of transparency in the peer review process; therefore, we enable the publication of all of the content of peer review and author responses alongside final, published articles. The editorial history of this article is available here: <https://doi.org/10.1371/journal.pone.0249635>

Copyright: © 2021 Nardello et al. This is an open access article distributed under the terms of the [Creative Commons Attribution License](https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Data Availability Statement: All relevant data are within the paper and its [Supporting Information](#) files.

Funding: The authors received no specific funding for this work.

Abstract

The present study investigated whether a difference exists in reactive and proactive control for sport considered open or closed skills dominated. Sixteen young (11–12 years) athletes (eight soccer players and eight swimmers) were asked to be engaged into two games competitions that required either a reactive and a proactive type of control. By means of kinematic (i.e. movement time and duration) and dynamic analysis through the force platform (i.e. Anticipatory Postural Adjustments, APAs), we evaluated the level of ability and stability in reacting and anticipating actions. Results indicated that soccer players outperformed swimmers by showing higher stability and a smaller number of falls during the competition where proactive control was mainly required. Soccer players were able to reach that result by anticipating actions through well-modulated APAs. On the contrary, during the competition where reactive control was mainly required, performances were comparable between groups. Therefore, the development of specific action control is already established at 11–12 years of age and is enhanced by the training specificity.

Introduction

Sports are traditionally classified in two general categories based on the relationship between the movements and the environmental changes allowed by the task at hand [1]. The categories are recognized as open and closed skills: open skills are those that take place in an unpredictable and constantly changing environment where movements need to be continually adapted (i.e. basketball, soccer, volleyball, handball); vice versa closed-skills are performed in an unchanged environment with movements that follow a relatively stable set of patterns as track and field or swimming [2–4]. Consider for instance the game of basketball where the ball and the players are constantly moving. In this case, it is fundamental to develop specific abilities as to adapt dynamically to the changes of the game contexts or to anticipate the actions performed by others and predict the trajectories of the ball [4, 5]. This is not the case for a swimmer; he/she is not asked to react to the other swimmers' actions nor to anticipate unknown outcomes, but instead to maintain core stability while performing in the most efficient way repeated patterns of action [6]. It turns out that the ability to deal with the relationship between

Competing interests: The authors have declared that no competing interests exist.

environmental contexts and movement responses for an open skilled athlete could be different than the one obtained by a closed skilled type of athlete [7]. Nevertheless, elite athletes whatever the sport practiced, develop common sensory-motor capabilities.

Sports are performed under conditions of stress due to the physical, psychological and environmental demands, for satisfying expectations and resisting to pressure while performing high level executions [8]. Such conditions exacerbate the athlete's ability to quickly and accurately pick up relevant information for the task at hand; this learning process would reduce the time of making a decision and allow more accurate action preparation [9, 10]. In addition, either in closed or open dominated-sport skills, fast reaction time (RT) underlines the presence of critical abilities considered advantageous to the player's successful performance [11]. In fact, in many sports, maximum speed is rarely reached or needed, while instead explosive reaction is often required [12]. Reacting faster to a stimulus has been considered a basic measure to assess many different sensory motor capacities, from simple daily life tasks [13], to high competitions as in karate [14] and athletic dash sprint [15].

Following behavioural results [16], researches asked what control will be necessary for developing open or closed type of motor skill by searching for differences between "proactive" and "reactive" control of movement through the disclosure of possible related neuronal underpinning [17]. Proactive control is mainly defined by a process that allows an early selection of the response helped by an appropriate attention and cue selection along with a goal-driven action [18]. This action control mechanism is applied as an essential knowledge for understanding the future of an action for being able to anticipate the action. Overall, this type of control is more present in an open environment [4]. On the contrary, reactive control requires to respond imperatively after the stimulus appear [18]. In this case a fast and appropriate reaction of external changes represents the typical control present in a closed environment [19]. The two controls require different neurophysiological processes: the proactive being more driven by a feedforward control while the reactive more by a feedback control [20].

One way to investigate the link between action planning (feedforward control) and execution (feedback control) is to measure the muscles activity before movement initiation, since voluntary actions are always preceded by postural changes [21, 22]. These changes occur prior to the movement itself and can be conceived of as Anticipatory Postural Adjustments (APAs). APAs are centrally programmed and their putative role is to minimize perturbations to vertical posture that would otherwise be induced by a movement (for a review see [23]). Starting from early pioneering research, APAs have been studied during lower limb movement [24], trunk movement and arm movement [25]. In literature, APAs are usually studied with through EMG analysis (i.e. early postural adjustments, EPA) [22, 25] and/or with force platform [24, 26–28]. APAs are typically quantified in terms of their magnitude or the onset timing of the signal (i.e. EMG or GRFs) before the initiation of the movement [26, 27]. When measured with the ground reaction force [29–31], APAs onset, amplitude and impulse are usually analysed from the ground reaction forces (GRFs) [24, 26–27] or centre of pressure [28].

To our knowledge, this is the first study that measures anticipatory mechanisms during game competition for comparing young but highly expert athletes that developed abilities in a more dynamic or in a more stable environment. Past literature has investigated the superiority of the skilled athletes over less skilled athletes [16, 32], but only a limited number of studies have directly compared anticipatory skills performed by athletes from closed skill-dominated and open skill-dominated sports [32, 33] and mostly considering adult athletes. Critically, these studies considered as a test mainly tasks to be performed on a computer table game situation as for instance the "task-switching paradigm" [17, 34]. Therefore, given the scarce literature about the development of proactive and reactive control mechanisms and the absence of test that considers more ecologically how a real body game situation let merges reactive and

proactive skills, we want to analyse the behaviour of APAs by comparing the anticipatory skills of soccer players (open skill-dominated sport) and swimmers (closed skill-dominated sport). This will reveal how the CNS control action anticipation in young athletes when engaged in a total body game competition requiring proactive and reactive control. The importance to test expert children is to better understand the development of the appearance of these anticipatory mechanisms indicating the influence that a sport training has in enhancing specific motor skills.

