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The individual training history shapes soccer players' ability to predict teammates' and opponents' moves

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In sports, players constantly engage in understanding others' actions and intentions. Previous studies have highlighted that possessing the observed action in the individual motor repertoire improves the prediction abilities of the observer. Here, we tested the extent to which players' ability to predict soccer actions is influenced by their motor repertoire, which is modulated not only by their generic expertise but also by the specific position played on the field. To these aims, two experiments were conducted by asking players to predict the result of typical soccer actions and comparing accuracies with data concerning their soccer career. Results revealed that both general expertise and position-specific experience significantly impacted prediction performance, with the highest accuracy observed when actions aligned with players' positional expertise. These findings highlight that the motor resonance mechanism is finely attuned to the individual's motor repertoire, which operates as a continuum – from no experience to advanced expertise in a specific position – enabling a dynamic, experience-driven enhancement of action prediction in sports.

Keywords Sports, Action prediction, Mirror mechanism, Motor repertoire, Motor skills, Motor resonance

In team sports, players' ability to "read" the game is a fundamental skill that involves rapidly comprehending others' actions and intentions and adapting their behavior accordingly[1]. The capacity to understand actions and predict their outcomes is mediated by the mirror mechanism, i.e., the neurophysiological mechanism that activates several motor regions not only during the execution but also during the observation of the same action[2,3]. In other words, sensory inputs are transformed into a motor format[3].

Several studies have attributed the mirror mechanisms a fundamental role in the perception and prediction of others' actions[4]. Fogassi et al.[5] demonstrated this in monkeys by recording from inferior parietal lobule (IPL) neurons. Monkeys performed two actions – grasping to eat or to place an object – and observed the experimenter performing similar actions. Results revealed that IPL neuron activity varied based on the action's intention during both active and observed grasping. This suggests that IPL neurons encode the overall action intention from the very first motor acts. Similar effects were found in the premotor area F5[6]. In humans, similar intention-modulated responses have been shown through electromyographic and fMRI studies[7,8]. Behavioral evidence also supports the role of the mirror mechanism in perceiving others' actions. Lesion-symptom mapping studies reveal that damage to the left inferior frontal, inferior parietal, and middle-superior temporal cortices (i.e., the hubs composing the action observation network[9]) is linked to deficits in action perception[10]. Patients with apraxia, particularly those with left inferior frontal gyrus damage, struggle more with recognizing gestures compared to non-apraxic patients[11]. Causal evidence from continuous theta-burst stimulation (cTBS) further confirms this action-perception link. cTBS over the left premotor cortex disrupts recognition of hand and mouth actions[12], while cTBS to inferior parietal regions impairs the ability to infer intentions from observed hand kinematics[13].

A fundamental prerequisite for the motor resonance mechanism is that the observed action is represented within the observer's motor repertoire. Buccino et al.[14] demonstrated that observers' parieto-frontal networks are

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activated for actions well-integrated into their motor repertoire (e.g., biting), regardless of the agent performing the action (e.g., human, monkey, or dog). Conversely, no such activation occurs for actions outside the motor repertoire (e.g., barking). This repertoire-dependent modulation is not restricted to biologically possible actions but is also shaped by the observer's expertise with specific actions. For instance, Calvo-Merino et al.[15] found that dancers exhibit greater mirror mechanism activation when observing movements from their area of expertise (e.g., capoeira vs. classical ballet). Furthermore, within the same type of dance, motor resonance is driven by motor experience rather than mere visual familiarity[16].

Sports provide a unique empirical context for studying the interplay between visual and motor expertise, as both are critical for understanding others' actions and predicting their outcomes. These skills enable athletes to predict opponents' intentions and respond appropriately before an action begins. A seminal study by Aglioti and coworkers[17] showed that elite basketball players (visuomotor experts) outperformed coaches and sports journalists (visual experts) in predicting free throw outcomes. Subsequent studies have consistently demonstrated that experts outperform novices in predicting opponents' intentions by identifying key cues such as action preferences, body posture, and predicted movements[18,19].

The visuomotor origin of this advantage has been further supported by behavioral studies demonstrating that expert athletes rely on initial kinematics or visual cues, such as ball trajectory, for predicting others' actions[20–22]. For example, in tennis, experts can detect kinematic information at early, pre-contact stages to predict ball direction and force[23], even though on-court position also contributes to the shot outcome prediction[24]. Similarly, the initial ball trajectory of volleyball floating services allowed both athletes and supporters to be more accurate than novices in predicting the fate of the service, yet only the former group could base their predictions on body kinematics[25]. Notably, prediction of tennis and volleyball serves induces stronger activation of the action observation network areas (superior parietal lobule - SPL, supplementary motor area - SMA) and cerebellar structures in expert athletes compared to novices, with activation extent linearly correlated with prediction performance[26]. Similar findings have been reported in other sports, such as handball[27], soccer[28–31], baseball[32], darts[33], and rugby[34–36]. In ecological situations, contextual elements provide fundamental cues for action prediction[37–39], potentially interacting with kinematic information and the observer's expertise[40]. However, the evidence above indicates that the mere visual experience of the observed action is insufficient to ensure prediction performance as accurate as that of visuomotor experts.

The link between action perception and athlete expertise operates not only at a categorical level (e.g., experts vs. naive vs. observers) but also among different members of the same team. Testing expert basketball players, Hohmann and colleagues[41] showed that they recognized actions presented as point-light displays better than novices and identified themselves more precisely than teammates when asked to name the actor. The notion that self-identification is enhanced by active motor experience, regardless of visual exposure, aligns with previous reports[42].

Building on these findings, an open question arises: does individual motor expertise among team members modulate the accuracy of action prediction, enabling players to decode both teammates' and opponents' behaviors? A previous study compared the ability of rugby players (kickers and non-kickers) and naïve participants to predict the outcome of placed kicks[36]. Kickers demonstrated greater accuracy than naïve participants and their expert teammates playing in other positions, suggesting that specialized training enhances the ability to understand others' behaviors on the field. Placed kicks in rugby exemplify "closed skill actions," defined as individual, uncontested motor actions unaffected by other players[43].

However, team sports predominantly involve dynamic, interactive environments where one player's action shapes the responses of others. This creates a complex system of interactions involving at least one "agent" (the sender of an action) and one "observer" (the receiver). Even when the agent executes the action flawlessly, the observer must accurately interpret and predict the action's outcome. Soccer provides numerous examples of this dynamic interplay[44]. Consider a cross from a winger into the penalty area: forwards must predict and position themselves to score, defenders must intercept the ball, and the goalkeeper must prepare for a potential clearance.

Soccer also highlights the interplay between general and position-specific motor expertise. While many soccer actions are shared across positions, players develop heightened skills in actions characteristic of their specific role. This creates a continuum of motor expertise, where actions are represented across all players but exhibit position-specific peaks of dexterity. For example, the accuracy of a forward's finishing differs from that of a defender's clearance despite overlapping motor skills. This continuum is further complicated by the dichotomy between visual and motor expertise inherent in team sports. Players frequently face opponents with differing positional expertise and motor repertoires, and this mismatch creates a virtual imbalance, as certain actions are predominantly performed by one group of players and mostly observed by another[45]. These dynamics underscore the intricate relationship between motor and visual expertise in action prediction and team coordination.

Building on these premises, our study investigates the role of motor expertise in predicting open-skill soccer actions by analyzing responses from players trained to execute these actions and those who typically have to face them on the field. This comparison allows us to extend current evidence by examining the predictive abilities of visuomotor experts versus "active" visual experts – players who regularly react to observed actions during gameplay. We included participants from all field positions, ensuring a comparable baseline of motor expertise while accounting for specialization based on their predominant playing positions over their careers. Moving beyond the heavily dichotomous scenarios extensively studied in the literature, such as striker-goalkeeper interactions during penalty kicks, we aim to generalize our findings to a wider range of real-game contexts and scenarios.

