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Visual Cognition and Experience Mediate the Relation Between Age and Decision Making in Youth Volleyball Players

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Ethical Approval

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Abstract

Significance: Experts in different sports show superior decision making skills compared to novices, but little is known about its development in youth players. This study shows that the age-related improvements in visual cognition and accumulation of sport-specific experience explain a considerable amount of the development in decision making in volleyball.

Purpose: The aim of this study was to investigate the mediating effects of visual cognition and volleyball experience on the relationship between age and decision making in youth volleyball players.

Methods: 171 Female volleyball players aged 6-17 years old performed a sport-specific, video-based test of decision making, as well as 4 different visual cognition tests. Using structural equation modeling, we examined if volleyball experience and a latent variable constructed from the four tests of visual cognition act as parallel mediators in the association between age and decision making.

Results: The parallel multiple mediation model for the association between age and decision making was supported in youth volleyball players. Moreover, significant indirect effects and a non-significant direct effect indicated that visual cognition and experience fully mediated the relation between age and decision making, and together explain 38% of the variance in decision making performance. The effects of both mediators were not significantly different and there was no residual correlation between experience and visual cognition, which indicates that these mediators are unrelated to each other.

Conclusions: Our findings demonstrate that visual cognition and volleyball experience mediate the relation between age and decision making independently, which indicates that they each influence different parts of the decision making process. These results highlight the importance of the development of perceptual-cognitive skill in young players and future research should further investigate the development of these skills as well as their underlying factors in different kinds of sports.

Dynamic team sports require an athlete to rapidly identify and perceive visual information regarding the spatial relationships between surrounding teammates and opponents, as well as the trajectory of the ball, in order to make split-second decisions that can have a direct impact on game outcomes.[1] It has been shown in many different sports (e.g., football, tennis, water polo) that adult expert athletes make faster and more accurate decisions compared to novices.[2–6] However, considerably less is known about the development of decision making, and more importantly the underlying factors that influence these decision-making abilities, in youth athletes. In our recent study of youth volleyball players,[7] we investigated the development of sport-specific decision making, anticipation and pattern recall through video-based occlusion tests in 7 to 26 year old volleyball players. Analyses of decision making performance in the different age groups indicated that decision making abilities start to develop at 11 years of age (i.e., only 8% of U9 and 30% of U11 scored above chance on the easiest decision making conditions), and then continue to improve with increasing age. Moreover, the greatest improvements in decision making were evident from 13 years old until young adulthood, where clear and distinct differences in decision making performance emerged between each of the different age groups. These results indicate a clear relation between age and decision making, where decision making seems to improve with increasing age. To date, however, there is a considerable gap in current literature regarding the mechanisms underlying the development of decision making in young athletes.

Developmental research in the social domain suggests that the development of decision making is influenced by two information processing systems: an analytical and an experiential system.[8] The analytic system entails analysis of the underlying structure of the problem, regardless of its context, and is based on normative reasoning and metacognition abilities.[8,9] Experiential processing, on the other hand, is viewed as highly context-specific, and implies that specific features of the context activate specific decision heuristics. This dual-processing system proposed by Jacobson and colleagues (2002) can also be related to the recognition-primed decision making theory.[10] Recognition primed decision making implies that an expert recognizes a situation as encountered previously and rapidly provides a solution. Hence, this implies that experts largely use their experience to make decisions, but still, some explicit reasoning will be crucial to analyze the underlying structure of the problem and match the given situation to a similar situation in memory.[11] When applied to sports, the implication is that both sport-specific experience (i.e., experiential system) and cognitive functions (i.e., analytical system) will mediate the development of decision making.