The main aim of this study is to shed light on the role of skills development (open and closed) by comparing APAs, by means of the ground reaction forces, in children highly experienced in open and closed disciplines respectively soccer and swim.

In a proactive game, we would expect a greater postural stability accomplished with a lower risk of falling for the open-skills players in comparison to the closed-skills ones. This augmented ability would be reflected by an early modulation of the Anticipatory Postural Adjustments. In a reactive game, instead, we assume no differences between open and closed skills.

Material and methods

Participants

Sixteen young male athletes were recruited for the experiment: eight were soccer players and eight swimmers. They were recruited from the A.C. Chievo Verona soccer club and from the CSS “Montebianco” swimming pool club in Verona, respectively. Their anthropometric characteristics and years of experience are reported in [Table 1](#).

All participants were free from any musculoskeletal disorder and neurologic disease that could affect the study. The project was approved by the Ethical Committee at the Department of Neurosciences, Biomedicine and Movement Sciences at University of Verona (Prot. 269664/2017) and all participants provided written informed consent before taking part in the experimental procedures.

Apparatus

Video clips were recorded by means of a digital camera (Panasonic, Lumix DMC FZ200, made in China, 100Hz, 12.1Megapixel, optical zoom 24x). The camera was located perpendicular to the sagittal plane of the game zone, on the left side of the players.

Two force platforms (model OR-5, AMTI, USA: 90 × 90 cm and model Kistler, Switzerland: 40 × 60 cm) were used to record the three components of the ground reaction forces with a sampling rate of 2000 Hz. Only the anterior-posterior component (GRFx) has been used for further analysis.

A couple of pads was attached on both palms for each subject with the Velcro®. The aluminium-made pads were covered with three layers of felt and externally with leather to soften the impact. One tri-axial accelerometer (model LSM6DS33TR, Farnell, ITALY, sampling rate

Table 1. Soccer players and swimmers group body characteristics (mean (SD)).

Variable	Soccer players	Swimmers
	(n = 8)	(n = 8)
Age (years)	11.8 (0.3)	11.6 (0.6)
Body Height (m)	1.54 (0.06)	1.54 (0.09)
Body Mass (kg)	44.7 (6.11)	43.7 (6.70)
Years of experience	3.8 (0.3)	3.6 (0.5)
Training hours for week	6.00	6.00

<https://doi.org/10.1371/journal.pone.0249635.t001>

2000 Hz) was attached internally to the pad which was tied to the player's dominant arm. The signals were used to quantify the movement time up to the impact.

Experimental procedure

Proactive type of game. In order to test action anticipation ability, subjects were asked to participate to the “push and fall” game. The game is played by a couple of individuals (player 1 *versus* player 2); each couple was formed by a soccer player (e.g. player 1) and a swimmer (e.g. player 2). The two players were standing barefoot on a force plate each, facing each other (Fig 1, panel a). As initial position they were asked to stand with feet together, to flex their upper arm by facing their palms to the opponent. The distance between the two players corresponded to the length of their arms as to be able to touch the shoulder of the opponent with their arm extended forward.

The main rule of the game was to push with palm contact the opponent palms to throw him off balance. The trial could be initiated after an external vocal command “push” was delivered. After the push command players were free to decide when to initiate the action. No constraints for time initiation of the movement was given. Each player was allowed to move just in one shot (i.e. a single push). In other words, fake actions were not allowed. More in specific extra movements for simulating fake actions were not allowed but players could choose not to move at all so that in some trials impact between the two players' palms was not present. The contact between the two players was allowed only by touching the palms; no other parts of the body could come into contact. The players were not asked to react as soon as possible to the push