We hypothesize that the position-specific motor expertise accumulated through years of specialized training enhances the ability to predict actions characteristic of the corresponding position. We will test this hypothesis in two experiments. In the first one, we evaluate the action prediction abilities of naïve individuals, amateurs, and professional players, examining whether the motor experience of the latter two groups leads to better performance in action prediction and whether individual motor expertise further shapes the performance. In the second experiment, we expand this perspective by testing four groups of active players, subdivided according to their primary playing roles. Our findings will suggest that the continuum of motor repertoire directly correlates with a continuum of prediction ability, aligning with the idea that motor resonance extends beyond action goals to encompass other motor features[46], such as kinematics[47,48], postures[49,50], and dynamics[51]. By emphasizing the nuanced relationship between motor expertise and action prediction, our findings could provide valuable insights for optimizing player performance and enhancing team dynamics.

Materials and methods

Two experiments are presented, evaluating how specialized and prolonged training in specific field positions influences soccer action prediction. We included (1) a sample of soccer players with heterogeneous levels of experience (Experiment 1) and (2) professional players recruited within the Atalanta Bergamasca Calcio Youth Sector, one of the top ten most profitable club academies worldwide (CIES Football Observatory, https://football-observatory.com/WeeklyPost446*)* (Experiment 2).

Both the experiments described below were approved by the Institutional Ethical Committee [Commissione per l'Etica e l'Integrità nella Ricerca - National Research Council (CNR), n. 00111709/2022, 15.02.2022] and were conducted according to the principles of the Declaration of Helsinki. The players shown in the videos gave written authorization to use their images. Both participants and their legal guardians obtained written informed consent.

Experiment 1

Participants

An a priori power analysis with G-Power 3.1 was conducted to determine the sample size suitable for a between-subjects ANOVA design, including three groups, namely Professional Players (PrP), Amateur Players (AmP), and Naïve (N). The output indicated a minimum sample size of 84 participants (28 for each group) with $\alpha = 0.05$, power $\beta = 0.90$, and a large effect size $f = 0.4$ per recommendations as in Cohen[52]. Considering potential dropouts and technical issues, we increased the group size to a minimum of 32 for each group. Participants were recruited via the Prolific platform (www.prolific.com*)* and redirected to the Gorilla Experiment Builder platform (http://www.gorilla.sc/*)* to complete the experiment. A preliminary questionnaire was administered to participants about their career as soccer players (e.g., *Have you ever played soccer? What is the highest soccer division you have played in? How many years have you played in the following positions: Forward, Center, Lateral, and Goalkeeper?).* Based on their responses, participants were assigned to one of three groups. Specifically, participants who played at least one year in top leagues (i.e., the nine soccer divisions set up by the Italian Football Federation, https://www.figc.it/it/federazione/la-federazione/la-federazione/*)* were labeled as Professional Players (PrP), those who played at least one year at an amateur level as Amateur Players (AmP), and finally, those who have never played soccer in their life as Naïve (N).

The final sample consisted of 105 male participants: 41 PrP (mean age = 24.2 ± 4.6), 32 AmP (mean age = 22.9 ± 1.8), and 32 NP (mean age = 22.7 ± 1.4). Based on the self-reported questionnaires, PrP and AmP participants were further labeled according to their most-played position (PP). If still active, participants with equal experience across multiple positions were assigned to their current PP. Those not playing at the time of the experiment were excluded due to the difficulty of determining their most-played position ($n = 5$). Hence, the final PrP group ($n = 40$) comprised 4 Forward Players (FP), 18 Center Players (CP), 14 Lateral Players (LP), and 4 Goalkeeper Players (GP), while the AmP group ($n = 28$) included 3 FP, 9 CP, 11 LP, and 5 GP.

Stimuli and experimental design

To assess participants' ability to predict soccer action outcomes, we recorded videos of soccer actions performed by a professional player. The videos featured actions specific to the four selected positions: Forward (F), Center (C), Lateral (L), and Goalkeeper (G), referred to as Observed Positions (OP) (see Fig. 1). For each OP, we videotaped three different actions (e.g., for the forward OP, we recorded a penalty, a shot outside the penalty area, and a shot inside the penalty area; see Supplementary Material, Table S1 for videos and a list of actions chosen for each field position).

Each action was recorded twice, varying only the directional outcomes (e.g., shooting left or right, high or low crosses). All videos were recorded with an allocentric (third person) perspective, placing the camera at the position typically occupied by the receiver of the action. For instance, the goalkeeper's perspective was used for a penalty, while the forward's perspective was used for a goalkeeper's save. Finally, videos were edited and frozen at a specific frame, challenging outcome recognition, resulting in an average duration of 2.7 ± 1.3 s per video. The videos were subsequently edited and frozen at specific frames to challenge participants' ability to predict the outcome. The average video duration was 2.7 ± 1.3 s. The final set included 24 unique videos (4 observed positions × 3 actions × 2 outcomes), each repeated four times, resulting in 96 trials.

The experiment was administered entirely on the Gorilla Experiment Builder platform (http://www.gorilla.sc/). After completing the preliminary soccer experience questionnaire, participants received written instructions and proceeded to the action prediction task. Specifically, for each trial, subjects were instructed first to read what kind of action outcome they had to predict, then start the video by pressing a play button and carefully watch it until the end, finally answering as fast as possible. Each trial was separated by a fixation cross lasting 500 ms. No breaks were provided, as participants could decide when to play each video. Ninety-six videos/trials were presented in a fully randomized order.