On the analytical side, the ability to process visuospatial information to form high-level representations that inform our understanding of the visual surrounds (i.e., visual cognition), are of particular interest. For example, expert adult athletes demonstrate superior visual cognition compared to their novice and sub-elite counterparts across a range of laboratory tasks that are not specific to a certain sports setting (i.e., Corsi block tapping, tower of London, multiple object tracking).[12–14] Furthermore, there is some evidence of a relationship between visual cognition and sport-specific decision making in adults, such as the fact that basketball players exhibiting higher levels of visuospatial working memory make more appropriate decisions than players with low levels of visuospatial working memory.[15] To date, however, there have been no studies on the relationship between visual cognition and sports-specific decision making in youth athletes. Visual cognition is known to develop rapidly between 6 and 13 years old, with continued refinements into young adulthood.[16,17] Contrary to work on adults,[12,14,18,19] Verburgh, Scherder, Van Lange, & Oosterlaan, (2014) reported no differences in visuospatial working memory between elite and non-elite youth soccer players (8-12 years old).[20] That said, the youth soccer players spanned the age range where there is a rapid development in visual cognition (i.e. 6 – 13 years old).[16] Accordingly, it could be that both elite and non-elite groups were comprised of youth soccer players with immature levels of visual cognitive development.

In terms of the experiential system, it is suggested that gaining experience/knowledge in context-specific situations plays a crucial role towards decision making development.[8,11] For example, firefighters have demonstrated to use their experience to immediately select their course of action instead of going over all possible actions first.[10] In a sports context, there is some evidence from retrospective analyses that various types of sport-related experience during childhood (e.g., team practice, competition, non coach-led play) play an important role in decision making during adulthood.[21,22] Roca and colleagues reported that hours per year in soccer activity between 6 and 18 years old differed between adult players with high and low levels of perceptual-cognitive skill.[22] Furthermore, the amount of sport-specific free play in childhood, as well as the amount of structured practice in adolescence, seem to be associated positively with decision making and anticipation capabilities of adult athletes in different sports.[21] However, despite the value of retrospective analyses, it is notable that there has been no direct investigation of the relationship between sport-specific experience and the development of decision making in young athletes.

To better understand the mechanisms underlying the development of decision making in young athletes, this study considered the role of volleyball experience and visual cognition in a large sample of volleyball players aged between 7 and 17 years old. We measured decision making performance using a sport-specific video-based occlusion task and visual cognition based on four validated tests (i.e., Spatial Span, Token Search, Odd One Out and Monkey Ladder).

Along with age and playing experience, these data were analyzed using Structural Equation Modelling with bootstrapping, thereby allowing us to investigate if the relationship between age and decision making in youth volleyball players is mediated by volleyball experience and visual cognition.

Methods

1. Participants

A total of 171 female volleyball players between 7 and 17 years old were recruited from two Flemish volleyball clubs. Both clubs received a 4 out of 5 star ranking from the federation youth sports fund 2018, which ensured the quality of their youth development. Prior to the study, participants provided written informed consent and were made aware of the fact that they could withdraw from the study at any time without consequences. For the youth players, the parents also provided written informed consent. This research was reviewed by an independent ethical review board and conforms with the principles and applicable guidelines for the protection of human subjects in biomedical research.

Players were recruited from 5 different age groups. The average age and average years of experience for players from the different age groups are displayed in table 1. Experience was measured as number of years that the participant has been enrolled in a volleyball club. While other studies have used accumulated hours of play, deliberate practice or other kinds of involvement in the specific sport, this approach was not deemed suitable for the current study. Firstly, all participants were following a highly similar trajectory with regard to the frequency and nature of training sessions, and thus would have accumulated a very similar number of hours of play throughout one year. Secondly, detailed practice histories were not directly available, and could only be estimated through retrospective procedures. In order to minimize potential errors of indirectly estimating the accumulated hours of play/practice, it was decided that years of experience provided a reliable alternative. Importantly, experience could be clearly distinguished from age because there was considerable variability in the age participants started playing volleyball (i.e., between 4 and 14 years old). This was confirmed with correlation analysis that showed only a moderate correlation ($r = 0.564$) between experience and age, with some older participants having less experience than their younger counterparts.