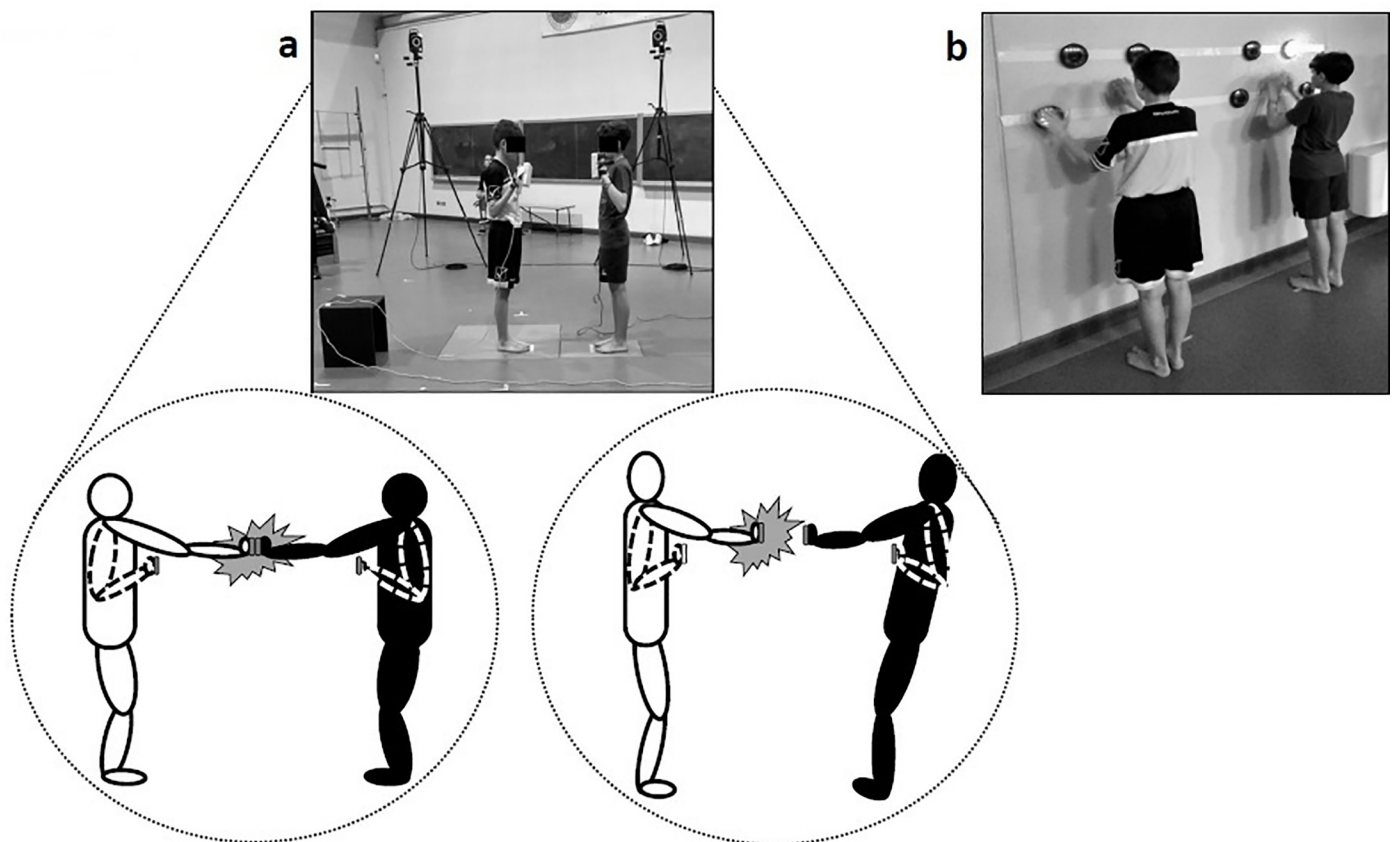


Fig 1. The experimental set-up. a. The proactive type of game (left diagram: the impact was associated with a perfect stability; right diagram: the impact was associated with a loss of stability). b. The reactive type of game.

<https://doi.org/10.1371/journal.pone.0249635.g001>

signal but instead to self-select their own time of action initiation. The main aim of the game was inducing players to guess the opponent's action for anticipating and actuating the best movement's strategy (Fig 1A, right diagram). At the end of each trial the players were asked to regain the initial position, ready to initiate the next trial. For each trial the experimenter checked the posture taken by players to make sure that the rules were followed.

A total of 10 blocks with 12 trials each were performed for each couple of players; there was an interval between blocks of 3 minutes to avoid fatigue. A total of 960 trials were performed; from this total we selected, from each couple, the number of trials where the impact was present, obtaining a total of 560 trials considering all the couples together. To assure the maximum game fairness the selection of players forming each couple was made based on the similarity in the anthropometrics measures in terms of body height and weight.

Reactive type of game. In order to test the reactive skills, a FITLIGHT Trainer (FITLIGHT Sports Corp., Ontario, Canada) was used. This is a wireless system consisting of light sensors. The lights were attached to the wall forming two semicircles made each of 4 light sensors. The two semicircles were identical and positioned at 1 meter distance from each other, within each semicircle each light was distant from each other by 20 cm. Each player was standing in front of one of the two semicircles that was positioned at the level of the player's shoulder high (Fig 1, panel b). Each player stood in front of the 4 lights at a comfortable distance. The rule of the game was: as soon as a light appeared on, shut it down as fast as possible by touching it, then one other light will appear on and again as fast as possible shut it down by touching it and so on. The time of each trial was made of 30 seconds, and four trials were administered for each couple of players. As performance measures we considered the time between lights shut down and the total number of lights shut down. Players were allowed to use both hands, the sequences of the lights on positions were random; players were performing individually but simultaneously and were placed at 1 metre distance from each other.

Prior to data collection, a period of familiarization was given to the players for both games (proactive and reactive). The whole experimental session lasted for about 60 min.

Data analysis

For the proactive game video-clips were taken. All video clips were scrutinized to identify the presence of falls by indicating for each player the "stability index" considering as value 1 the perfect stability and value 0 loss of stability (e.g. loss of stability was considered when one of the two feet or both were detached from the force platform as illustrated in Fig 1A, right diagram). The percentage of falls for each player was also measured. Each video was analyzed twice by the same operator in order to confirm data reliability.

Acceleration data were processed offline using the MATLAB software (MathWorks, Natick, MA, USA), and the signal from the three coordinates of the accelerometer was integrated. The acceleration data were digitally low-pass filtered at 20 Hz using a fifth order, zero-lag Butterworth filter. Firstly, the instant at which the subject initiated the movement (T_0) was calculated when the magnitude of this integrated acceleration exceeded 3% of its peak absolute magnitude in that particular trial. These values were confirmed by visual inspection. Secondly, the instant of impact (T_1) was appreciated by considering the mean value of the time of peak acceleration between the soccer player and the swimmer (see Fig 2 which shows a representative trial of the anterior-posterior GRF for a player). Movement time was calculated as the time from T_0 to T_1 . The difference between the T_0 of the soccer player and the T_0 of the swimmer was considered as time lag that defines the player that initiated the action as first.