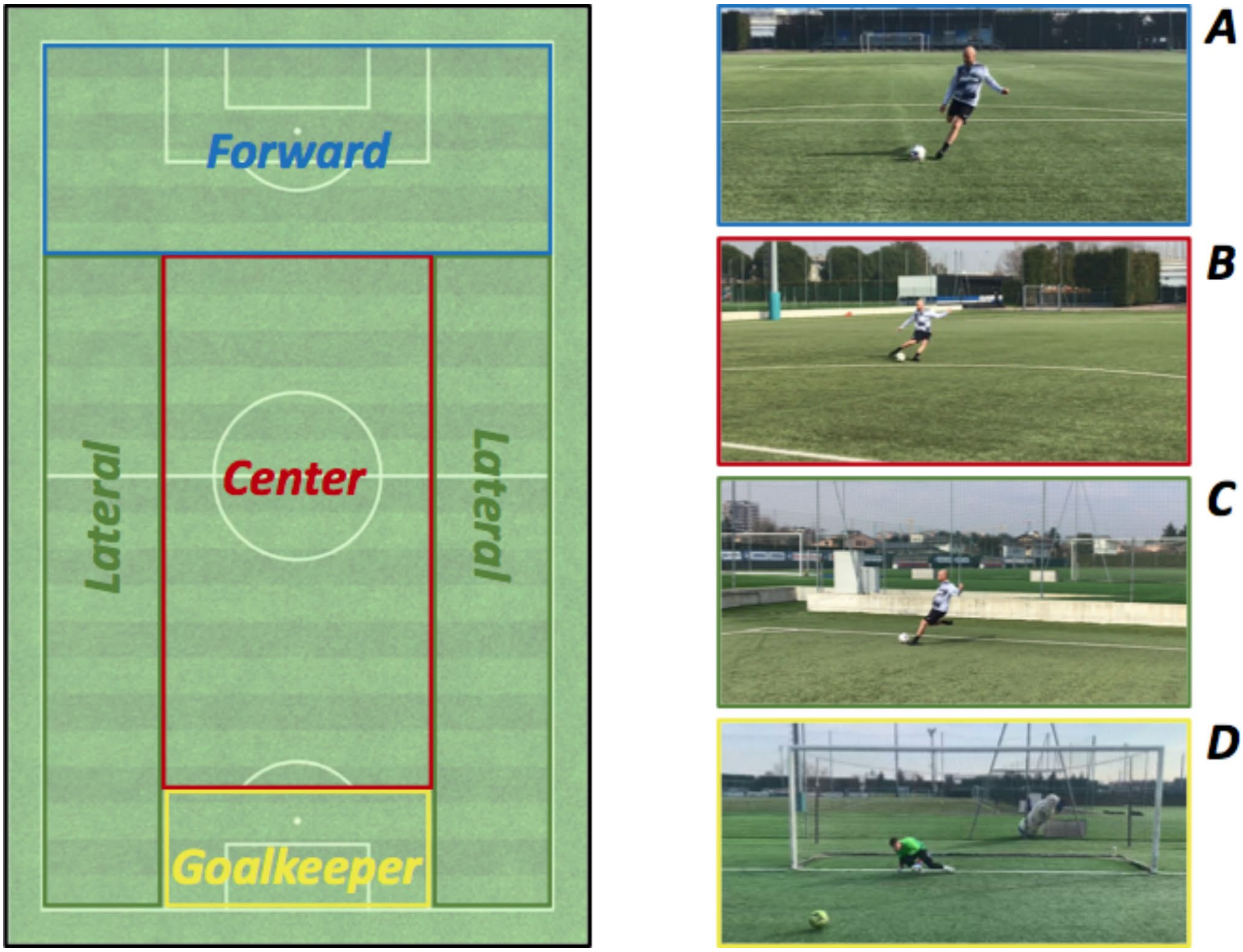

Fig. 1. Subdivision of a soccer field according to the four playing/observed positions analyzed in the study. Panels (**A**), (**B**), (**C**), and (**D**) represent the final frame of videos showing a penalty kick (Forward), a reverse pass (Center), a cross (Lateral), and a save (Goalkeeper), respectively.

Data scoring

For each participant, we computed the Overall Accuracy (OA) – the percentage of correct answers – and the Position-specific Accuracy (PsA) – the rate of correct answers for videos showing actions related specifically to the participant's most-played position.

Statistical analyses

A one-way ANCOVA was conducted to evaluate whether the OA differed among groups (PrP, AmP, and N). The action prediction task session duration was included as a covariate to control for its potential influence on overall accuracy. *Post hoc* comparisons were Bonferroni corrected to account for multiple comparisons. Subsequently, focusing only on participants with soccer expertise (i.e., PrP and AmP), two separate correlation analyses were conducted to test whether position-specific prolonged knowledge led to improved prediction performance for videos corresponding to the same observed position group. Thus, in the final sample (40 PrP and 28 AmP), non-parametric Spearman's correlation coefficients were calculated between participants' years of experience in their most played position (Yexp) and the corresponding PsA.

Results

The one-way ANCOVA on the OA pointed out the main effect of groups in outcome prediction [$F_{(2,96)} = 4.22$, $p = 0.017$]. As shown in Fig. 2 (panel A), PrP significantly outperformed both AmP [$Mean_{PrP} = 0.64$, $Mean_{AmP} = 0.58$; $t_{(66)} = 3.12$, $p_{(corrected)} = 0.007$] and N [$Mean_{N} = 0.59$; $t_{(70)} = 2.35$, $p_{(corrected)} = 0.02$]. No differences emerged between AmP and N ($t_{(58)} = -0.56$, $p_{(corrected)} = 0.58$).

Spearman's analysis revealed a positive, significant correlation between Yexp and PsA, but only when considering the PrP group ($R = 0.40$, $p = 0.009$, see panel B in Fig. 2). This suggests that for experienced players, the more position-specific experience they have, the more accurate they are in predicting the outcome of position-specific actions. This result was not found for the AmP group ($R = 0.05$, $p = 0.81$).

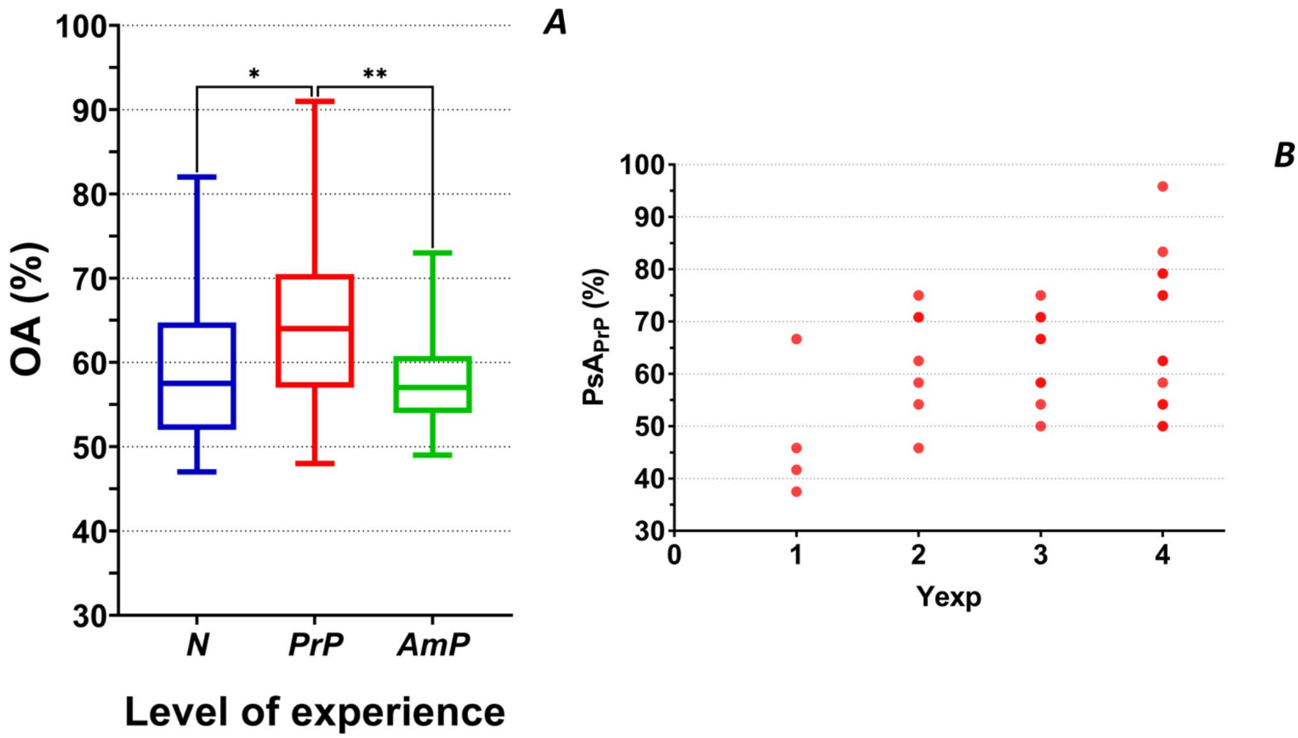

Fig. 2. Accuracy among groups (panel **A**) and correlations between years of experience (Yexp) and position-specific accuracy (PsA) for professional players (PrP) (panel **B**). In panel A, the boxes' upper and lower limits represent the 25th and 75th percentiles, respectively, and the midline in boxes represents the mean of each distribution. Whiskers go down to the smallest value and up to the largest. On the x-axis of panel B: 1 = 1–3 Yexp, 2 = 3–5 Yexp, 3 = 5–10 Yexp, 4 = > 10 Yexp. OA: Overall Accuracy; N: Naïve; PrP: Professional Players; AmP: AmateurPlayers; PsA: Position-specific Accuracy; Yexp: Years of experience; *: $p < 0.05$; **: $p < 0.01$.