Table 1. Mean age and experience of participants in the different age groups. (U9 = under 9's, U11 = under 11's, U13 = under 13's, u15 = under 15's, U17 = under 17's)

Age Group	Mean Age (SD) (in years)	Mean Experience (SD) (in years)	n
U9	8.41 (0.90)	1.68 (0.99)	23
U11	10.13 (0.64)	2.39 (1.57)	26
U13	11.65 (0.76)	3.75 (2.00)	37
U15	13.59 (0.78)	4.29 (2.47)	43
U17	15.63 (0.93)	6.45 (3.21)	42
TOTAL			**171**

2. Materials & procedures

2.1. Sport-Specific Decision Making

A volleyball-specific video-based occlusion test for decision making was used for this study.[7] The video clips displayed the opposing team taking defensive positions while an offensive sequence is being built up by the spiker's team, filmed from the spiker's perspective. The test consisted of four viewing conditions, with 2, 3, 4 or 6 defending players on the opposing side. The participant was asked to decide which zone of the opposing field would render the highest chance of scoring a point for the spiker by pressing the corresponding button on a keyboard as fast as possible. For the first two conditions, where the defense consisted of 2 and 3 players, participants could choose from 6 zones, while for the last two conditions, with 4 or 6 defenders, the field was divided in 9 zones. This increase in zones was implemented because each progressing condition also included a larger field size and thus more zones were needed to keep the size of the zones relatively similar across conditions. The number of opponents, the size of the field, the number of zones and the number of clips per level or viewing condition are displayed in table 2. The video clips lasted about 5 seconds, after which the participants had 5 seconds to execute their response. A screenshot of one of the video clips is presented in figure 1, and a schematic of the test setting is shown in figure 2. Importantly, participants did not have to wait until occlusion to execute their response.

Table 2. Characteristics of the different viewing conditions in the decision making task[7]

Viewing Condition	Number of opponents	Size of the field (LxW in meters)	Number of zones to choose from	Number of clips
1 (2x2)	2	6m x 4.5m	6	10
2 (3x3)	3	6m x 6m	6	10
3 (4x4)	4	7m x 7m	9	8
4 (6x6)	6	9m x 9m	9	10
TOTAL				**38**

Figure 1. Screenshot of the decision making test.

The video clips were back projected on a 1.07m (w) x 0.6m (l) projection screen using a LED HD video projector (LG PH550G, Seoul, South Korea) that was placed on a table 1.5m from the screen. Subjects were instructed to stand behind this table at 2.00m from the screen. A regular USB-connected keyboard was utilized to record the participants' responses. Video clips were displayed with OpenSesame software,[23] which was also used to record the keyboard responses.

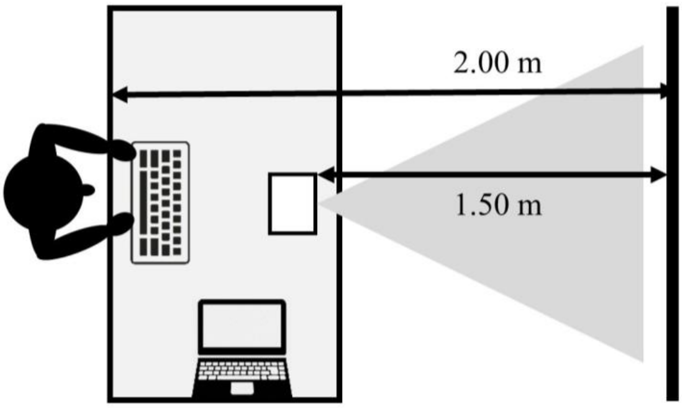

Figure 2. Schematic of the test set-up.

At the start of the decision making test, participants received detailed explanations as well as an example and two practice trials. All participants completed the different viewing conditions in the same order as they are numbered in table 2, starting with the minimum number of opponents (2) and ending with the maximum number of opponents (6). Within each condition, trials were randomized for each participant separately. For each new viewing condition, a familiarization clip was shown, as the number of players and size of the court would change. The decision making test lasted about 10 minutes.

Decision making scores were calculated as follows: participants received 3 points for making the best choice (i.e., choosing the zone that will always render a point), 2 points for making a 'mediocre' choice, and 1 point for making the worst choice (i.e. choosing the zone in which a defender is standing). The scores for each decision making situation and each zone were judged by a panel of expert coaches, and only those situations on which all coaches agreed were used in the test. For each participant, the sum of all trials was used as the outcome variable for decision making.