Also, the force data were digitally low-pass filtered at 20 Hz using a fifth order, zero-lag Butterworth filter. Anticipatory Postural Adjustments (APAs) were calculated as the absolute

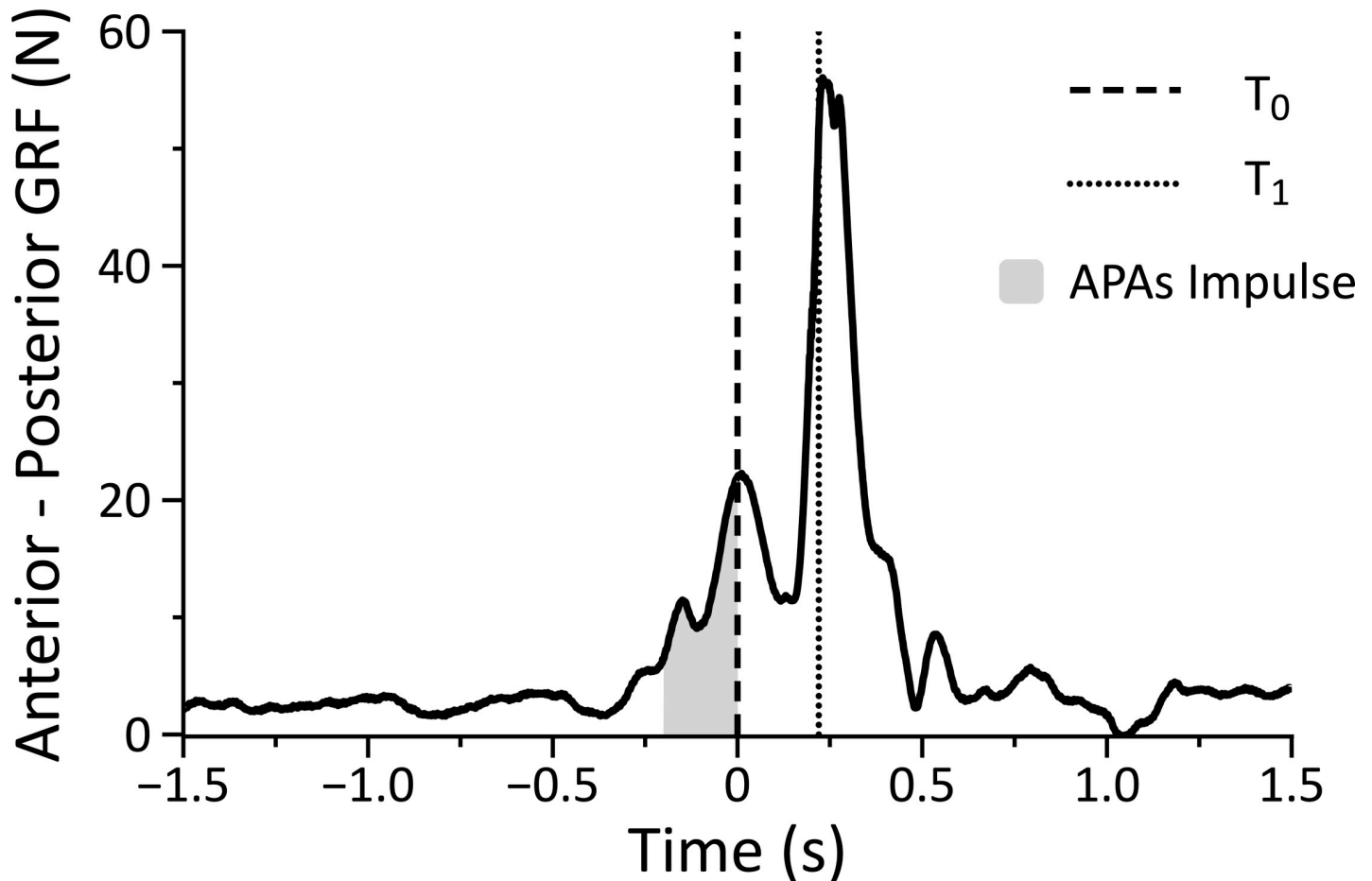


Fig 2. A representative trial of the anterior-posterior GRF for a player. T_0 is the instant at which the subject initiated the movement; T_1 is the instant of impact; absolute APAs impulse has been calculated as the integrated signal of the anterior-posterior GRF over a fixed window time (from -200 ms to T_0).

<https://doi.org/10.1371/journal.pone.0249635.g002>

impulse generated by the anterior-posterior GRF over a window time from -200 ms to T_0 . It is worth noting that, we only considered the anterior-posterior component of force because the movement took place mainly in such direction during the game. The fixed time of 200 ms was chosen based on previous APAs studies during fast voluntary movements [29, 35], as well as a priori visual inspection of the GRFs during the data analysis.

For the reactive game the number of lights off and the timing between each light off (reaction time expressed in seconds) were measured with the FITLIGHT Trainer.

Statistical analysis

Results are presented as mean and standard deviation (SD). A Student t-test for paired data was performed to investigate group differences in anthropometrical and general characteristics ($p < 0.05$).

The normality of the distributions was assessed with the Kolmogorov-Smirnov goodness of fit test. For each variable (movement time, time lag, APAs impulse, and stability index), we performed a Mann-Whitney U-test for independent samples to investigate differences between soccer players and swimmers ($n = 8$; $p < 0.05$). Also, simple linear regression analysis was computed to investigate the correlations among all variables; the reliability (significance) of

Table 2. Data studied for the proactive type of game and the reactive type of game (mean (SD)), and statistical significance between soccer players and swimmers.