Preliminary discussion

The results of Experiment 1 showed that professional players predicted soccer action outcomes more accurately than amateur players and naïve participants. Moreover, for professional players only, an association emerged between the time spent playing a specific position on the field and their corresponding position-specific prediction abilities (see Fig. 2, panel B). This finding aligns with previous observations in rugby[34–36], i.e., that the motor experience of a specific action enhances outcome prediction during observation. Notably, this experience-dependent modulation was observed exclusively among professional players, not amateurs, suggesting that the boost in predicting position-specific action outcomes arises primarily within professional training environments.

Previous studies consistently demonstrate that motor expertise is critical in predicting the outcomes of observed movements. Evidence supporting this comes from comparisons between expert and novice samples, where experts consistently outperform novices in predicting the outcomes of actions within their motor repertoire[17,35,36,53–56]. Our findings align with this literature: soccer experts demonstrated significantly higher prediction accuracy than novices. Interestingly, we also observed that the advantages of motor experience emerge only after professional, and not amateur, training.

Despite accumulating years of motor experience, the amateur group was similar to novices in prediction ability. This suggests that motor representations of movement are continuously evolving, with their robustness influenced by the type of training undertaken. Furthermore, our results indicate that the more years players spend specializing in a specific role, the greater their ability to predict the outcomes of actions typical of that role. This finding supports the continuum concept where motor experience evolves alongside predictive skills, shaped by the duration and nature of training.

Evidence highlighting the role of motor experience in shaping action prediction[36,57,58] is counterbalanced by an alternative explanation: visual exposure to teammates, opponents, or coaches enhances the ability to extract relevant movement information efficiently[45,59–61]. Consequently, the relative contribution of motor experience versus visual exposure remains a topic of debate. An ideal scenario to address this motor vs. visual dichotomy involves simultaneously testing all players from the same teams. In such cases, contextual factors (e.g., level and frequency of training, overall team quality) are balanced, yet players still possess unique individual motor expertise. Based on this rationale, we designed the second experiment to compare the predictive ability of players across different positions within the same teams. This design allowed us to distinguish instances where the observed action matched the players' positions from those where discrepancies existed.

Given the behavioral nature of our study, we cannot be conclusive about the underlying mechanisms behind these findings. However, it seems reasonable to hypothesize that professional training environments, which emphasize the development of technical skills through consistent, high-quality instruction from qualified coaches, enable players to fine-tune their motor repertoires more effectively. In contrast, an amateur level may be insufficient to foster the specialized motor skills required for high-level action prediction. This could explain the lack of a significant relationship between motor expertise and prediction accuracy among amateur players. Additionally, the small size of our professional sample leaves the question of whether this experience-dependent gain is modulated across different playing positions unanswered. Testing this hypothesis would require a larger sample size and players exposed to highly similar training environments to minimize potential confounding factors.

For this reason, we conducted a second experiment using the same behavioral task, administering it to 153 participants from youth teams of a professional Italian soccer club.

Experiment 2

Participants

Participants were recruited from young elite soccer players (i.e., Under-14 to Under-19, mean age = 15.8 ± 1.7) of Atalanta Bergamasca Calcio (Bergamo, Italy). This recruitment strategy provided two main advantages: (1) the sample included youth players trained at one of the top ten most profitable club academies worldwide (CIES Football Observatory, https://football-observatory.com/WeeklyPost446*)*, ensuring exposure to the highest professional standards, and (2) all playing positions were represented.

Each Atalanta player completed the same experimental procedures of Experiment 1 via the Gorilla Experiment Builder platform (http://www.gorilla.sc/*)*. As in Experiment 1, participants completed a preliminary questionnaire to identify their most-played position (PP) and track their position-specific expertise. If participants reported the same years of experience (Yexp) for more than one position, a clarifying question was asked: *Which position have you played the most in your career?* This approach ensured the accurate classification of each player's most-played position, avoiding categorization issues encountered in Experiment 1.

The final sample consisted of 153 male participants divided into 37 Forward Players (FP), 71 Central Players (CP), 30 Lateral Players (LP), and 15 Goalkeeper Players (GP).

Stimuli and experimental design

Stimuli and experimental design were the same as in Experiment 1.

Data scoring

Overall Accuracy (OA) was calculated as described above, while Position-specific Accuracy (PsA) was calculated for each OP. To account for interindividual differences and the possible inhomogeneity in prediction difficulty across videos, for each participant and OP, we computed a corrected version of the PsA as the deviance from the participant's overall accuracy:

$$\widehat{PsA}_{i,j} = PsA_{i,j} - OA_i \tag{1}$$

Finally, subtracting the mean $\widehat{PsA}$ across subjects from the obtained value:

$$PsA_{Corrected,i,j} = \widehat{PsA}_{i,j} - \frac{\sum_{i=1}^{N} \widehat{PsA}_{i,j}}{N} \tag{2}$$

where i indicates the participant, j the OP, and N the total number of participants. We obtained a measure of how each value detaches from the within- and between-subjects' average accuracy.

Statistical analyses

An independent-sample t-test was conducted to compare Atalanta's players in Experiment 2 with the Professional Players (PrP) from Experiment 1 to ensure the two samples were balanced in terms of Yexp. If so, it would be reasonable to assume that Atalanta's players also show the relationship between Yexp and PsA. To test this hypothesis, we computed Pearson's linear correlation between Atalanta's players Yexp and their corresponding PsA, as performed in Experiment 1.

Differences in PsA were statistically evaluated via a mixed 4 × 4 ANCOVA, with PP as the between factor, OP as the within factor, and session duration as the covariate. Since PsA values are still sensitive to interindividual differences and possible inhomogeneity in prediction difficulty across videos, a second mixed ANOVA was conducted on *corrected* PsA, with PP as the between factor and OP as the within factor. Moreover, to include participants' Yexp, which is expected to give a parametric advantage on the position-specific prediction ability, we applied a weighted version of the ANOVA with Yexp as weight. To ensure that participants did not differ in terms of years of experience depending on their most played position we performed a one-way ANOVA on years of experience with the most played position as between-subject factors (Forward, Center, Lateral, Goalkeeper). The ANOVA showed a non-significant effect [$F_{(3,149)} = 2.037$, $p = 0.111$] of group (Yexp - F = 8.86 ± 2.95; Yexp - C = 8.36 ± 2.56; Yexp - F = 7.90 ± 2.59; Yexp - G = 9.80 ± 2.04). In other words, such analysis allowed us to compare participants' prediction ability on actions typical of different field positions depending on their most frequently played role, thus considering their past motor expertise and avoiding spurious effects due to inter-individual and inter-actions differences. In this direction, we assessed the significance of the OP x PP interaction, and a planned comparison design was adopted to limit the investigation to the comparisons of interest. Indeed, to determine whether motor experience gained in a specific field position provides an advantage in recognizing typical actions associated with that area, we evaluated whether participants in each Played Position (PP) exhibited higher accuracy in predicting actions that matched their played position compared to actions from other areas (e.g., whether forward players predicted with higher accuracy forward videos compared to the center, lateral and goalkeeper ones). Similarly, other comparisons were planned to evaluate whether actions typical of one specific field position were better predicted by participants in the matching PP than other positions (e.g., forward video outcomes were better predicted by forward players than center, lateral, and goalkeeper players). See Figure S1 in Supplementary Materials for the 24 resulting planned comparisons list. Therefore, for these comparisons, the significance threshold was adjusted by dividing it by 24, resulting in $\alpha^* = 0.002$.

Finally, we tested whether the participants' years of experience could predict the corrected PsA values. We created a regression model for each observed position, considering the Yexp in each role as regressors (see Eq. 3). Thus, we then assessed the R^2 and significance for each model as well as the significance of each regressor considering the following model:

$$PsA_{Corrected,\,i} = \beta_0 + \beta_1 * Y_{Exp,\,F} + \beta_2 * Y_{Exp,\,C} + \beta_3 * Y_{Exp,\,L} + \beta_4 * Y_{Exp,\,G} \tag{3}$$

where *i* indicates the Observed Position, Yexp F/C/L/G the participant's years of experience in each position, and β1/2/3/4 the corresponding model parameters.