2.2. Visual Cognition Tests

Four tests of the Cambridge Brain Sciences (CBS) test battery were selected to measure visual cognition. The four tests used in this study were Spatial Span, Token Search, Odd One Out and Monkey Ladder. These tests are all based on well validated neuropsychological tasks, but have been adapted to be suitable for computerized testing.[24] The test battery has been used and validated in several large sample studies, and has dynamically varying difficulty levels (i.e. difficulty of a trial decreases or increases depending on whether or not the previous response was correct) that make it suitable for almost all ages and less sensitive to floor and ceiling effects.[25–27]

Spatial Span is a task designed to measure the participants' capacity to recall the (relationship between) objects in space, and is based on the Corsi Block Tapping Task.[28] In this task, a grid of 4x4 boxes was displayed, where the boxes would light up in random order and participants had to tap the same boxes in the correct order. All participants started the test with a four-block trial, and after a successful trial, the next trial would contain one extra box. After an unsuccessful trial, the next trial would contain one box less. After three unsuccessful trials, the test ended. Response accuracy was measured as the maximum number of blocks remembered correctly for each participant.

Token Search is self-guided search task primarily designed to assess visual-spatial memory.[29] In this task, a number of boxes were displayed in random positions on the screen, and participants were instructed to find as many hidden token underneath the boxes as there were boxes on the screen. The token could never be in the same box twice, and its next hiding place could not be predicted. A trial was successful when a token had been found in each of the boxes, without selecting an empty box twice or selecting a box that had previously held the token. All participants started the test with a four-block trial, and after a successful trial, the next trial would contain one extra box. After an unsuccessful trial, the next trial would contain one box less. After three unsuccessful trials, the test ended. Response accuracy was measured as the maximum number of tokens found without error for each participant.

Odd One Out is a visual search task, where the participant is asked to find and identify an ‘odd target’. In this task, nine shapes that differ in color, shape and size are shown on screen. The participant has to identify the shape that is most different from the other shapes as fast as possible. When the participant successfully identified the odd target, the next trial would be more complex and thus include more variance on the three levels (color, shape, size). Participants were asked to identify as many odd targets as they could within 180 seconds. Response accuracy was calculated as the number of correct attempts *(N attempts – N errors)* for each participant.

Monkey Ladder is a task designed to measure visual-spatial working memory. In this task, a number of boxes were displayed in random positions on the screen, each containing a number ranging from 1 to the number of boxes shown. Participants were instructed to memorize the numbers on the boxes and to tap the boxes in numerical order after the numbers had disappeared. All participants started the test with a two-block trial, and after a successful trial, the next trial would contain one extra box. After an unsuccessful trial, the next trial would contain one box less. After three unsuccessful trials, the test ended. Response accuracy was measured as the maximum number of boxes tapped in the correct numerical order for each participant.

The visual cognition test battery lasted about 15 minutes for each participant and was administered on a 9.7 inch Apple iPad 2017 that had to be held in an upright position. Before the test, participants received a general explanation of the test battery as well as detailed explanations of each test. A trained researcher was present to ensure the test was executed correctly, and to answer any additional questions.

3. Data Analysis

Structural Equation Modelling with bootstrapping was used to test the parallel mediation model of visual cognition and volleyball experience on the relationship between age and volleyball-specific decision making. In such analyses, mediation is significant if the 95% bootstrapped confidence intervals (CIs) for the indirect effect do not include 0. Model fit is also reported using the following criteria for fit measures: the Comparable Fit index (CFI) >0.95,[30] Root Mean Square Error of Approximation (RMSEA) and Standardized Root Mean Square Residual (SRMR) <0.05,[31] All variables were standardized prior to the analyses, thus standardized coefficients are reported for the direct, indirect and total effects. Analyses were performed using the Lavaan package in R studio.[32]

Results

To provide a qualitative description of the data, we first plotted the mean (±SD) performance on the visual cognition and decision making tests as a function of age group (see figures 3 and 4). The bar charts demonstrate an increase in test performance with age, which resulted in regression lines with a positive slope, of which the R^2 values and regression equations are presented in figures 3 and 4 (panel A-D).

