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Title Analysis of coordinated group behavior based on role-sharing: Practical application from an experimental task to a 3-on-3 basketball game as a pilot study

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Abstract

A human group shares a common goal and distributes roles to implement activities that are difficult to accomplish alone and higher performance than an individual. In such coordination, nonverbal behavior among three or more members makes it difficult to explain the mechanism because of complex and dynamic interactions. In cognitive science, a crucial role is indicated, which intervenes moderately with others and adjusts the whole balance without interrupting their main smooth interactions, using an experimental task. It suggests that the third role and related playing supports to coordination. This is similar to off-ball movements in team sports, which are not involved directly with the ball and are focused on mainly in sports science because common statistical data do not reflect. A new perspective for discussing coordination has arisen because existing theories, such as synchronization, cannot explain the mentioned role; however, there is room for its usefulness. Therefore, this study applied the experimental findings to the sports field. We designed a 3-on-3 basketball game in which the relevant offensive role is key and introduced it to the practice of the university team as a pilot study. Participants repeatedly engaged in the mini-game, and the playing on the offensive team was compared before and after receiving tips on this role. Consequently, in the bins of the relatively large distance between the participant required in this role and each defensive player, the frequencies after the tips were significantly higher, and the winning rate on the offensive team improved temporarily. It suggests that the spacing skill, which indicates a reasonable distance for intervening with the other offensive players, emerged. This study may provide findings that satisfy usefulness and ecological validity, and make an educational contribution about giving the tips of off-ball movements.

Introduction

A human group implements activities that are difficult to accomplish alone and higher performance than an individual through sharing a common goal and social interactions (e.g., [1-4]). This is encapsulated by the saying “Two heads are better than one,” and is defined as planned coordination (coordination) in psychology and cognitive science [5]. For coordination, members in a group often share some roles considering workloads and task specifications. The distributed cognition theory explains that an overall group function works through interactions among subsystems and between subsystems and environments where each subsystem is a role [6,7]. It suggests that internal and external resources in individuals and a group are properly distributed, and each member’s workload decreases. Furthermore, cognitive interactions among roles based on different perspectives lead to problem-solving and discovering various strategies (e.g., [8-12]). Particularly, team sports are typical examples of benefits of role-sharing by on- and off-ball players (e.g., [13-16]); it is required to achieve a common goal and high performance under rules, time, and defensive pressures. Meanwhile, team sports often comprise three or more members, and they aim to achieve a common goal through physical interactions, which are complex and dynamic characteristics. Complexity indicates that explaining the mechanism is more complicated than a pair because the relationships among members diversify, such as role-sharing, and are not interpreted by one-dimensional behaviors, such as leader-follower and approach-avoidance [17,18]. Dynamics suggests nonverbal and time-series features, which strongly develop during a short period like body movements [19,20]. Cognitive science focuses mainly on higher-order information processing, and coordinated behaviors among three or more members are not fully investigated. Considering that physical interactions are primitive and that a

group of three or more members is often observed in real life, it is significant for cognitive science, which discusses intelligence in social group, to investigate complex and dynamic coordination [17].

This study focuses on a crucial role in coordinated behavior of a triad based on role-sharing, which is suggested by an experimental task in cognitive science study [21]. We are challenged to bridge the gap between experimental findings and real-world applications like team sports and contribute to the understanding and development of coordination mechanisms.

As related works, the sports science study recorded 5-on-5 basketball games and identified the coordinated defensive structures of role-sharing according to emergent situations by the top-level university team in Japan [1]. Recently, coordinated structures with role-sharing have been modeled by machine learning using the dataset of professional leagues in soccer and basketball (e.g., [22-24]). Moreover, network science studies investigate robust coordination in soccer using network models in which nodes are players and links represent passing (e.g., [25-27]). Meanwhile, collective behavior studies investigate coordinated hunting. These observed that role-sharing of chasing and blocking naturally emerged (e.g., [28,29]). Additionally, multi-agent simulation using deep reinforcement learning can replicate this process. In the simulation, agents perceive and observe the environment, including the prey, and learn the optimal behaviors to maximize their rewards [30]. The findings suggest that role-sharing creates favorable situations. In principle, these studies mentioned above in sports science, machine learning, network science, and collective behavior aim to understand coordinated physical structures. However, the information processing behind these characteristics is not fully discussed. Furthermore, educational applications in are not considered.

Notably, although not competitive, the previous study in cognitive science investigated a crucial role in coordinated behavior of a triad based on role-sharing by the experimental task [21]. It is indicated that the role of intervening moderately with other roles and adjusting the whole balance was related to high task performance. Such resilient helping action is important in team sports, military organizations, and business management, not only in experimental tasks (e.g., [1,31-34]). Conversely, this role is also required not to interrupt their main smooth interactions. Hence, the third role needs to decide whether to intervene or not based on the situations. A new perspective for discussing coordination mechanisms has arisen because explaining the role of intervention decision and adjustment is problematic for existing theories, such as synchronization (e.g., [35-38]), in cognitive science and sports science. These findings suggests that adjustment to create favorable situations without interrupting other members supports overall coordination. Related playing is similar to off-ball movements in team sports, which are not directly involved with the ball and included the use of one's own and defensive space. Recently, it has been focused on mainly in sports science because common statistical data do not reflect (e.g., [13,16,39,40]). However, there is room for the usefulness of the crucial role suggested in the behavioral experiment.

Therefore, we applied the experimental findings to the sports field as a pilot study. This study focused on team sports that must achieve a common goal and high performance within some constraints. We used a 3-on-3 basketball game, which makes it easy to record group behavior because of the relatively small number of players (three on each team) and court size. The purpose of this study is to investigate the usefulness of the role of intervention decision and adjustment through the practical application of the experimental task. We designed the mini-game, where the relevant

offensive role is key, and introduced it to the practice of the university team. Players repeatedly engaged in the game. After the first half, the offensive team received the tips about overall coordination focusing on this role. The offensive playing and team performance were compared before and after receiving the tips. Our study connects cognitive science and sports science because this pilot study includes the further investigation of information processing behind complex and dynamic coordination, which is not fully discussed, and the educational application about giving the tips of off-ball movements. Bridging the gap between controlled experimental settings and real-world applications is a challenging endeavor. Next, we explain the details of this practice.

Methods

Participants

The six female students on the university basketball team, of which the second author is the head coach, participated in this practice. They usually play 5-on-5 in the official game. In November 2023, when this practice was conducted, this team was affiliated with the third division of the Tokai area league in Japan. Their averages of ages, heights, and basketball experiences were 19.17 age ($SD = 0.90$), 165.08 cm ($SD = 5.88$), and 10.58 years ($SD = 2.70$), respectively. The participants were divided into the offensive and defensive teams to make their abilities competitive by the head coach (see the Supplementary Materials). The participants on each team were fixed. It is kept in mind that we applied the experimental findings to the sports field as a pilot study.