Results

The t-test showed no significant difference between the PrP of Experiment 1 and Atalanta Players (AtP) in terms of Yexp ($MeanYexp_{PrP} = 6.61$ vs. $MeanYexp_{AtP} = 6.92$; $t_{(192)} = 0.63$, $p = 0.53$) suggesting that despite the young age, Atalanta's players had already accumulated expertise positioning at the level of professional experts. This conclusion finds further support in the correlation results, also indicating for this sample a positive and significant correlation between Yexp and PsA ($t_{(153)} = 2.13$, $R = 0.17$, $p = 0.03$), in line with Experiment 1.

The first 4×4 mixed ANCOVA on overall accuracy showed a main effect of PP [$F_{(3,148)} = 3.65$, $p = 0.014$], a main effect of OP [$F_{(3,444)} = 3.09$, $p = 0.026$], and a significant PPxOP interaction [$F_{(9,444)} = 3.56$, $p < 0.001$]. Post-hoc revealed that goalkeeper players (*MeanGP* = 72.5% ± 6.7%) significantly outperformed forward and lateral players in predicting outcomes (*MeanFP* = 66.3% ± 7.2%, $p_{(corrected)} = 0.04$, and *MeanLP* = 65.3% ± 7.7%, $p_{(corrected)} = 0.01$, respectively), independently of the observed position. Also, Bonferroni corrected pairwise comparisons revealed that both lateral (*MeanL* = 62.5% ± 10.7%) and goalkeeper videos (*MeanG* = 65.5% ± 14.2%) were associated with a lower prediction accuracy compared to forward (*MeanF* = 72.4% ± 14.2%) and central videos (*MeanC* = 70.7.% ± 11.0%), each comparison showing a $p_{(corrected)} < 0.001$. The significance of such main effects highlighted interindividual differences and non-homogeneous prediction difficulty across videos, thus making the PPxOP interaction interpretation hard to parse.

Results of the 4×4 weighted ANOVA on corrected data highlighted a significant PPxOP interaction [$F_{(9,3906)} = 30.55$, $p < 0.001$]. Bonferroni corrected planned comparisons (see Table S2 in Supplementary Materials for the entire list of comparisons) revealed that participants, except for the center players, exhibited significantly higher accuracy in predicting actions specific to their career-experienced positions compared to actions proper of other (less trained) positions (Fig. 3, comparisons of different colored bars within the same panel). Indeed, goalkeeper players performed best in predicting videos showing goalkeeper actions compared to other positions' actions (all p-values < 0.001). Forward players predicted videos showing forward movement more accurately than videos showing central and goalkeeper actions (all p-values < 0.001). As far as lateral players are concerned, they predicted lateral video outcomes with higher accuracy compared to forward and center videos (all p-values < 0.001). A similar behavior emerged when considering how participants of different PP predicted the outcome of the same action (Fig. 3, comparisons of same-colored bars between different panels). Indeed, we found that goalkeeper and forward actions were better predicted by participants belonging to the matching played position groups (all p-values < 0.001). Also, we found that lateral actions were better predicted by lateral players rather than central and goalkeepers (all p-values < 0.001). Additionally, we carried out complex planned comparisons, evaluating corrected PsA values in conditions where the observed and played positions matched, against the average of the other three conditions. Results of these complex planned comparisons are reported in Table S3 of the supplementary materials, highlighting that Forwards, Laterals, and Goalkeepers had significantly higher accuracy in predicting their matching position actions (all p-values < 0.001).

To account for the experience accumulated by players across various roles over the years, we repeated the same analysis, weighting for years of experience in roles other than the most frequently played one. By doing so, we moved beyond the exclusive association between each participant and their most played position, instead considering their overall expertise. The results are shown in the supplementary materials (see Supplementary Table S4) and align with those presented in the previous weighted ANOVA. Specifically, matching played-observed position cases still preserves the highest level of accuracy.

Finally, we evaluated whether the position-specific accuracy could be predicted by the years of experience gained in various positions over time. Hence, we tested a regression model for each observed position, considering the years of experience in every possible position as regressors. The only two significant models were those related to the position-specific accuracy of lateral ($R^2 = 0.118$, $p < 0.001$) and goalkeeper ($R^2 = 0.077$, $p = 0.017$) videos. Also, looking into the model parameters, years of experience of the matching played-observed positions were the only regressors showing a trend toward significance ($PsA_{Corrected,\,L}$: $\beta_3 = 0.005$, $p = 0.049$; $PsA_{Corrected,\,G}$: $\beta_4 = 0.008$, $p = 0.058$). Hence, it suggests that when players face a role-specific action, the years of experience gained over different positions from the observed one play a marginal (if not confounding) role in the ability to predict the action outcome. On the contrary, the greater the number of years of experience related to the observed position, the higher the accuracy in predicting the action.