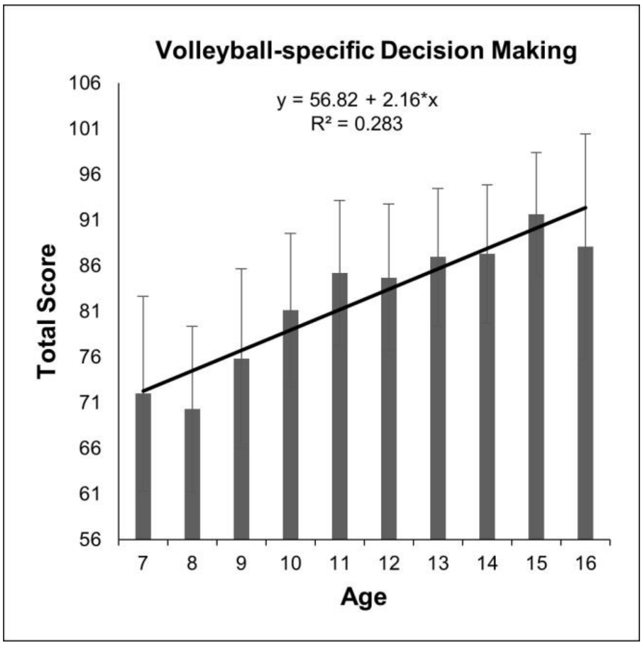

Figure 3. Decision making scores plotted by age with trend line, R^2 value and the regression equation for the linear regression between age and decision making.