Characteristic	Soccer players	95% CI	Swimmers	95% CI	Effect size (r)	p value
	(n = 8)		(n = 8)			
Proactive type of game						
Movement Time (s)	0.27 (0.04)	0.24–0.31	0.30 (0.06)	0.24–0.35	-0.211	p = 0.399
Time Lag (s)	0.11 (0.03)	0.08–0.14	0.12 (0.02)	0.09–0.14	-0.160	p = 0.522
Trials with time lag (%)	32.6 (14.6)	18.0–47.2	37.4 (13.3)	24.1–50.1	-0.158	p = 0.527
APAs Impulse (N·s)	2.34 (1.39)	0.96–3.70	2.16 (1.01)	1.15–3.20	-0.053	p = 0.834
Stability Index	0.87 (0.09)	0.77–0.96	0.66 (0.11)	0.55–0.77	-0.709	p < 0.01
Reactive type of game						
Reaction Time (s)	0.45 (0.05)	0.41–0.50	0.48 (0.07)	0.41–0.55	-0.263	p = 0.294
Number of lights off	39.3 (2.18)	37.1–41.5	38.2 (3.52)	34.7–41.7	-0.276	p = 0.270

<https://doi.org/10.1371/journal.pone.0249635.t002>

these relationships was established based on the coefficient of correlation (r) and the appropriate degrees of freedom (n-2) (e.g. [36]). The level of significance was set at $p < 0.05$. Statistical analysis was performed using SPSS program (version 22 for Windows).

Results

There were no significant differences between the two groups in mean age, height, weight and years of experience (see Table 1) (Student t-test for paired data; $p > 0.05$).

Average and standard deviation values measured in both proactive and reactive game are reported in Table 2 for soccer players and swimmers (Mann-Whitney U-test for independent samples; $p < 0.05$).

In the proactive game, the time lag (mean \pm SD of soccer players and swimmers: 0.11 ± 0.03 and 0.12 ± 0.02 s; $p = 0.522$), the movement time (0.27 ± 0.04 and 0.30 ± 0.06 s; $p = 0.399$) and APAs impulse (2.34 ± 1.39 and 2.16 ± 1.01 N·s; $p = 0.834$) were not significantly different between the two groups.

Importantly, though soccer players were significantly more stable than swimmers presenting a higher index of stability (0.87 ± 0.09 and 0.66 ± 0.11 ; $p < 0.01$; mean \pm SD of soccer players and swimmers) and a significantly less percent of falls (13.4 ± 9.5 and $34.4 \pm 11.0\%$; $p < 0.01$, respectively) (Fig 3, panel a). Moreover, just soccer players, presented a significant linear correlation between APAs impulses and time lag (APAs Impulse = $-1.211 - 32.929 \cdot$ time lag for soccer players: $r = 0.751$; $p < 0.01$) while there was none correlation for swimmers (APAs Impulse = $3.218 - 9.024 \cdot$ time lag for swimmers: $r = 0.205$; $p = \text{ns}$). (Fig 3, panel b). No other significant correlations were found for the proactive game.

As for the reactive game, the statistical analysis showed none significant difference between soccer players and swimmers: all players turned off a similar number of lights (39.3 ± 2.18 and 38.2 ± 3.52 ; $p = 0.270$) by applying the same time (0.45 ± 0.05 and 0.48 ± 0.07 s; $p = 0.294$).

Discussion

Our study was designed to investigate the development of anticipatory and strategic skills in total body games competitions comparing young expert soccer players (open skill-dominated sport) with swimmers (closed skill-dominated sport) of the same age and level of sport expertise.

In particular, we aimed at disentangling proactive and reactive control mechanisms in individuals trained in different sports as close and open skills related. In general, we found that while there were none differences between swimmers and soccer players in their ability to apply reactive control, soccer players outperformed swimmers when engaged in a competition where a proactive control was required. Importantly results showed that the superior ability