Informed consent

We explained how we would video-record and collect data. Written informed consent was obtained from all the participants. This study was approved by the ethics and safety committee of Shizuoka University and Tokoha University, where the first author is affiliated, and this practice was conducted. Our study was carried out following these regulations. According to the informed consent, all the images in the manuscript do not contain individual identifiers.

Designed 3-on-3 basketball game

Fig 1 shows the diagram of the designed mini-game in which the circles and squares represent the offensive and defensive players, respectively. Players from #1 to #3 on each team are the same participants in all the games (trials). Offensive #3 is required to play the role of intervention decision and adjustment focused on in this study. The winning condition on the offensive team is that within a 15-second time limit, someone draws a defensive player, and a shooter is unmarked in an open space. Conventionally, the defensive team must play without satisfying it. The above condition is defined independently of individual skills to investigate coordination. The team performance reported in the Results section is consistent with this definition.

In the mini-game, we set some rules to guide the same situation at the game start and to compare playing across the trials. The ball handler of #1 is fixed, and the player begins without directly passing to #3. Additionally, the start position of each offensive player is assigned to maintain a certain distance for observing the coordination process that the role of intervention decision and adjustment involves in the other players. Meanwhile, on the defensive team, #1 and #2 confront offensive #1 and #2, and their start positions are voluntary. The start position of defensive #3 is

also voluntary. Just before the game, the 2-man game are randomized on the right (Fig 1) or left side of the basket goal by the instruction to eliminate the influence of the dominant hand. The start positions on the offensive team are called the two-guard and are also used in a 5-on-5 game.

For the offensive team's win, it is crucial for #3 to intervene with the other players, adjust the 2-man game, and create favorable situations, such as (1) handing the ball off directly with #1 or #2 ("hand off"), (2) working as a wall to interrupt the defensive players ("pick and roll"), and (3) moving to a corner area and taking a three-point shot. Conversely, it is key not to interrupt #1 and #2 without forcibly intervening based on the situations. The offensive coordination required in this game is fundamental. However, the head coach mentioned that the participants were could not implement such interaction in the official game at that time.

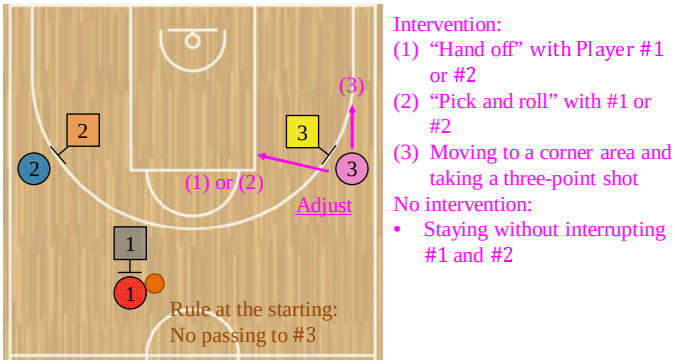

Fig 1. Diagram of the designed 3-on-3 basketball game in this study. In this mini-game, the circles and squares represent the offensive and defensive players, respectively. The winning condition on the offensive team is that within a 15-second time limit, someone draws a defensive player, and a shooter is unmarked in an open space. The ball handler of #1 is fixed, and the player begins without directly passing to #3. Additionally, the start position of each offensive player is assigned (see the Designed 3-on-3 basketball game section to confirm the other rules). Here, #3 is crucial to win the mini-game. The offensive player is required to intervene with the other ones, adjust the 2-man game, and create favorable situations, such as (1) handing the ball off directly with #1 or #2 ("hand off"), (2) working as a wall to interrupt the defensive players ("pick and roll"), and (3) moving to a corner area and taking a three-point shot. Conversely, it is key not to interrupt #1 and #2 without forcibly intervening based on the situations.

Environment and procedures

Fig 2A shows the environment conducted in the university gymnasium. The court area follows the official size of a 5-on-5 game [41] except for the vertical sideline. The digital countdown timer was set the experimenter and the participants to watch

the remaining time (mollten Corp., UX0110). All the trials were recorded from a bird's-eye view on the stage using a video camera (Sony Corp., HDR-CX680).

Regarding the procedures, the experimenter briefly announced the practice schedule (see the Supplementary Materials). After that, the participants performed a warm-up and received colored bibs for individual identification (Fig 1). Then, the experimenter explained the team assignment and the mini-game rules. At this point, the first author did not instruct the offensive team on the role of intervention decision and adjustment and related group behavior. The three practice trials, including a trial by the timer error, were conducted, and the participants could confirm the rules. Subsequently, in the first half as a pre-test, three sessions comprising seven trials per session were conducted for 21 trials. The interval between the trials was approximately 30 seconds. Meanwhile, it was about a minute between the sessions. These were conducted considering that the participants' fatigue did not influence team performance. After the first half, a guest coach, who had already understood the purpose of this study, gave each team tips based on the observations of the mini-games. The coach was a professional player in Japan and is currently the head coach of the junior youth team. In this practice, giving tips reflecting the essence of this study to the offensive team was indispensable. Thus, we asked the guest who is superior to coaching to do it. The tips to the offensive team focused on overall coordination based on the role of intervention decision and adjustment. Meanwhile, the defensive team received general tips on help defense, not including participant- and game-specific strategies. Table 1 represents the details of the tips given to each team. While one team received them, the other waited at a distance to prevent their information gathering. After that, the second half as a post-test was conducted similarly to the first one.