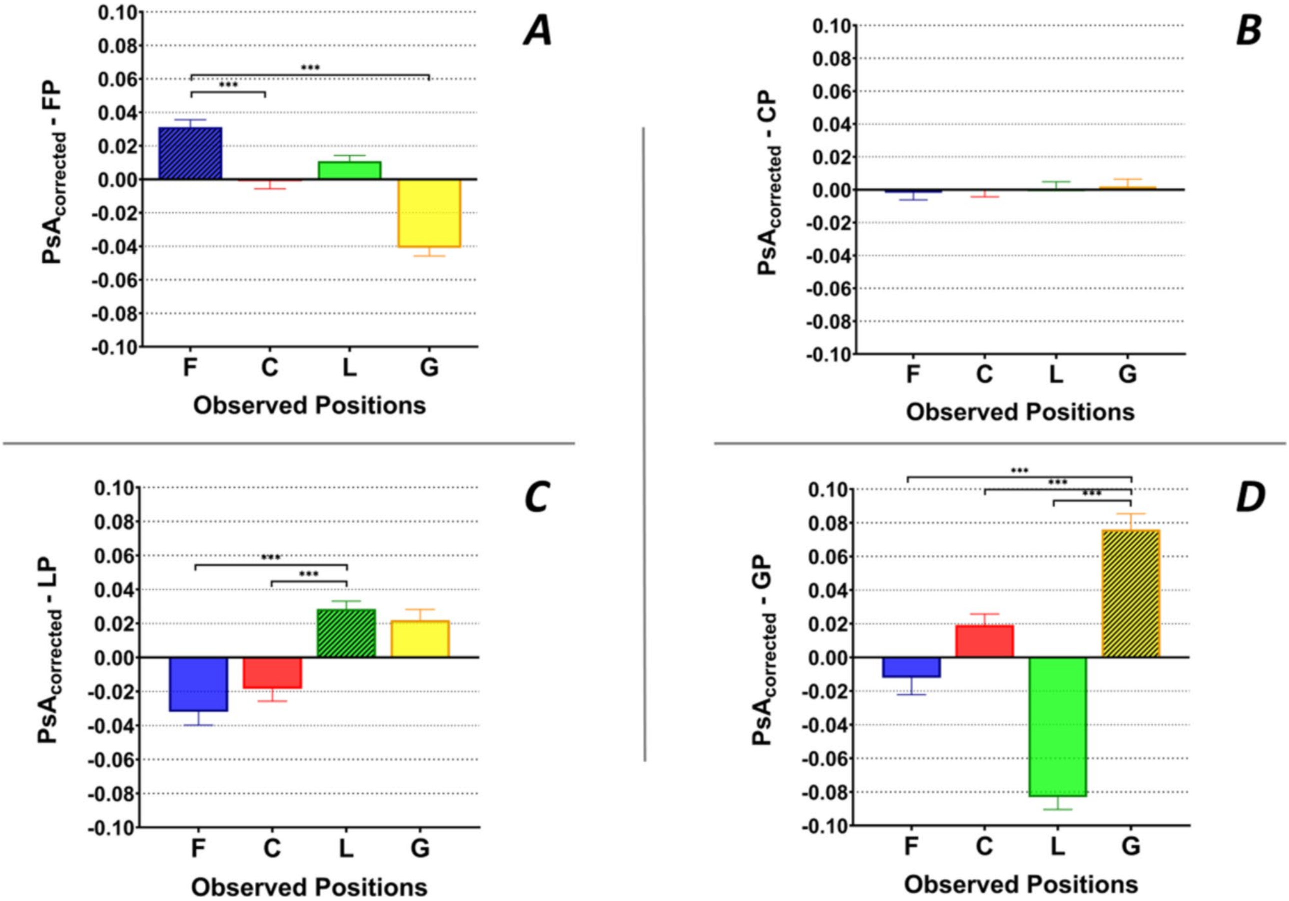

Fig. 3. Bonferroni corrected planned comparisons of OPxPP weighted mixed ANOVA. Panel (**A**) shows the performance of FP in predicting forward, central, lateral, and goalkeeper action outcomes (depicted in blue, red, green, and yellow, respectively). In the same way, panels (**B**), (**C**), and (**D**) show CP, LP, and GP performances, respectively. Black band bars indicate the match between the observed and the played position (e.g., forward-forward in panel A). Bars on histograms represent the standard error mean. $PsA_{corrected}$ = Position-specific Accuracy (corrected); F: Forward videos; C: Central videos; L: Lateral videos; G: Goalkeeper videos; FP: Forward Players; CP: Central Players; LP: Lateral Players; GP: Goalkeeper Players. $^{***}p_{(corrected)} < 0.001$.

Discussion

As demonstrated in Experiment 1, professional soccer players outperformed both amateurs and novices in predicting soccer actions. Furthermore, prolonged professional training in a specific position consistently led to superior accuracy in predicting action outcomes specific to that position. Experiment 2 corroborated these findings, showing that prediction accuracy was highest when the observed action aligned with the players' position-specific expertise, whereas mismatched cases resulted in lower accuracy. These results suggest that both training level and position-specific skills play pivotal roles in shaping the motor system's ability to recognize and predict others' actions.

The superior prediction performance of professional players relative to amateurs likely stems from a more robustly trained motor system, which enhances motor resonance and facilitates the recognition and prediction of actions observed in others. Even within a cohort of players with largely overlapping motor skills, the highest prediction accuracies were consistently observed for actions specific to each player's role. The notion that action prediction abilities depend on the position players occupy on the field is not novel, being already reported - for example - in soccer[29,45] and handball[27,62,63]. However, such findings have often emerged from comparisons between groups with extremely different expertise (e.g., goalkeepers vs. kickers). In our study, we expanded this perspective by subdividing the sample into four positions. We demonstrated that the superiority of prediction accuracy for matched played/observed cases holds for three out of four positions (goalkeepers, lateral, forwards). This indicates that extensive role-specific training fine-tunes the motor repertoire, enabling players to predict actions they regularly perform more accurately. Interestingly, central players were the exception, displaying balanced accuracy scores across all observed positions (see Experiment 2). This finding suggests that central players, often functioning as "playmakers," develop a more generalized motor repertoire. Their role requires continuous interactions with players from all positions and broader field coverage, which may promote heterogeneous motor expertise. Consequently, central players' prediction abilities appear less reliant on position-specific expertise compared to more specialized players, such as forwards, lateral or goalkeepers.

Notably, our results emphasize that executing players demonstrate superior predictive abilities compared to receiving players, reinforcing prior research highlighting the dominance of motor experience over visual experience in driving action recognition skills. This dynamic is well illustrated in scenarios such as penalty kicks, where goalkeepers and forwards engage in intensive visual training to predict opponents' intentions – whether to save or score a goal. However, visual experience alone does not offset the advantage of motor expertise. The superior ability of goalkeepers and forwards to decode actions specific to their roles supports this conclusion. These findings align with previous studies showing that motor-matching representations are systematically more efficient than associative representations[64].

Different theoretical accounts have been proposed to explain the processes underlying action prediction in sports. For instance, the perceptual-cognitive theory[65] postulates that athletes process and interpret visual and sensory information to make decisions, recognize patterns, and predict actions. This approach emphasizes the role of perception, attention, memory, and decision-making in action prediction and overall performance. Conversely, embodied cognition[66,67] extends beyond perceptual and cognitive functions, highlighting the decisive role of sensory and motor experiences in shaping action prediction and, more broadly, cognitive processing. While our study was not designed to test specific theories, our findings can be framed within this ongoing debate. On one hand, mirror activity is often considered a cornerstone of embodied accounts, as it bridges motor performance with perceptual and cognitive operations[68,69]. The notion of a continuum of motor repertoire driving action prediction reinforces this view, strengthening the link between the capacity to decode others' actions and one's own motor experience. At the same time, our data – and prior literature – do not suggest that mirror activity or individual motor repertoires are the exclusive means for predicting others' actions. Functions such as attention and working memory certainly play a fundamental role in promoting action prediction, without forgetting their capacity to modulate the responsiveness of the motor system itself during action observation[46,70].

A significant implication of these findings in sports lies in understanding deceptive actions - strategies designed to mask a player's genuine intentions or provide misleading cues, prompting incorrect predictions by the observer. Numerous studies demonstrate that motor expertise and perceptual-cognitive and visual skills are crucial for identifying deceptive behaviors in sports (see[71] for a comprehensive review). Research on movement kinematics during deceptive behaviors[72,73] has shown that players often minimize kinematic cues critically for executing the intended action while emphasizing irrelevant or misleading movements. Training in performing deceptive actions may refine the motor system's knowledge, equipping players with enhanced predictive abilities. This could explain why expert players in sports such as rugby[34], basketball[74], handball[62,63] and feint[58] consistently outperform novices in detecting deceptive intentions[75]. These considerations underscore the role of motor expertise in action prediction and the ability to recognize and counter deception during gameplay.

In summary, our study revisits the role of the individual motor repertoire in action prediction. Traditionally conceptualized as a motor vocabulary that includes or excludes the observed action, our findings suggest that mere experience with actions is insufficient to guarantee optimal prediction abilities. Instead, factors such as the quality and duration of training, particularly at a high level, and the motor specializations an individual develops play critical roles. In other words, our ability to understand others' actions improves not simply because we can perform them, but because of the specific expertise and dexterity honed through performing those actions.

The deliberate focus on sports provides a unique and valuable context as professional athletes demonstrate motor skills demanding the highest levels of control and precision. This setting allows even subtle differences in expertise to significantly affect motor and cognitive abilities, such as action prediction. Future research could extend these findings by exploring how players predict outcomes of deceptive actions, both typical and atypical of their most-played positions. For instance, it could be hypothesized that position-specific motor expertise protects against misleading predictions, enhancing players' ability to differentiate genuine and deceptive movements.

From a practical perspective, our results suggest that the most effective way to improve interaction with teammates and counter-opponents in sports is to train with their movements and skills[76]. Theoretically, our findings expand the understanding of motor resonance processes in action prediction. These processes extend beyond the representation of action goals – a concept traditionally used to distinguish experts from novices - to include detailed representations of motor features such as kinematics, postures, and dynamics. These motor features are essential for precise action execution and are closely associated with players demonstrating superior prediction abilities. This offers a nuanced perspective on the relationship between motor expertise and cognitive function, highlighting how motor skills can shape action prediction at an advanced level.