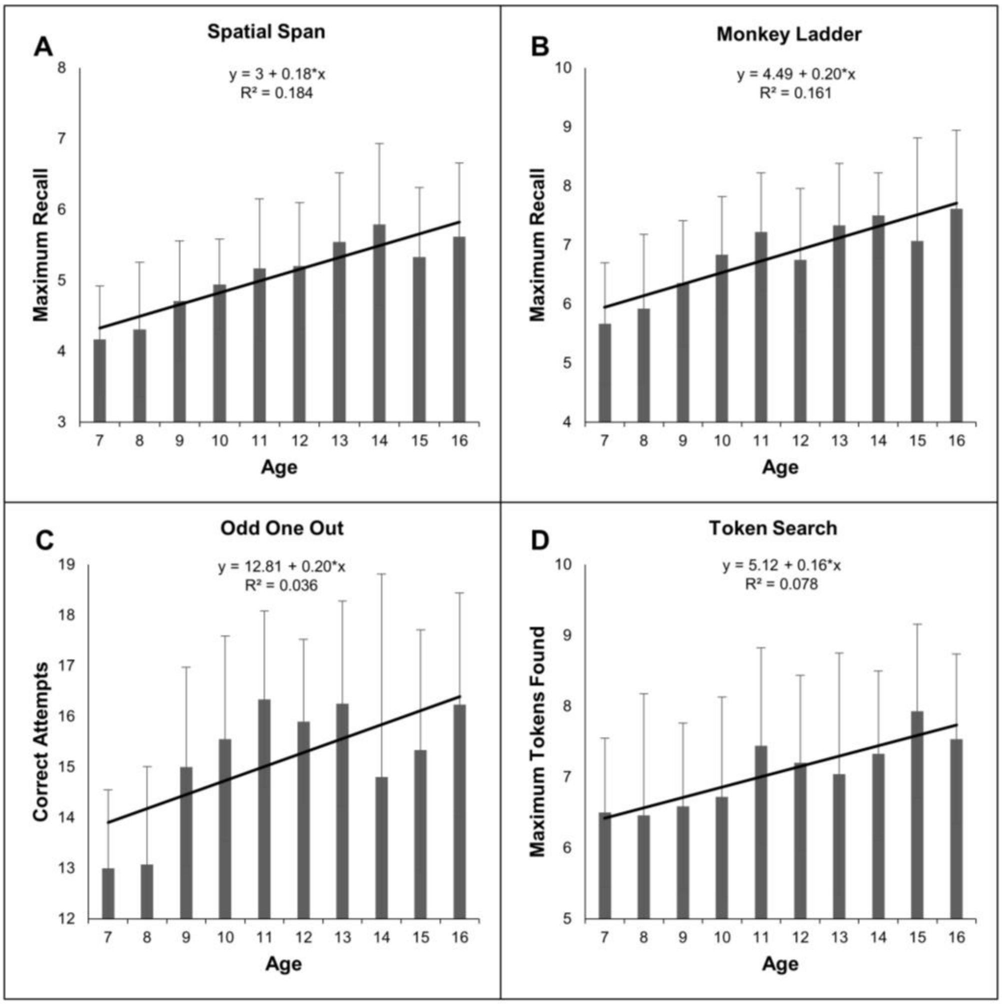

Figure 4. Scores on the visual cognition tests plotted by age with trend lines, R^2 values and the regression equations for the linear regression between age and each visual cognition test.

Structural Equation Modelling based on 5000 bootstrapped samples indicated a significant total effect (β_{total}=0.537; SE=0.073; 95% CI 0.40 to 0.67) and a non-significant direct effect (β_{direct}=0.12; SE=0.634; 95% CI -0.61 to +0.45) for the relation between age and decision making. All other direct effects were significant (see figure 5). In addition, both the indirect effect of age to decision making through visual cognition (($\beta_{IE(VisualCognition)}$=0.288; SE=0.517; 95% CI 0.06 to 0.882) and through volleyball experience ($\beta_{IE(Experience)}$=0.129; SE=0.124; 95% CI 0.04 to 0.29) were significant. Contrasts of the indirect effects indicated that the mediating effects of experience and visual cognition did not significantly differ from each other (($\beta_{contrast}$=0.159; SE=0.414; 95% CI -0.06 to +0.66). The overall structural equation model provided an adequate fit for the data (χ^2 = 6.905; df = 11; CFI = 1.00, RMSEA = 0.000 [0.00,0.05]; SRMR = 0.02) and explained 38% of the variance in decision making ($R^2_{DecisionMaking}$=0.377).

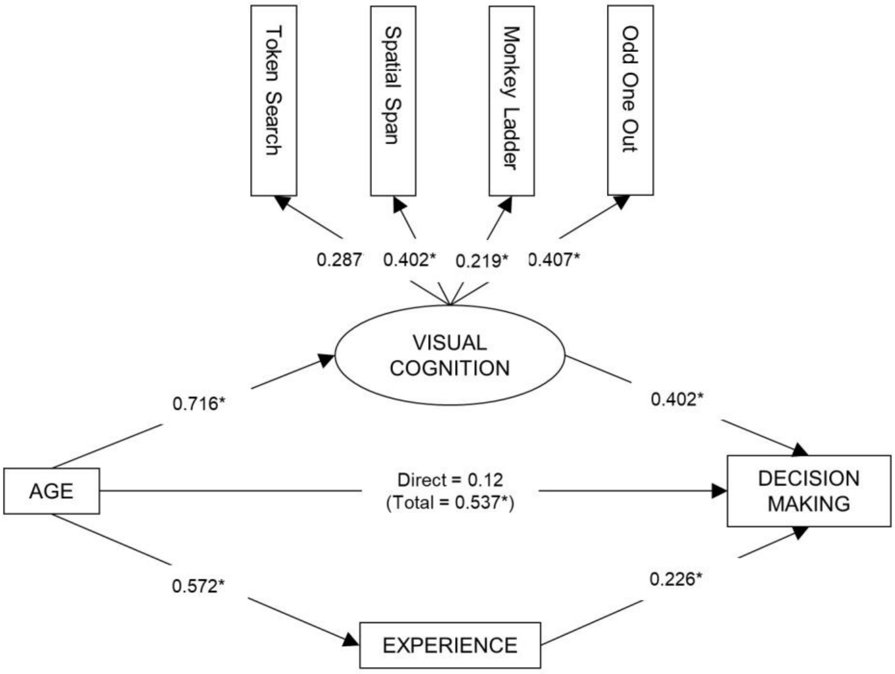

Figure 5. Parallel Mediation model for the mediation of visual cognition and volleyball experience on the relation between age and decision making. Standardized estimates of direct paths and factor loadings are presented. Significance is indicated by an asterisk.