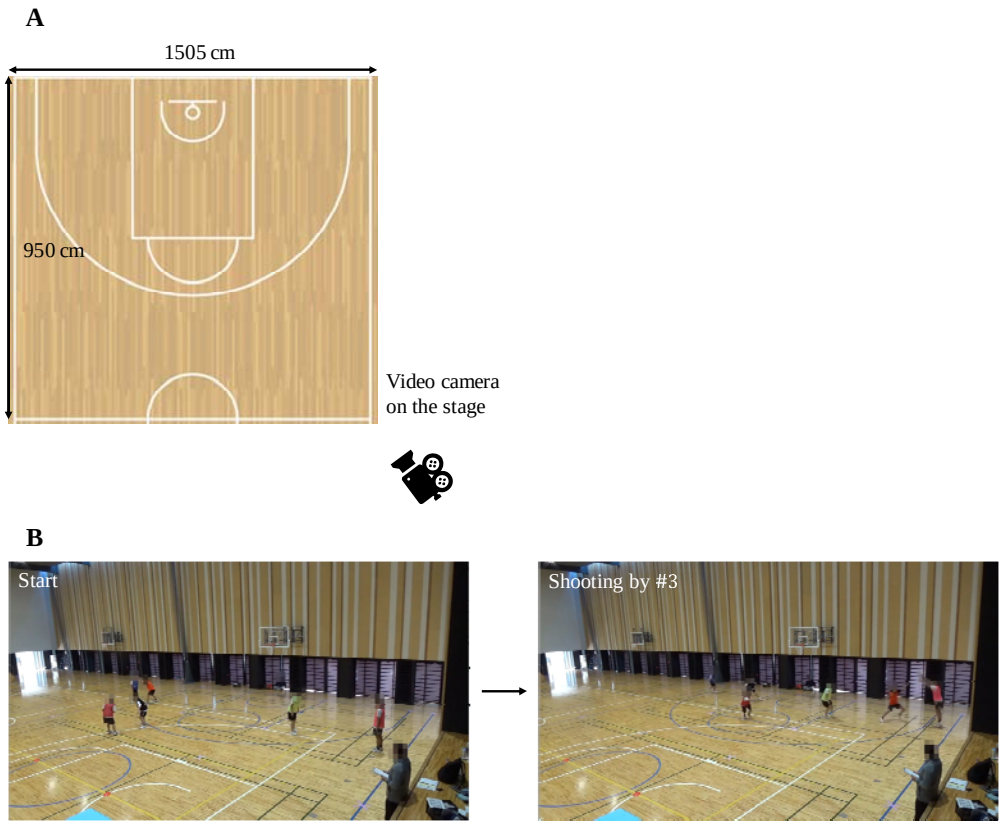

Fig 2. Environment in this practice. We conducted the designed 3-on-3 basketball game in the university gymnasium (A). The court area follows the official size of a 5-on-5 game [41] except for the vertical sideline. All the trials were recorded from a bird's-eye view (B) on the stage using a video camera. After receiving the tips about the role of intervention decision and adjustment, the offensive participant required in this role, wearing a pink bib (#3 in Fig 1), moves to a corner area while keeping a distance from the defensive players, and aims to take a three-point shot. The images were recorded by the first author. We explained how we would video-record and collect data. Written informed consent was obtained from all the participants. According to the informed consent, the images are shown while blurring some parts to avoid identifying individuals.

Table 1. Tips to the offensive and defensive teams by the guest coach.

Team	Tips
Offense	• Player #3 checks the position of defensive #3. When defensive #3 helps, #3 moves to where the driving offensive player (#1 or #2) can see #3, such as a corner area ("deep corner"), so that #3 can easily take a three-point shot with an open space created. • The very first thing #1 and #2 should do is to play a 2-man game where #1 or #2 drives, that is, dribbles toward the area under the basket goal ("paint area"). If #1 pretends to cooperate with #2 working as a wall to interrupt the defensive players ("pick and roll") and drives to the other side of the wall ("reject"), defensive #3 is to move to help. Then, #3 moves to the corner along the three-point line taking advantage of a wide space. • However, as an exception, in cases where #3 is in a high position (2-man game position), if defensive #3's back is visible from #3 and defensive #3 goes for help, #3 should dive to the paint area because moving along the three-point line and receiving the pass would take time. • #3 should not move too much. #3 should carefully check the defensive players' positions while staying around: (1) the wing position (45-degree position on the three-point line with the goal as the origin), (2) the position near the three-point line changing from straight to curved, or (3) the corner position.
Defense	• If #3 does not help, the space near the basket becomes open for a shot, so #3 has to move to help in defensive playing. If offensive #3 receives the ball, #3 should mark offensive #3 immediately. The defensive players need to check where the ball is, making them easier to help. If not, the offensive player can take an uncontested shot with a running jump ("lay-up shot"). • Force the offensive player to make a long, arching pass in order to buy time for getting the defensive ones ready. The defensive players' keeping their hands up will force the offensive player to make an arching pass, creating time for them to close the distance with the offensive player ("closeout ").

a # indicates each participant in each team in Fig 1. Offensive #3 is required to play the role of intervention decision and adjustment focused on in this study. Single and double underlines correspond to the intervention and non-intervention with the other offensive players, respectively. Double quotation marks represent technical terms in basketball.

Results

Team Performance

This study calculated the winning numbers of the mini-games for the offensive team to compare them between the first and second halves. Those in the first half for 21 trials from Sessions 1 to 3 and in the second one from Sessions 4 to 6 were 9 and 11, respectively. Table 2 represents the cross-tabulation table of the event and performance of the offensive team. A chi-square test indicated no significant relationship between them, and an effect size φ was small ($\chi^2(1) = 0.095, p = 0.757, \varphi = 0.048$).

Meanwhile, Fig 3 shows the progression of the winning rate of the offensive team over the sessions. The rates of Sessions 1 and 2 in the first half were at the chance level, indicating four wins in the seven trials. After that, it decreased in Session 3. Meanwhile, in the second half, it recovered in Session 4 and drastically improved in Session 5, indicating six wins. However, it significantly decreased in Session 6. After receiving the tips about the role of intervention decision and adjustment, the performance of the offensive team improved temporarily. Therefore, playing this role might be related to improving team performance.

Table 2. Cross-tabulation table of the event and performance of the offensive team.

Event	Offensive performance	
	Win	Loss
First	9	12
Second	11	10

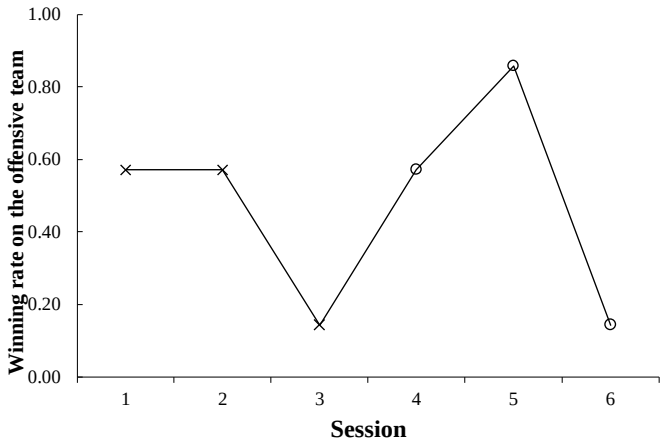

Fig 3. Progression of the winning rate of the offensive team over the sessions. Each session consists of seven trials. After Session 4, given the tips about the role of intervention decision and adjustment, the performance of the offensive team improves temporarily.

Playing the offensive role of intervention decision and adjustment

Analysis procedures

We obtained the time-series position data of each participant in the two dimensions, the x- and y-components, by the image processing of a bird's-eye view (Fig 2B). This study compared the movements of the offensive player, as shown by the pink in Fig 1, required in the role of intervention decision and adjustment between the first and second halves using the dataset. The participants on the movies (20 fps, 1280 px × 720 px) were tracked by ByteTrack [42] based on YOLOX. Additionally, the experimenter manually corrected false detectives and undetected positives using the labeling platform Labelbox [43], and prepared the dataset from real coordinate transformations. The average of the absolute measurement errors was 3.165 cm ×

2.102 cm. In this practice, it is difficult to detect a ball by image processing because of the recording environment and technical problems; this is a future work.