Data availability

Data and video stimuli supporting the conclusions of this article will be made available by the corresponding author at Zenodo at the following link: https://zenodo.org/records/14185404.

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References

1. Rizzolatti, G., Fabbri-Destro, M., Nuara, A., Gatti, R. & Avanzini, P. The role of mirror mechanism in the recovery, maintenance, and acquisition of motor abilities. *Neurosci. Biobehav Rev.* **127**, 404–423 (2021).
2. Rizzolatti, G. & Sinigaglia, C. The functional role of the parieto-frontal mirror circuit: Interpretations and misinterpretations. *Nat. Rev. Neurosci.* **11**, 264–274 (2010).

3. Rizzolatti, G., Cattaneo, L., Fabbri-Destro, M. & Rozzi, S. Cortical mechanisms underlying the organization of goal-directed actions and mirror neuron-based action understanding. *Physiol. Rev.* **94**, 655–706 (2014).
4. Bonini, L., Rotunno, C., Arcuri, E. & Gallese, V. Mirror neurons 30 years later: Implications and applications. *Trends Cogn. Sci.* **26**, 767–781 (2022).
5. Fogassi, L. et al. Parietal lobe: From Action Organization to Intention understanding. *Science* **308**, 662–667 (2005).
6. Bonini, L. et al. Ventral premotor and inferior parietal cortices make distinct contribution to action organization and intention understanding. *Cereb. Cortex*. **20**, 1372–1385 (2010).
7. Cattaneo, L. et al. Impairment of actions chains in autism and its possible role in intention understanding. *Proc. Natl. Acad. Sci.* **104**, 17825–17830 (2007).
8. Iacoboni, M. et al. Grasping the intentions of others with one's own mirror neuron system. *PLoS Biol.* **3**, e79 (2005).
9. Caspers, S., Zilles, K., Laird, A. R. & Eickhoff, S. B. ALE meta-analysis of action observation and imitation in the human brain. *Neuroimage* **50**, 1148–1167 (2010).
10. Urgesi, C., Candidi, M. & Avenanti, A. Neuroanatomical substrates of action perception and understanding: An anatomic likelihood estimation meta-analysis of lesion-symptom mapping studies in brain injured patients. *Front. Hum. Neurosci.* **8**, 344 (2014).
11. Pazzaglia, M., Smania, N., Corato, E. & Aglioti, S. M. Neural underpinnings of gesture discrimination in patients with limb apraxia. *J. Neurosci.* **28**, 3030–3041 (2008).
12. Michael, J. et al. Continuous theta-burst stimulation demonstrates a causal role of premotor homunculus in action understanding. *Psychol. Sci.* **25**, 963–972 (2014).
13. Patri, J. F. et al. Transient disruption of the inferior parietal lobule impairs the ability to attribute intention to action. *Curr. Biol.* **30**, 4594–4605 (2020).
14. Buccino, G. Action observation treatment: A novel tool in neurorehabilitation. *Philos. Trans. R Soc. Lond. B Biol. Sci.* **369**, 20130185 (2014).
15. Calvo-Merino, B., Glaser, D. E., Grèzes, J., Passingham, R. E. & Haggard, P. Action Observation and Acquired Motor skills: An fMRI study with Expert dancers. *Cereb. Cortex*. **15**, 1243–1249 (2005).
16. Calvo-Merino, B., Grèzes, J., Glaser, D. E., Passingham, R. E. & Haggard, P. Seeing or doing? Influence of visual and motor familiarity in action observation. *Curr. Biol.* **16**, 1905–1910 (2006).
17. Aglioti, S. M., Cesari, P., Romani, M. & Urgesi, C. Action anticipation and motor resonance in elite basketball players. *Nat. Neurosci.* **11**, 1109–1116 (2008).
18. Gray, J. T., Neisser, U., Shapiro, B. A. & Kouns, S. Observational learning of ballet sequences: the role of kinematic information. *Ecol. Psychol.* **3**, 121–134 (1991).
19. Mann, D. L., Schaefers, T. & Cañal-Bruland, R. Action preferences and the anticipation of action outcomes. *Acta Psychol. (Amst)*. **152**, 1–9 (2014).
20. Abernethy, B. & Zawi, K. Pickup of essential kinematics underpins expert perception of movement patterns. *J. Mot Behav.* **39**, 353–367 (2007).
21. Smeeton, N. & Huys, R. Anticipation of tennis-shot direction from whole-body movement: The role of movement amplitude and dynamics. *Hum. Mov. Sci.* **30**, 957–965 (2011).
22. Bishop, D. T., Wright, M. J., Jackson, R. C. & Abernethy, B. Neural bases for anticipation skill in soccer: An fMRI study. *J. Sport Exerc. Psychol.* **35**, 98–109 (2013).
23. Abernethy, B. & Russell, D. G. Expert-novice differences in an applied selective attention task. *J. Sport Exerc. Psychol.* **9**, 326–345 (1987).
24. Loffing, F. & Hagemann, N. On-court position influences skilled tennis players' anticipation of shot outcome. *J. Sport Exerc. Psychol.* **36**, 14–26 (2014).
25. Urgesi, C., Savonitto, M. M., Fabbro, F. & Aglioti, S. M. Long- and short-term plastic modeling of action prediction abilities in volleyball. *Psychol. Res.* **76**, 542–560 (2012).
26. Balser, N. et al. The influence of expertise on brain activation of the action observation network during anticipation of tennis and volleyball serves. *Front. Hum. Neurosci.* **8**, 568 (2014).
27. Loffing, F., Sölter, F., Hagemann, N. & Strauss, B. Accuracy of outcome anticipation, but not gaze behavior, differs against left-and right-handed penalties in team-handball goalkeeping. *Front. Psychol.* **6**, 1820 (2015).
28. Makris, S. & Urgesi, C. Neural underpinnings of superior action prediction abilities in soccer players. *Soc. Cogn. Affect. Neurosci.* **10**, 342–351 (2015).
29. Wang, Y., Ji, Q. & Zhou, C. Effect of prior cues on action anticipation in soccer goalkeepers. *Psychol. Sport Exerc.* **43**, 137–143 (2019).
30. Renden, P. G., Kerstens, S., Oudejans, R. R. & Cañal-Bruland, R. Foul or dive? Motor contributions to judging ambiguous foul situations in football. *Eur. J. Sport Sci.* **14**, S221–S227 (2014).
31. Pedullà, L. et al. The last chance to pass the ball: Investigating the role of temporal expectation and motor resonance in processing temporal errors in motor actions. *Soc. Cogn. Affect. Neurosci.* **15**, 123–134 (2020).
32. Cañal-Bruland, R., Kreinbucher, C. & Oudejans, R. R. D. Motor expertise influences strike and ball judgements in baseball. *Int. J. Sport Psychol.* **43**, 137–152 (2012).
33. Mulligan, D., Lohse, K. R. & Hodges, N. J. An action-incongruent secondary task modulates prediction accuracy in experienced performers: Evidence for motor simulation. *Psychol. Res.* **80**, 496–509 (2016).
34. Jackson, R. C., Warren, S. & Abernethy, B. Anticipation skill and susceptibility to deceptive movement. *Acta Psychol. (Amst)*. **123**, 355–371 (2006).
35. Gabbett, T. J. & Abernethy, B. Expert–novice differences in the anticipatory skill of rugby league players. *Sport Exerc. Perform. Psychol.* **2**, 138–155 (2013).
36. Paolini, S. et al. Kicking in or kicking out? The role of the individual motor expertise in predicting the outcome of rugby actions. *Front. Psychol.* **14**, 1122236 (2023).
37. Murphy, C. P. et al. Contextual information and perceptual-cognitive expertise in a dynamic, temporally-constrained task. *J. Exp. Psychol. Appl.* **22**, 455 (2016).
38. Murphy, C. P., Jackson, R. C. & Williams, A. M. The role of contextual information during skilled anticipation. *Q. J. Exp. Psychol.* **71**, 2070–2087 (2018).
39. Murphy, C. P., Jackson, R. C. & Williams, A. M. Contextual information and its role in expert anticipation. In Anticipation and Decision Making in Sport 43–58 (Routledge, (2019).
40. Loffing, F. & Cañal-Bruland, R. Anticipation in sport. *Curr. Opin. Psychol.* **16**, 6–11 (2017).
41. Hohmann, T., Troje, N. F., Olmos, A. & Munzert, J. The influence of motor expertise and motor experience on action and actor recognition. *J. Cogn. Psychol.* **23**, 403–415 (2011).
42. Bläsing, B. E. & Sauzet, O. My action, my self: Recognition of self-created but visually unfamiliar dance-like actions from point-light displays. *Front. Psychol.* **9**, 1909 (2018).
43. Di Russo, F. et al. Benefits of sports participation for executive function in disabled athletes. *J. Neurotrauma*. **27**, 2309–2319 (2010).
44. Causer, J., Smeeton, N. J. & Williams, A. M. Expertise differences in anticipatory judgements during a temporally and spatially occluded task. *PLOS ONE*. **12**, e0171330 (2017).