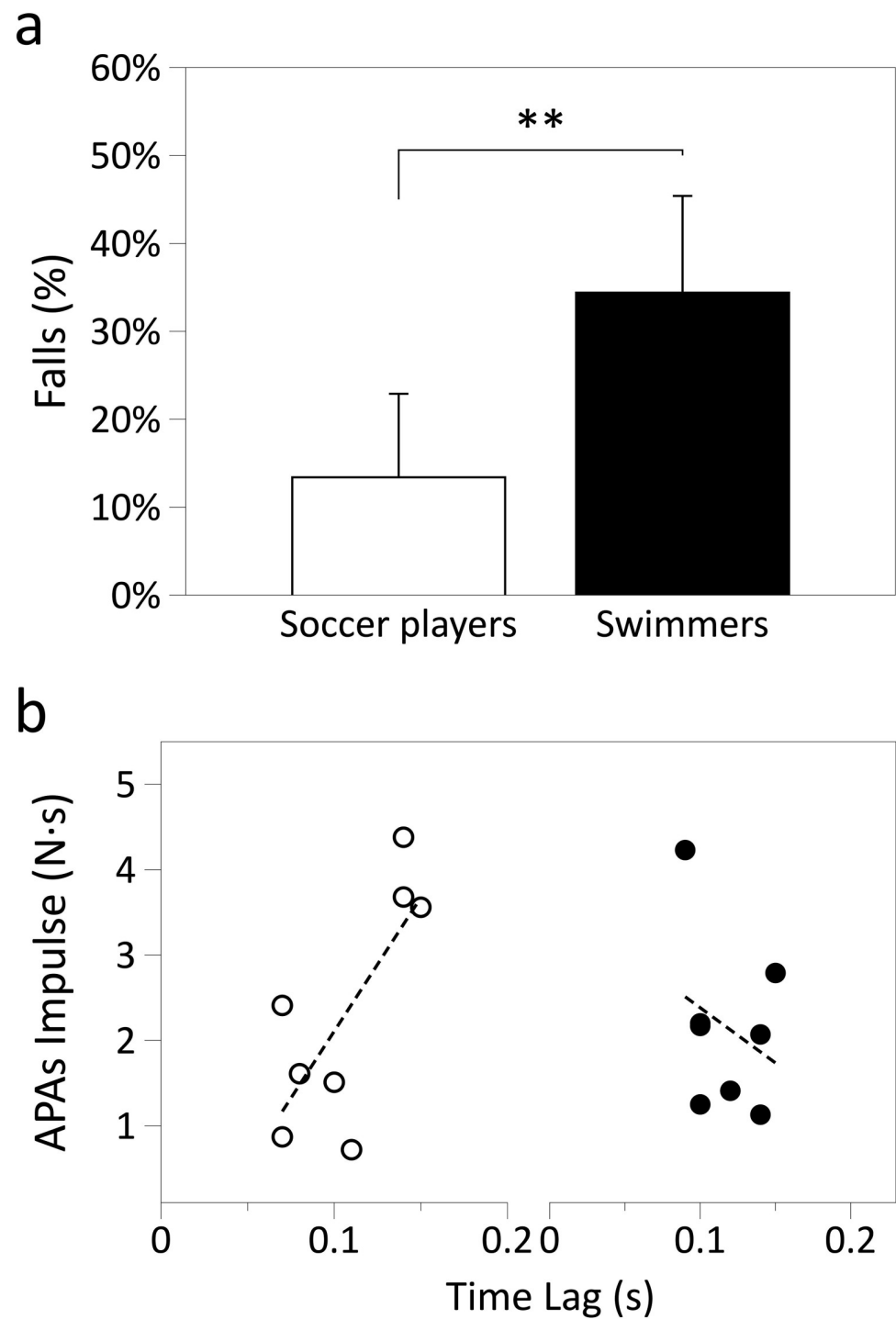


Fig 3. Proactive game's findings. **a.** Percentage of falls of soccer players (white bars) and swimmers (black bars) for the proactive type of game. Average values \pm SD have been reported, as well as statistical significance. **b.** APAs Impulse is plotted as a function of time lag for the proactive type of game. The symbols refer to: soccer players \circ , and swimmers \bullet .

<https://doi.org/10.1371/journal.pone.0249635.g003>

presented by soccer players was ascribed to the proper modulation of Anticipatory Postural Adjustments in preparation to their attack to the opponent. These findings underline the specific development of skills abilities due to the peculiarity of a sport training.

Our results were consistent with previous studies [33], in defining skills/environment relationship where in a highly predictable environment closed skills are required as a prompt reaction given a known signal, while in the unpredictable environment athletes are forced to anticipate impending events by using open skills. In swimming, the sound of the starter's gun indicates the race initiation and a fast reaction to auditory stimuli is required; a slight delay in reacting to the gun sound might change the overall result in a competition [2, 4]. On the other hand, soccer players have been trained in a team and the game is performed in a highly dynamic environment in which athletes continuously predict the ball and the opponents position now and sooner after now [37].

Here we showed that during a typical proactive competition, soccer players were able to beat the swimmers by maintaining higher stability and falling a significantly smaller number of times. Importantly, we showed that the main "weapon" soccer players used was to activate a proper action anticipation by modulating their APAs. APAs were arranged based on the amount of body impulse impinged on the force platform before action initiation and this amount of force was a function of the time gap between the action initiation of the soccer player with respect to the action initiation of the opponent. Higher impulse was impinged for more anticipated actions and lower impulse for less anticipated action, and this impulse modulation was present only for soccer players. We sustain that this was the strategy that allowed a soccer player to obtain a greater postural stability at the instant of the impact with the body's swimmer and, as a consequence, to win the game. In other words, soccer players were able to modulate their APAs based on their force/timing relationship impinged in their body preparation defined by their prediction of future movement initiation of the opponent player [5, 37].

Our results are sustained by researches showing that open skill related athletes outperform closed skills related athletes in the proactive contests [38], but here we added the relevant information of the feedforward motor command from the motor cortex that sustains the development of these type of skills. Some researches posed the question whether results can be obtained only when the task to be performed is specific of the sport in which the athletes excel [17]. Here, we applied a game competition that involved actions that were not specific for soccer nor for swim sport. This was important for showing that the proactive type of control is independent from the type of movement performed [17].

In line with previous works [39], as in our research, reaction time has been evaluated by means of an oculo-manual coordination task using the FITLIGHT Trainer system (Sports Corp., Ontario, Canada). In this case the game was mainly based on reactive control including the competition since the two players were performing the game at the same time and they could have the sense of the other's performance. But in this case, we found similar performance for soccer players and swimmers, suggesting that all the recruited athletes presented a high physical condition, promptness, ability to face stressful situations and great concentration [3]. Furthermore, all our subjects could execute likewise the mental operations needed by the task at hand, with the same speed of processing, showing an equal index of efficiency [40].

We believe that the results from our study are unlikely confounded by the consistency of the sample gender. Future studies should be done considering also a female gender sample.

Limitations

This paper presents a number of limitations. We recruited a limited number of participants, 16 athletes, but this was partially compensated by a large number of trials performed by each

participant: at least 65 trials for each couple of athletes. In future works, it would be interesting to involve a larger number of participants and testing different levels of sport experience [41] and following closely the development of reactive and proactive control ability as children grow and acquire over time specialized training. An interesting additional component that could be considered in future experiment will be eye and head movement to detect more finely the anticipated intention of the player and or possible subtle fake strategies. This issue could be addressed in future by employing some specific technologies such as the electronic goggles and a head movement controller.

Supporting information

S1 Table. Normality test.

(PDF)

S1 Data. File data.

(XLSX)

Acknowledgments

We would like to thank Edoardo Ribani and Enrico Salgarollo for their help in data collection and analysis, and the subjects for participating the study.

Author Contributions

Conceptualization: Francesca Nardello, Paola Cesari.

Data curation: Francesca Nardello, Matteo Bertucco, Paola Cesari.

Formal analysis: Francesca Nardello, Matteo Bertucco, Paola Cesari.

Funding acquisition: Francesca Nardello, Paola Cesari.

Investigation: Francesca Nardello, Matteo Bertucco, Paola Cesari.