This study analyzed (1) the distance (cm) between the offensive participant required in the role of intervention decision and adjustment and each defensive player, as shown by the black, orange, or yellow in Fig 1, and (2) that between the offensive key player and each other participant, as shown by the red or blue in Fig 1. We evaluated spacing skill to play the relevant role. The spacing is generally crucial for both offensive and defensive coordination in basketball (e.g., [13,14,16,44,45]). In the mini-game, if reasonable distances from the defensive players are maintained, the pressure from the defensive ones are reduced, and this role makes it easy to intervene moderately to coordinate with the other offensive players based on the situations, as explained in Table 1. Meanwhile, if those among the offensive players are maintained, it is easy to pass the ball to this role, and the defense will break down. The characteristic also reflects staying in place without interrupting the other offensive players, as mentioned in Table 1.

This analysis calculated both indices of (1) and (2) for each time frame and made these histograms to understand the overall characteristics, referring to the previous studies on passing coordination in soccer and children's group behavior [4,18,46]. The histograms were made in each trial, and the normalized frequencies were averaged for the first and second halves. A *t*-test was conducted to compare them between them in each bin, and an effect size ($Cohen's\ d$) was calculated. If the tips to the offensive team influences, focused on overall coordination based on the role of intervention decision and adjustment, it is expected that the significant differences of the normalized frequencies in the indices of (1) and (2) are confirmed between the first and second halves. This analysis conducted the exploratory

comparisons of reasonable distances between the participants because we analyzed complex and dynamic group behavior in the sports field. Meanwhile, this study investigated the validity of the statistical tests by calculating the effect sizes and powers ($1 - \beta$) in all the bins for both indices of (1) and (2). We set at the significant level of 5% ($\alpha = 0.05$), the calculated effect size, and the sample size *n* (21 trials) in each half. Therefore, this analysis comprehensively evaluated the differences between the first and second halves in term s of the *p*-value, effect size, and power indices. We did not apply the Bonferroni method to avoid the multiple comparisons problem because the numbers of the bins in both indices of (1) and (2) were large, and it was easy to cause the type II error. Our policy was to avoid this problem by calculating the three indices and investigating from the different perspectives. The distances between the participants were analyzed using MATLAB R2021b. The statistical tests and the investigation of these validities were conducted using R 4.3.3 and G*Power 3.1, respectively.

Results of the distance with each defensive player

Fig 4A shows a time-series example of the distance (cm) between the offensive participant required in the role of intervention decision and adjustment and each defensive player in a trial. Meanwhile, Fig 4B shows the histogram in each session. The upper and lower of Fig 4B represent the results of the first and second halves, respectively. The horizontal and vertical axes indicate the bin and the average of the normalized frequencies across seven trials of each session, respectively.

In each bin, the average of normalized frequencies across 21 trials in the first half from Sessions 1 to 3 was compared to that in the second one from Sessions 4 to 6. Notably, the *t*-tests confirmed the significant differences in the bins of 400 cm, 1200

cm, and 1400 cm, and these effect sizes were from medium to large, and the powers were high ($400\ cm$: $t(20) = 2.739, p = 0.013, d = 0.894, 1 - \beta = 0.973$; $1200\ cm$: $t(20) = -2.269, p = 0.034$, $d = 0.732, 1 - \beta = 0.891$; $1400\ cm$: $t(20) = -2.581, p = 0.018, d = 0.668, 1 - \beta = 0.829$, Fig 5A–C). In the bin of relatively small 400 cm, the normalized frequency in the second half was significantly lower than that in the first one. Conversely, in the bins of relatively large 1200 cm and 1400 cm, those in the second half were significantly higher than the first one. In the other bins, no significant differences were confirmed (see the Supplementary Materials).

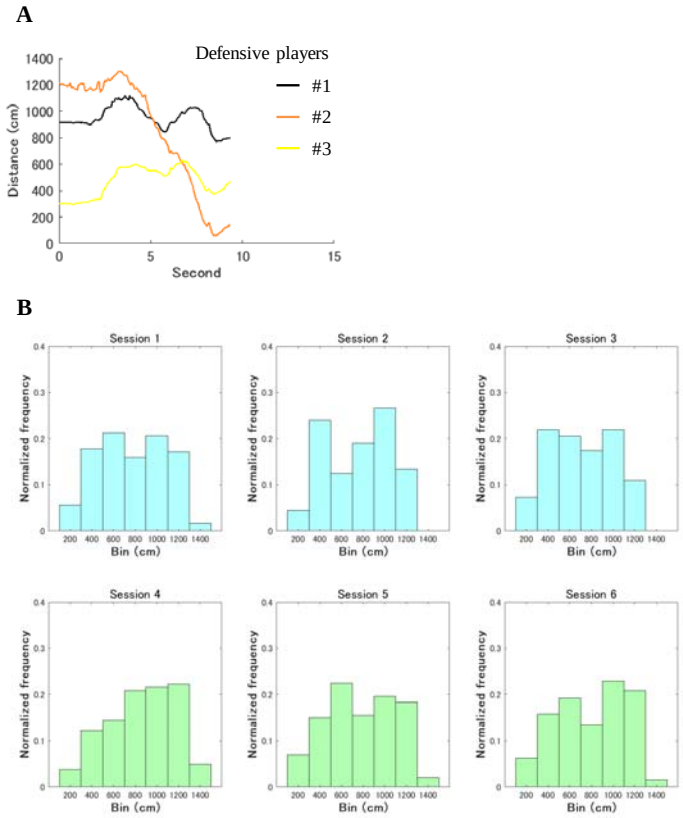

Fig 4. Overall characteristics of the distances (cm) between the offensive player required in the role of intervention decision and adjustment and each defensive participant. Its time-series example (A) in a trial fluctuates up and down. Meanwhile, the upper and lower of the histogram (B) in each session represent the results of the first and second halves, respectively. The horizontal and vertical axes indicate the bin and the average of the normalized frequencies across seven trials of each session, respectively.