45. Tomeo, E., Cesari, P., Aglioti, S. M. & Urgesi, C. Fooling the kickers but not the goalkeepers: Behavioral and Neurophysiological Correlates of Fake Action Detection in Soccer. *Cereb. Cortex.* **23**, 2765–2778 (2013).
46. Kemmerer, D. What modulates the Mirror Neuron System during action observation? Multiple factors involving the action, the actor, the observer, the relationship between actor and observer, and the context. *Prog Neurobiol.* **205**, 102128 (2021).
47. Avanzini, P. et al. The dynamics of sensorimotor cortical oscillations during the observation of hand movements: An EEG study. *PloS One*. **7**, e37534 (2012).
48. Press, C., Cook, J., Blakemore, S. J. & Kilner, J. Dynamic modulation of human motor activity when observing actions. *J. Neurosci.* **31**, 2792–2800 (2011).
49. Urgesi, C., Candidi, M., Ionta, S. & Aglioti, S. M. Representation of body identity and body actions in extrastriate body area and ventral premotor cortex. *Nat. Neurosci.* **10**, 30–31 (2007).
50. Alaerts, K., Heremans, E., Swinnen, S. P. & Wenderoth, N. How are observed actions mapped to the observer's motor system? Influence of posture and perspective. *Neuropsychologia* **47**, 415–422 (2009).
51. Senot, P. et al. Effect of weight-related labels on corticospinal excitability during observation of grasping: A TMS study. *Exp. Brain Res.* **211**, 161–167 (2011).
52. Cohen, J. Set correlation and contingency tables. *Appl. Psychol. Meas.* **12**, 425–434 (1988).
53. Abernethy, B. Expertise Visual search, and information pick-up in Squash. *Perception* **19**, 63–77 (1990).
54. Wright, M. J., Bishop, D. T., Jackson, R. C. & Abernethy, B. Functional MRI reveals expert-novice differences during sport-related anticipation. *NeuroReport* **21**, 94–98 (2010).
55. Abreu, A. M. et al. Action anticipation beyond the action observation network: A functional magnetic resonance imaging study in expert basketball players. *Eur. J. Neurosci.* **35**, 1646–1654 (2012).
56. Li, Y. et al. Visual search strategies of performance monitoring used in action anticipation of basketball players. *Brain Behav.* **13**, e3298 (2023).
57. Casile, A. & Giese, M. A. Nonvisual motor training influences biological motion perception. *Curr. Biol.* **16**, 69–74 (2006).
58. Güldenpenning, I., Steinke, A., Koester, D. & Schack, T. Athletes and novices are differently capable to recognize feint and non-feint actions. *Exp. Brain Res.* **230**, 333–343 (2013).
59. Huys, R. et al. Global information pickup underpins anticipation of Tennis Shot Direction. *J. Mot Behav.* **41**, 158–171 (2009).
60. Mann, D. T. Y., Williams, A. M., Ward, P. & Janelle, C. M. Perceptual-cognitive expertise in Sport: A Meta-analysis. *J. Sport Exerc. Psychol.* **29**, 457–478 (2007).
61. Mark Williams, A., Huys, R., Cañal-Bruland, R. & Hagemann, N. The dynamical information underpinning anticipation skill. *Hum. Mov. Sci.* **28**, 362–370 (2009).
62. Cañal-Bruland, R. & Schmidt, M. Response bias in judging deceptive movements. *Acta Psychol. (Amst).* **130**, 235–240 (2009).
63. Cañal-Bruland, R., van der Kamp, J. & van Kesteren, J. An examination of motor and perceptual contributions to the recognition of deception from others' actions. *Hum. Mov. Sci.* **29**, 94–102 (2010).
64. Barchiesi, G. & Cattaneo, L. Early and late motor responses to action observation. *Soc. Cogn. Affect. Neurosci.* **8**, 711–719 (2013).
65. Williams, A. M., Ford, P. R., Eccles, D. W. & Ward, P. Perceptual-cognitive expertise in sport and its acquisition: Implications for applied cognitive psychology. *Appl. Cogn. Psychol.* **25**, 432–442 (2011).
66. Barsalou, L. W., Simmons, W. K., Barbey, A. K. & Wilson, C. D. Grounding conceptual knowledge in modality-specific systems. *Trends Cogn. Sci.* **7**, 84–91 (2003).
67. Shapiro, L. & Spaulding, S. Embodied cognition and sport. *Hanbook Emodied Cogn. Sport Psychol.* 3–22 (2019).
68. Garbarini, F. & Adenzato, M. At the root of embodied cognition: Cognitive science meets neurophysiology. *Brain Cogn.* **56**, 100–106 (2004).
69. Gallese, V. & Lakoff, G. The Brain's concepts: The role of the sensory-motor system in conceptual knowledge. *Cogn. Neuropsychol.* **22**, 455–479 (2005).
70. Muthukumaraswamy, S. D. & Singh, K. D. Modulation of the human mirror neuron system during cognitive activity. *Psychophysiology* **45**, 896–905 (2008).
71. Güldenpenning, I., Kunde, W. & Weigelt, M. How to trick your opponent: A review article on deceptive actions in interactive sports. *Front. Psychol.* **8**, 917 (2017).
72. Brault, S., Bideau, B., Kulpa, R. & Craig, C. M. Detecting deception in movement: the case of the side-step in rugby. *PloS One*. **7**, e37494 (2012).
73. Urgesi, C. Visual and motor components of action anticipation in basketball and soccer. *Mov. Bodies Interaction—Interacting Bodies Motion Intercorporeality Interkinesthesia Enaction Sports* 93–111 (2017).
74. Sebanz, N. & Shiffrar, M. Detecting deception in a bluffing body: The role of expertise. *Psychon Bull. Rev.* **16**, 170–175 (2009).
75. Jackson, R. C. & Cañal-Bruland, R. Deception in sport. in Anticipation and Decision Making in Sport 99–116 (Routledge, (2019).
76. Ridderinkhof, K. R., Snoek, L., Savelsbergh, G., Cousijn, J. & Van Campen, A. D. Action intentions, Predictive Processing, and mind reading: Turning Goalkeepers into Penalty killers. *Front. Hum. Neurosci.* **15**, 789817 (2022).

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Author contributions

S.P. and P.P. designed the study, performed the research, analyzed data, and wrote and revised the manuscript. E.S., G.B. and G.R. revised the manuscript. M.F.-D. and P.A. designed the study and wrote and revised the manuscript. All authors contributed to the article and approved the submitted version.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

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