Methodology: Francesca Nardello, Matteo Bertucco, Paola Cesari.

Project administration: Francesca Nardello, Paola Cesari.

Resources: Francesca Nardello, Matteo Bertucco, Paola Cesari.

Software: Francesca Nardello, Matteo Bertucco, Paola Cesari.

Supervision: Francesca Nardello, Paola Cesari.

Validation: Francesca Nardello, Matteo Bertucco, Paola Cesari.

Visualization: Francesca Nardello, Matteo Bertucco, Paola Cesari.

Writing – original draft: Francesca Nardello, Matteo Bertucco, Paola Cesari.

Writing – review & editing: Francesca Nardello, Matteo Bertucco, Paola Cesari.

References

1. Knapp B. Skill in sport: The attainment of proficiency. London: Routledge & Paul; 1963.
2. Itamar N, Schwartz D, Melzer I. Postural control: differences between young judokas and swimmers. *J Sports Med Physic Fitness*. 2013; 53: 483–489.
3. Zhongfan L, Inomata K, Takeda T. Soccer players' and closed-skill athletes' execution of a complex motor skill. *Perceptual and Motor Skills*. 2002; 95: 213–218. <https://doi.org/10.2466/pms.2002.95.1.213> PMID: 12365256

4. Wang CH, Chang CC, Liang YM, Shih CM, Chiu WS, Tseng P, et al. Open vs. closed skill sports and the modulation of inhibitory control. *PLOS ONE*. 2013; 8(2): e55773. <https://doi.org/10.1371/journal.pone.0055773> PMID: 23418458
5. Aglioti SM, Cesari P, Romani M, Urgesi C. Action anticipation and motor resonance in elite basketball players. *Nature Neuroscience*. 2008; 11(9): 1109–1116. <https://doi.org/10.1038/nn.2182> PMID: 19160510
6. Allard F, Starkes JL. Motor-skill experts in sports, dance, and other domains. In Ericsson K.A., & Smith J.(Eds.) *Toward a general theory of expertise: Prospects and limits*. Cambridge (pp. 126–152); 1991.
7. Di Russo F, Bultrini A, Brunelli S, Delussu AS, Polidori L, Taddei F, et al. Benefits of sports participation for executive function in disabled athletes. *Journal of Neurotrauma*. 2010; 27: 2309–2319. <https://doi.org/10.1089/neu.2010.1501> PMID: 20925480
8. Gould D, Jackson S, Finch L. Sources of stress in national champion figure skaters. *J Sport Exercise Psychol*. 1993; 15: 134–159. <https://doi.org/10.1080/02701367.1993.10607599> PMID: 8278672
9. Savelsbergh GJP, Williams AM, Van der Kamp J, Ward P. Anticipation and visual search behaviour in expert soccer goalkeepers. *Ergonomics*. 2005; 48: 1686–1697. <https://doi.org/10.1080/00140130500101346> PMID: 16338733
10. Shim J, Carlton LG, Chow JW, Chae WS. The use of anticipatory visual cues by highly skilled tennis players. *Journal of Motor Behaviour*. 2005; 37(2): 164–175. <https://doi.org/10.3200/JMBR.37.2.164-175> PMID: 15730949
11. Mori S, Ohtani Y, Jmanaka K. Reaction times and anticipatory skills of karate athletes. *Human Movement Science*. 2002; 21(2): 213–230. [https://doi.org/10.1016/s0167-9457\(02\)00103-3](https://doi.org/10.1016/s0167-9457(02)00103-3) PMID: 12167300
12. Vences de Brito A, Silva C. Reaction time in karate athletes. *Journal of Martial Arts Anthropology*. 2011; 11(4): 35–39.
13. Metin B, Wiersema JR, Verguts T, Gasthuys R, van Der Meere JJ, Roeyers H, et al. Event rate and reaction time performance in ADHD: testing predictions from the state regulation deficit hypothesis using an ex-Gaussian model. *Children Neuropsychology*. 2016; 22: 99–109. PMID: 26835532
14. Layton L. A deconstruction of Kohut's concept of the self. *Contemporary Psychoanalysis*. 1991; 26(3): 420–429. <http://dx.doi.org/10.1080/00107530.2015.1056076>
15. Collett C. Strategic aspects of reaction time in world-class sprinters. *Perceptual Motor Skills*. 1999; 88(1): 65–75. <https://doi.org/10.2466/pms.1999.88.1.65> PMID: 10214633
16. Williams AM, Huys R, Canal-Bruland R, Hagemann N. The dynamical information underpinning anticipation skill. *Human Movement Science*. 2008; 28(3): 362–370. <https://doi.org/10.1016/j.humov.2008.10.006> PMID: 19081648
17. Yu Q, Chan CCH, Chua B, Fu ASM. Motor skill experience modulates executive control for task switching. *Acta Psychologica*. 2017; 180: 88–97. <https://doi.org/10.1016/j.actpsy.2017.08.013> PMID: 28923518
18. Braver TS. The variable nature of cognitive control: a dual mechanisms framework. *Trends in Cognitive Sciences*. 2012; 16(2): 106–113. <https://doi.org/10.1016/j.tics.2011.12.010> PMID: 22245618
19. Taddei D. From rational to behavioural: new tendencies in decision theory and cognitive psychology and their impact on the routine level analysis of organizations. PhD Thesis; 2012. Available from: <https://eprints.luiss.it/1090/>.
20. Desmurget M, Grafton S. Forward modelling allows feedback control for fast reaching movements. *Trends in Cognitive Sciences*. 2000; 4(11): 423–431. [https://doi.org/10.1016/s1364-6613\(00\)01537-0](https://doi.org/10.1016/s1364-6613(00)01537-0) PMID: 11058820
21. Belen'kii VE, Gurfinkel VS, Pal'tsev EL. Control elements of voluntary movements. *Biofizika*. 1967; 12: 135–141. PMID: 5623488
22. Zattara M, Bouisset S. Posturo-kinetic organization during the early phase of voluntary upper limb movement. 1. Normal subjects. *Journal Neurology Neurosurgery Psychiatry*. 1988; 51: 956–965. <https://doi.org/10.1136/jnnp.51.7.956> PMID: 3204405
23. Massion J. Movement, posture and equilibrium: Interaction and coordination. *Progress in Neurobiology*. 1992; 38(1): 35–56. [https://doi.org/10.1016/0301-0082\(92\)90034-c](https://doi.org/10.1016/0301-0082(92)90034-c) PMID: 1736324
24. Duarte M, Latash M. Effects of postural task requirements on the speed-accuracy trade-off. *Experimental Brain Research*. 2007; 180(3): 457–467. <https://doi.org/10.1007/s00221-007-0871-x> PMID: 17273871
25. Piscitelli D, Falaki A, Solnik S, Latash M. Anticipatory Postural Adjustments and Anticipatory Synergy Adjustments: preparing to a postural perturbation with predictable and unpredictable direction. *Experimental Brain Research*. 2017; 235(3): 713–730. <https://doi.org/10.1007/s00221-016-4835-x> PMID: 27866261