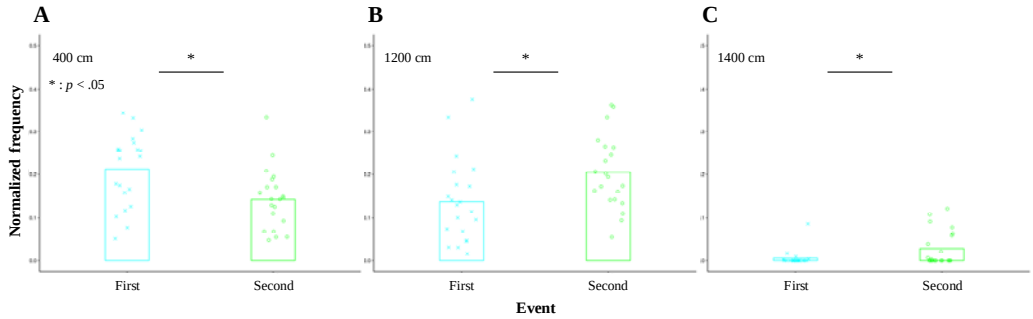

Fig 5. Averages of the normalized frequencies in the bins confirmed the significant differences between the first and second halves in Fig 4B. In the bin of relatively small 400 cm (A), the normalized frequency in the second half is significantly lower than that in the first one. Conversely, in the bins of relatively large 1200 cm (B) and 1400 cm (C), those in the second half are significantly higher than the first one.

Results of the distance with each other offensive player

Fig 6A shows a time-series example of the distance (cm) between the offensive player required in the role of intervention decision and adjustment and each other participant in a trial. Meanwhile, Fig 6B shows the histogram in each session. The upper and lower of Fig 6B represent the results of the first and second halves, respectively. The horizontal and vertical axes indicate the bin and the average of the normalized frequencies across seven trials of each session, respectively.

In each bin, the average of normalized frequencies across 21 trials in the first half from Sessions 1 to 3 was compared to that in the second one from Sessions 4 to 6. Considering the results of the *t*-tests, effect sizes and powers, the clear differences were not confirmed between the first and second halves. Meanwhile, although the effect sizes were medium and the powers were lower than those reported in the previous section, the *t*-tests indicated the significant trends of differences in the bins

of 200 cm, 800 cm, and 1600 cm ($200\ cm$: $t(20) = -2.002, p = 0.059, d = 0.517, 1 - \beta = 0.616$; $800\ cm$: $t(20) = 1.856, p = 0.078, d = 0.628, 1 - \beta = 0.782$; $1600\ cm$: $t(20) = -1.745, p = 0.096, d = 0.572, 1 - \beta = 0.703$, Fig 7A–C). In the bins of relatively small 200 cm and large 1600 cm, the normalized frequencies in the second half tended to be significantly higher than those in the first one. Conversely, in the middle bin of 800 cm, that in the second half tended to be significantly lower than the first one. These showed a U-shape trend. In the other bins, no significant differences were confirmed (see the Supplementary Materials).

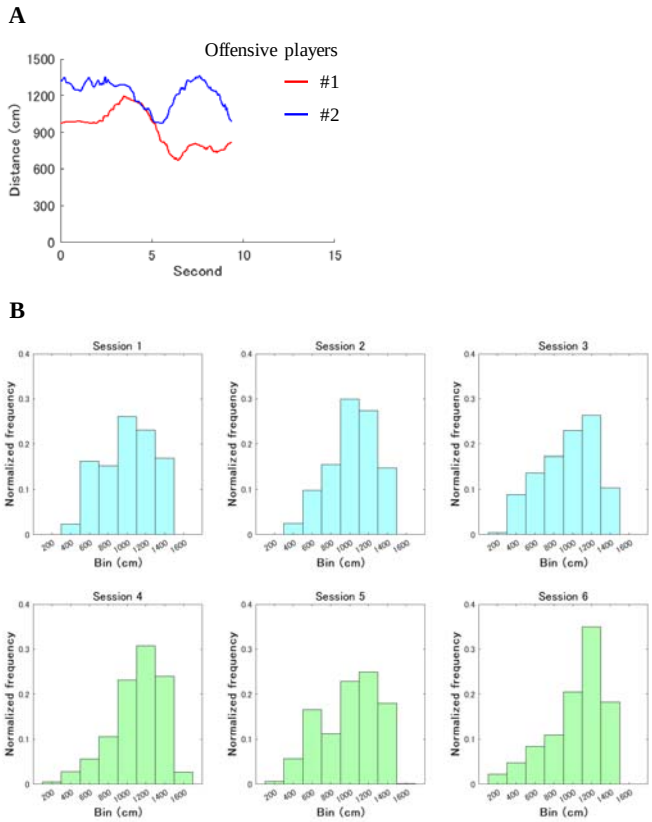

Fig 6. Overall characteristics of the distances (cm) between the offensive player required in the role of intervention decision and adjustment and each other participant. Its time-series example (A) in a trial fluctuates up and down. Meanwhile, the upper and lower of the histogram (B) in each session represent the results of the first and second halves, respectively. The horizontal and vertical axes indicate the bin and the average of the normalized frequencies across seven trials of each session, respectively.

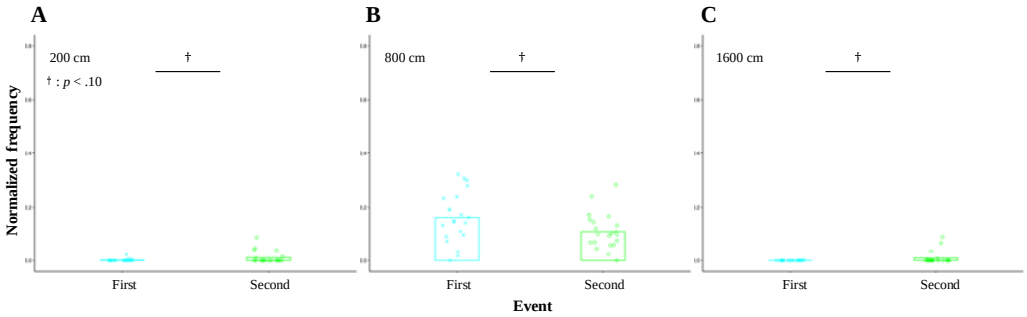

Fig 7. Averages of the normalized frequencies in the bins confirmed the significant trends of differences between the first and second halves in Fig 6B. In the bins of relatively small 200 cm (A) and large 1600 cm (C), the normalized frequencies in the second half tend to be significantly higher than those in the first one. Conversely, in the middle bin of 800 cm (B), that in the second half tends to be significantly lower than the first one.

Discussion

This study designed the mini-game of 3-on-3 basketball, where the offensive role of intervention decision and adjustment is crucial for winning. We introduced it to the practice of the university team as a pilot study. In this practice, the overall results confirmed that in the bins of the relatively large distance between the participant required in this role and each defensive player, the frequencies after receiving the tips about the relevant role were significantly higher than before (Fig 5B,C). Conversely, in the bin of the relatively small distance, that after the tips was significantly lower than before (Fig 5A). Additionally, the winning rate on the offensive team improved temporarily (Fig 3). It suggests that the spacing skill, which indicates a reasonable distance for intervening with the other offensive players, emerged. Such playing might be related to overall coordination. Spacing is crucial to establish coordinated

behavior in intrusive sports, solely in basketball (e.g., [47,48]). If the distance between the offensive participant required in the role of intervention decision and adjustment and a defensive one is relatively large, the player can involve in the other offensive participants and adjust to create a favorable situation, such as running a corner area and aiming to take a three-point shot, as explained in Table 1 (Fig 8). It is similar to the previous findings [16,44]. The playing mentioned above would increase countermeasures for the defensive participants and make it hard to anticipate the next action of the relevant role. Therefore, the participant might establish the strategy, including not approaching opponents' reachable areas, and share it with the other offensive players.

Meanwhile, although the effect sizes and powers were lower than those in the analysis of the distance with each defensive participant, the interesting characteristics were also confirmed in the distances among the offensive players. In the bins of the relatively small and large distances, the frequencies after the tips tended to be significantly higher than before (Fig 7A,C). In the bin of the middle distance, the converse result was obtained (Fig 7B). Such a U-shape trend might represent that the player required in the role of intervention decision and adjustment also stayed in place without interrupting the other offensive participants, as explained in Table 1. However, these discussions must be investigated more deeply, as described in future studies.

This study may provide the results that satisfy usefulness and ecological validity of the role of intervention decision and adjustment, and make an educational contribution about giving the tips of off-ball movements. Ecological validity is related to the problem that experimental environment and observed actions significantly differ from real life [49]. The crucial and basic playing observed in the designed mini-

game would also contribute to a 5-on-5 game. However, after receiving the tips of this role, high performance on the offensive team could not be maintained in the last session (Session 6). The factor that significantly decreased the winning rate was the establishment of the defensive countermeasure. After this practice, the experimenter asked the defensive team about it; the participants reported that #3 in Fig 1 marking the relevant offensive role pretended to help the other players and actually kept marking. Thus, it was easy to establish the countermeasure because the offensive pattern was standardized. The offensive team had to handle the defensive one flexibly through bargaining based on the tips. However, the participants could not achieve developed coordination, and there was a limit in a single practice. Flexible coordination with dynamic situations is required in various activities regardless of team sports [31, 50-52]. Moreover, both top-down and bottom-up information processing are crucial for coordination. Shared mental model of such a strategy leads to efficient group interactions because the members are able to explain and anticipate an action each other. Meanwhile, a group also needs to fine-tune to dynamically changing environment and others' unanticipated actions [53-55]. The defensive coordination in 5-on-5 basketball games for the top-level university team in Japan shows that the structures of role-sharing switch according to emergent situations [1]. The university team in this practice was affiliated with the third division of the Tokai area league in Japan. Hence, the offensive team would share the mental model based on the tips about the role of intervention decision and adjustment. Although such top-down processing worked, developed bottom-up one might not be established in this team.

In future studies, we need to investigate the usefulness of the role of intervention decision and adjustment through continuous and cross practices.

Additionally, to deeply understand the coordination process that the relevant role involves in the other offensive players, it is crucial to examine the interactive structure. This study conducted the basic analysis of the distances with the defensive players and among the offensive ones to understand the overall characteristics, and compared them before and after receiving the tips. In soccer and basketball, a player either approach to receive the ball or stay in place without interrupting other offensive ones, depending on the game situation. It represents the decision of whether to intervene or not. Future analysis considering the context, such as passing, dribbling, and shooting are also required (e.g., [13-16]). It is kept in mind that the results of this study indicated the overall characteristics of playing related to the particular role based on the experimental findings in cognitive science [21]. It is a first step in understanding and applying complex and dynamic coordination to the sports fields. The academic and social impacts would be significant because we show an example of how to bridge the gap between experimental settings and real-world applications; these are also expected for educational contributions.

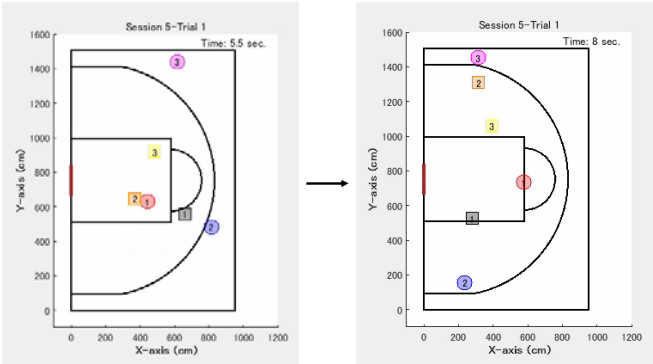

Fig 8. Typical example of offensive coordination after receiving the tips about the role of intervention decision and adjustment. In this situation, #1 runs toward the area under the basket goal ("paint area") and catches the ball from #2. Subsequently, #3 required in this role moves to a corner area while keeping a distance from the defensive players, catches the ball from #1, and aims to take a three-point shot.

Conclusions

We applied the experimental findings of the crucial role in coordinated behavior of a triad based on role-sharing to the sports field as a pilot study. This study investigated the usefulness of the role of intervention decision and adjustment, which is proposed using the experimental task in cognitive science. The mini-game of 3-on-3 basketball was designed, where the relevant offensive role is key, and introduced it to the practice of the university team. The results showed that in the bins of the relatively large distance between the participant required in this role and each defensive player, the frequencies after receiving the tips of the mentioned role were significantly higher; the winning rate on the offensive team improved temporarily. It suggests that the spacing skill, which indicates reasonable distances for intervening with the other offensive players, emerged. This study may provide findings that satisfy usefulness and ecological validity, and make an educational contribution about giving the tips of

off-ball movements. In future studies, we need to investigate the usefulness of this role through continuous and cross practices. Additionally, it is crucial to examine the interactive structure to discuss the offensive coordination process considering the context, such as passing, dribbling, and shooting.

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Data availability

Relevant data are provided in the Supporting Information files.

Author contributions

JI conceived the original concept of applying an experimental task to a 3-on-3 basketball game, designed and conducted the practice, analyzed the data, and wrote the paper. MY contributed primarily to the design and implementation of the practice, while KF provided valuable comments throughout the research process.

Competing interests

The authors have declared no competing interest.

References

1. Fujii, K., Yokoyama, K., Koyama, T., Rikukawa, A., Yamada, H., & Yamamoto, Y. (2016). Resilient help to switch and overlap hierarchical subsystems in a small human group. Scientific Reports, 6. https://doi.org/10.1038/srep23911
2. Takagi, A., Hirashima, M., Nozaki, D., & Burdet, E. (2019). Individuals physically interacting in a group rapidly coordinate their movement by estimating the collective goal. eLife, 8. https://doi.org/10.7554/eLife.41328.001
3. Woolley, A. W., Chabris, C. F., Pentland, A., Hashmi, N., & Malone, T. W. (2010). Evidence for a collective intelligence factor in the performance of human groups. Science, 330(6004), 686–688. https://doi.org/10.1126/science.1193147
4. Yokoyama, K., Shima, H., Fujii, K., Tabuchi, N., & Yamamoto, Y. (2018). Social forces for team coordination in ball possession game. Physical Review E, 97(2). https://doi.org/10.1103/PhysRevE.97.022410
5. Knoblich, G., Butterfill, S., & Sebanz, N. (2011). Psychological research on joint action: Theory and data. Psychology of Learning and Motivation, 54, 59–101. https://doi.org/10.1016/B978-0-12-385527-5.00003-6
6. Hollan, J., Hutchins, E., & Kirsh, D. (2000). Distributed cognition: Toward a new foundation for human-computer interaction research. ACM Transactions on Computer-Human Interaction, 7(2), 174–196. https://doi.org/10.1145/353485.353487
7. Hutchins, E. Cognition in the Wild. Cambridge: MIT press, 1995.