26. Bertuccio M, Cesari P. Does movement planning follow Fitt's law? Scaling anticipatory postural adjustments with movement speed and accuracy. *Neuroscience*. 2010; 171: 205–213. <https://doi.org/10.1016/j.neuroscience.2010.08.023> PMID: 20804822
27. Bertuccio M, Cesari P, Latash M. Fitts' Law in Early Postural Adjustments. *Neuroscience*. 2013; 12(231): 61–69.
28. Lee Y, Liang JN, Chen B, Aruin AS. Characteristics of medial-lateral postural control while exposed to the external perturbation in step initiation. *Scientific Reports*. 2019; 9: 16817. <https://doi.org/10.1038/s41598-019-53379-9> PMID: 31727992
29. Aruin AS, Latash ML. Directional specificity of postural muscles in feed-forward postural reactions during fast voluntary arm movements. *Exp Brain Res*. 1995; 103: 323–332. <https://doi.org/10.1007/BF00231718> PMID: 7789439
30. Yamagata M, Gruben K, Falaki A, Ochs WL, Latash ML. Biomechanics of Vertical Posture and Control with Referent Joint Configurations. *Journal of Motor Behavior*. 2020; 53(5): 1–11. <https://doi.org/10.1080/00222895.2020.1723483> PMID: 32041492
31. Yamagata M, Falaki A, Latash ML. Stability of vertical posture explored with unexpected mechanical perturbations: synergy indices and motor equivalence. *Experimental Brain Research*. 2018; 236(2). <https://doi.org/10.1007/s00221-018-5239-x> PMID: 29564504
32. Jackson RC, Warren S, Abernethy B. Anticipation skill and susceptibility to deceptive movement. *Acta Psychologica*. 2006; 123(3): 355–371. <https://doi.org/10.1016/j.actpsy.2006.02.002> PMID: 16546104
33. Nuri L, Shadmehr A, Ghotbi N, Behrouz Attarbashi M. Reaction time and anticipatory skill of athletes in open and closed skill-dominated sport. *European Journal of Sport Science*. 2013; 13(5): 431–436. <https://doi.org/10.1080/17461391.2012.738712> PMID: 24050458
34. Yu Q, Chau BKH, Lam BYH, Wong AWK, Peng J, Chan CCH. Neural processes of proactive and reactive controls modulated by motor-skill experiences. *Frontiers in Human Neuroscience*. 2019; 13: Article 404. <https://doi.org/10.3389/fnhum.2019.00404> PMID: 31798435
35. Aruin AS, Latash ML (1996) Anticipatory postural adjustments during self-initiated perturbations of different magnitude triggered by a standard motor action. *Electroencephalogr Clin Neurophysiol*. 101:497–503. [https://doi.org/10.1016/s0013-4694\(96\)95219-4](https://doi.org/10.1016/s0013-4694(96)95219-4) PMID: 9020822
36. Thomas JR, Nelson JK, Silverman SJ. Research methods in statistical analysis. 5th ed., Human Kinetics, Champaign, IL, United States (pp. 125–145); 2005.
37. Tomeo E, Cesari P, Aglioti SM, Urgesi C. Fooling the kickers but not the goalkeepers: behavioral and neurophysiological correlates of fake action detection in soccer. *Cerebral Cortex*. 2011; 23(11): 2765–2778.
38. Fontani G, Lodi L, Felici A, Migliorini S. Attention in athletes of high and low experience engaged in different open skill sports. *Perceptual and Motor Skills*. 2006; 102(3): 791–805. <https://doi.org/10.2466/pms.102.3.791-805> PMID: 16916159
39. Reigal RE, Barrero S, Martin I, Morales-Sanchez V, Juarez-Ruiz de Mier R, Hernandez-Mendo A. Relationships between reaction time, selective attention, physical activity, and physical fitness in children. *Frontiers in Psychology*. 2019; 10: Article 2278. <https://doi.org/10.3389/fpsyg.2019.02278> PMID: 31681086
40. Boisgontier MP, Wittenberg GF, Fujiyama H, Levin O, Swinnen SP. Complexity of central processing in simple and choice multi-limb reaction-time tasks. *PLoS ONE*. 2014; 9(2): e90457. <https://doi.org/10.1371/journal.pone.0090457> PMID: 24587371
41. Deary IJ, Geoff D. Reaction time, age, and cognitive ability: longitudinal findings from age 16 to 63 years in representative population samples. *Aging, Neuropsychology, and Cognition*. 2005; 12(2): 187–215.