8. Hayashi, Y. (2018). The power of a “Maverick” in collaborative problem solving: An experimental investigation of individual perspective-taking within a group. Cognitive Science, 42(S1), 69–104. https://doi.org/10.1111/cogs.12587
9. Hayashi, Y., Miwa, K., & Morita, J. (2006). A laboratory study on distributed problem solving by taking different viewpoints. In: Proceedings of the 28th Annual Meeting of the Cognitive Science Society (CogSci 2006), 333–338.
10. Shirouzu, H., Miyake, N., & Masukawa, H. (2002). Cognitively active externalization for situated reflection. Cognitive Science, 26(4), 469–501.
11. Sun, C., Shute, V. J., Stewart, A., Yonehiro, J., Duran, N., & D’Mello, S. (2020). Towards a generalized competency model of collaborative problem solving. Computers and Education, 143. https://doi.org/10.1016/j.compedu.2019.103672
12. Zhang, Z., Bekker, T., Markopoulos, P., & Skovbjerg, H. M. (2024). Supporting and understanding students’ collaborative reflection-in-action during design-based learning. International Journal of Technology and Design Education, 34, 307–343. https://doi.org/10.1007/s10798-023-09814-0
13. Kono, R. & Fujii, K. (2024). Mathematical models for off-ball scoring prediction in basketball. arXiv. http://arxiv.org/abs/2406.08749
14. Lamas, L., Santana, F., Heiner, M., Ugrinowitsch, C., & Fellingham, G. (2015). Modeling the offensive-defensive interaction and resulting outcomes in basketball. PLoS ONE, 10(12). https://doi.org/10.1371/journal.pone.0144435
15. Supola, B., Hoch, T., & Baca, A. (2023). Modeling the extra pass in basketball–an assessment of one of the most crucial skills for creating great ball movement. International Journal of Computer Science in Sport, 22(1), 13–29. https://doi.org/10.2478/ijcss-2023-0002

16. Wu, Y., Deng, D., Xie, X., He, M., Xu, J., Zhang, H., Zhang, H., & Wu, Y. (2023). OBTracker: Visual analytics of off-ball movements in basketball. IEEE Transactions on Visualization and Computer Graphics, 29(1), 929–939. https://doi.org/10.1109/TVCG.2022.3209373

17. Ichikawa, J. & Fujii, K. (2020). Proposal of a research approach for discussion of a dynamic coordination mechanism: Investigation of anticipating others' behaviors and adaptation through quantitative analysis of group behavior. Bulletin of the Japanese Cognitive Science Society, 27(3), 377–385. https://doi.org/10.11225/cs.2020.026

18. Yokoyama, K. & Yamamoto, Y. (2011). Three people can synchronize as coupled oscillators during sports activities. PLoS Computational Biology, 7(10). https://doi.org/10.1371/journal.pcbi.1002181

19. Braun, D. A., Ortega, P. A., & Wolpert, D. M. (2009). Nash equilibria in multi-agent motor interactions. PLoS Computational Biology, 5(8). https://doi.org/10.1371/journal.pcbi.1000468

20. Chackochan, V. T. & Sanguineti, V. (2019). Incomplete information about the partner affects the development of collaborative strategies in joint action. PLoS Computational Biology, 15(12). https://doi.org/10.1371/journal.pcbi.1006385

21. Ichikawa, J. & Fujii, K. (2022). Analysis of group behavior based on sharing heterogeneous roles in a triad using a coordinated drawing task. Frontiers in Psychology, 13. https://doi.org/10.3389/fpsyg.2022.890205

22. Fujii, K., Kawasaki, T., Inaba, Y., & Kawahara, Y. (2018). Prediction and classification in equation-free collective motion dynamics. PLoS Computational Biology, 14(11). https://doi.org/10.1371/journal.pcbi.1006545

23. Fujii, K., Takeuchi, K., Kuribayashi, A., Takeishi, N., Kawahara, Y., & Takeda, K. (2024). Estimating counterfactual treatment outcomes over time in complex multiagent scenarios, IEEE Transactions on Neural Networks and Learning Systems. 1–15. https://doi.org/10.1109/TNNLS.2024.3361166

24. Nakahara, H., Tsutsui, K., Takeda, K., & Fujii, K. (2023). Action valuation of on- and off-ball soccer players based on multi-agent deep reinforcement learning. IEEE Access, 11, https://doi.org/10.1109/ACCESS.2023.3336425

25. Buldú, J. M., Busquets, J., Echegoyen, I., & Seirul.lo, F. (2019). Defining a historic football team: Using Network Science to analyze Guardiola's F.C. Barcelona. Scientific Reports, 9. https://doi.org/10.1038/s41598-019-49969-2

26. Clemente, F. M., Sarmento, H., & Aquino, R. (2020). Player position relationships with centrality in the passing network of world cup soccer teams: Win/loss match comparisons. Chaos, Solitons & Fractals, 133. https://doi.org/10.1016/j.chaos.2020.109625

27. Ichinose, G., Tsuchiya, T., & Watanabe, S. (2021). Robustness of football passing networks against continuous node and link removals. Chaos, Solitons & Fractals, 147. https://doi.org/10.1016/j.chaos.2021.110973

28. Gazda, S. K., Connor, R. C., Edgar, R. K., & Cox, F. (2005). A division of labour with role specialization in group-hunting bottlenose dolphins (Tursiops truncatus) off Cedar Key. Florida. Proceedings of the Royal Society B: Biological Sciences, 272(1559), 135–140. https://doi.org/10.1098/rspb.2004.2937

29. Stander, P. E. (1992). Behavioral ecology and sociobiology cooperative hunting in lions: The role of the individual. Behavioral Ecology and Sociobiology, 29, 445–454. https://doi.org/10.1007/BF00170175

30. Tsutsui, K., Tanaka, R., Takeda, K., & Fujii, K. (2024). Collaborative hunting in artificial agents with deep reinforcement learning. eLife, 13. https://doi.org/10.7554/eLife.85694

31. Bowers, C., Kreutzer, C., Cannon-Bowers, J., & Lamb, J. (2017). Team resilience as a second-order emergent state: A theoretical model and research directions. Frontiers in Psychology, 8. https://doi.org/10.3389/fpsyg.2017.01360

32. Burke, C. S., Stagl, K. C., Salas, E., Pierce, L., & Kendall, D. (2006). Understanding team adaptation: A conceptual analysis and model. Journal of Applied Psychology, 91(6), 1189–1207. https://doi.org/10.1037/0021-9010.91.6.1189

33. Johnston, J. H., Phillips, H. L., Milham, L. M., Riddle, D. L., Townsend, L. N., DeCostanza, A. H., Patton, D. J., Cox, K. R., & Fitzhugh, S. M. (2019). A team training field research study: Extending a theory of team development. Frontiers in Psychology, 10. https://doi.org/10.3389/fpsyg.2019.01480

34. Palmer, C. (2008). A theory of risk and resilience factors in military families. Military Psychology, 20(3), 205–217. https://doi.org/10.1080/08995600802118858

35. Richardson, M. J., Marsh, K. L., Isenhower, R. W., Goodman, J. R. L., & Schmidt, R. C. (2007). Rocking together: Dynamics of intentional and unintentional interpersonal coordination. Human Movement Science, 26(6), 867–891. https://doi.org/10.1016/j.humov.2007.07.002

36. Schmidt, R. C., Carello, C., & Turvey, M. T. (1990). Phase transitions and critical fluctuations in the visual coordination of rhythmic movements between people. Journal of Experimental Psychology: Human Perception and Performance. 16(2). 227–247.

37. Shimizu, D. & Okada, T. (2021). Synchronization and coordination of art performances in highly competitive contexts: Battle scenes of expert breakdancers. Frontiers in Psychology, 12. https://doi.org/10.3389/fpsyg.2021.635534

38. Walton, A. E., Washburn, A., Langland-Hassan, P., Chemero, A., Kloos, H., & Richardson, M. J. (2018). Creating time: Social collaboration in music improvisation. Topics in Cognitive Science, 10(1), 95–119. https://doi.org/10.1111/tops.12306

39. Hojo, M., Fujii, K., Inaba, Y., Motoyasu, Y., & Kawahara, Y. (2018). Automatically recognizing strategic cooperative behaviors in various situations of a team sport. PLoS One, 13(12). https://doi.org/10.1371/journal.pone.0209247

40. Spearman, W. (2018). Beyond expected goals. In: Proceeding of the 12th MIT Sloan Sports Analytics Conference, 1-17.

41. Japan Basketball Association. (2023). 2022 Official Basketball Rules. Retrieved January 25, 2023, from http://www.japanbasketball.jp/files/referee/rule/2023rule.pdf

42. Zhang, Y., Sun, P., Jiang, Y., Yu, D., Weng, F., Yuan, Z., Luo, P., Liu, W. & Wang, X. (2022). ByteTrack: Multi-object tracking by associating every detection box. arXiv. https://doi.org/10.48550/arXiv.2110.06864

43. Labelbox (2018). Labelbox The Data Factory for Next Gen AI. Retrieved April 26, 2024, from https://labelbox.com

44. Esteves, P. T., Silva, P., Vilar, L., Travassos, B., Duarte, R., Arede, J., & Sampaio, J. (2016). Space occupation near the basket shapes collective behaviours in youth basketball. Journal of Sports Sciences, 34(16), 1557–1563. https://doi.org/10.1080/02640414.2015.1122825

45. Franks, A., Miller, A., Bornn, L., & Goldsberry, K. (2015). Characterizing the spatial structure of defensive skill in professional basketball. Annals of Applied Statistics, 9(1), 94–121. https://doi.org/10.1214/14-AOAS799

46. Ichikawa, J., Fujii, K., Nagai, T., Omori, T., & Oka, N. (2021). Quantitative analysis of spontaneous sociality in children's group behavior during nursery activity. PLoS ONE, 16(2). https://doi.org/10.1371/journal.pone.0246041

47. Gonçalves, B., Esteves, P., Folgado, H., Ric, A., Torrents, C., & Sampaio, J. (2017). Effects of pitch area-restrictions on tactical behavior, physical, and physiological performances in soccer large-sided games. The Journal of Strength & Conditioning Research, 31(9), 2398-2408. https://doi.org/10.1519/JSC.0000000000001700

48. Taki, T. & Hasegawa, J. (2000). Visualization of dominant region in team games and its application to teamwork analysis. In: Proceedings of Computer Graphics International 2000, pp. 227-235.

49. Neisser, U. Cognition and Reality: Principles and Implications of Cognitive Psychology. New York: WH Freeman and Company, 1976.

50. Amon, M. J., Vrzakova, H., & D'Mello, S. K. (2019). Beyond dyadic coordination: Multimodal behavioral irregularity in triads predicts facets of collaborative problem solving. Cognitive Science, 43(10). https://doi.org/10.1111/cogs.12787

51. Gorman, J. C., Cooke, N. J., Amazeen, P. G., & Fouse, S. (2012). Measuring patterns in team interaction sequences using a discrete recurrence approach. Human Factors, 54(4), 503–517. https://doi.org/10.1177/0018720811426140

52. Kijima, A., Shima, H., Okumura, M., Yamamoto, Y., & Richardson, M. J. (2017). Effects of agent-environment symmetry on the coordination dynamics of

triadic jumping. Frontiers in Psychology, 8. https://doi.org/10.3389/fpsyg.2017.00003

53. Cooke, N. J., Gorman, J. C., Myers, C. W., & Duran, J. L. (2013). Interactive team cognition. Cognitive Science, 37(2), 255–285. https://doi.org/10.1111/cogs.12009

54. Gorman, J. C. (2014). Team Coordination and Dynamics: Two Central Issues. Current Directions in Psychological Science. 23(5), 355–360.

55. Steiner, S., Macquet, A. C., & Seiler, R. (2017). An integrative perspective on interpersonal coordination in interactive team sports. Frontiers in Psychology, 8. https://doi.org/10.3389/fpsyg.2017.01440

Supporting Information

S1 Note. Participants.

S2 Note. Procedures.

S3 Note. Results.

S1 Fig. Averages of the normalized frequencies in all the bins for the index of the distance (cm) between the offensive player required in the role of intervention decision and adjustment and each defensive participant. The range of the bins is from 200 cm to 1400 cm.

S2 Fig. Averages of the normalized frequencies in all the bins for the index of the distance (cm) between the offensive player required in the role of intervention decision and adjustment and each other participant. The range of the bins is from 200 cm to 1600 cm.

S1 Table. Results of the first and second halves-questionnaires on the offensive and defensive teams.

S1 Dataset. Analysis results of the *t*-value, degree of freedom, *p*-value, effect size, and power indices.