Discussion

The aim of this study was to investigate the relationship between age and the development of decision making in youth volleyball players, and more importantly, whether this is mediated by volleyball experience and visual cognition. Structural Equation Modelling with bootstrapping indicated that the relation between age and decision-making abilities is fully mediated by both volleyball experience and visual cognition development, which together explain 38% of the variance in decision making performance. There was also no residual correlation between experience and visual cognition, which indicates that these mediators are unrelated to each other and both play an important role in the development of decision making in youth volleyball players.

To our knowledge, this is the first study to directly examine the effect of experience during childhood and adolescence on the development of decision making. Our findings corroborate those of retrospective studies that have suggested adult athletes with higher levels of perceptual cognitive skill (e.g., decision making) in sports such as soccer, football and surfing, report higher levels of sporting experience during childhood and adolescence.[19,21,33] The implication is that experience (e.g., team practice, competition, non coach-led play) in sport settings provides more opportunities to explore the perceptual landscape and form knowledge structures which are crucial for skilled decision making.[34] It is important to note that, while age and experience are closely related, as getting older allows an athlete to accumulate more years of experience, age and experience are not the same. The fact that experience mediates the relation between age and decision making indicates that decision making does not simply develop as a function of age, but that exposure to the sport-specific setting and experience on the field in that sport is a crucial part of the development of decision capabilities in youth players.

Another unique finding from the current study is that age-related changes in visual cognition, independent of experience, also influence decision making development in youth athletes. This finding confirms that visual cognition is a key underlying factor to decision making, as has been suggested by studies with adult experts and studies outside of the sports domain.[8,9,13] Moreover, these results suggest that visual cognition, which is thought to be a determinant of sports expertise in adults,[35] already plays a crucial role in the early development of expertise in youth athletes. It is therefore important that the role of visual cognitive development towards athlete development, as well as its influence on an athlete's future career, is further explored. Furthermore, the finding that visual cognitive development occurs independent of volleyball experience indicates that participating in team sports does not directly enhance visual cognition. This is in line with the recent findings of Beavan et al.,[36] who demonstrated that the development of visual cognition in high level soccer players between 5 and 22 years old follows the same trajectory that has been found in a regular population. Furthermore, it has been found that elite soccer players between 8 and 16 years old, who had on average one extra year of experience than non-elite players, did not outperform their counterparts on visual cognition tasks.[20]

How, then, might one explain the finding that visual cognition and volleyball experience independently influence decision making in youth athletes? Although this should be the subject of further study, it could be that visual cognition and volleyball experience each influence different parts of the decision making process. This is consistent with developmental research in social and behavioral context, which suggests a dual system, where both experience and cognition influence decision making development.[8,11] On the one hand, the development of visual cognition might enable a young athlete to efficiently scan the environment and quickly extract, process and retain relevant information from different cues. On the other hand, athletes might need sport-specific experience to efficiently use this information extracted from the environment. Through exposure to complex sport-specific situations, athletes develop advanced internal representations and knowledge structures that allow them to make the most accurate decision in different situations.[34] Hence, it can be assumed that young athletes need adequate visual cognition skill as well as sport-specific experience, in order to develop their decision making capabilities. Research on gaze behavior during decision making in adults has provided some insight into the roles of experience and visual cognition. Successful decision makers tend to use more goal directed gaze behavior, which might be underpinned by knowledge of relevant areas of the display gained through years of experience. These successful decision makers also exhibit more fixations of shorter durations, which might indicate that they need less time to process information from each fixation location, and might in turn be underpinned by superior visual cognition.[5]

Even though this study makes an important step towards understanding the development of decision making in team sports, it has to be recognized that the two factors considered (i.e., experience and visual cognition) explained only 38% of the variance in decision making. Therefore, it remains to be determined what additional factors could account for the remaining unexplained variance in decision making capabilities of youth volleyball players. In this regard, other general cognitive skills such as attention and inhibition could play an important role in decision making.[37] Additionally, this study used static visual cognition tasks, whereas more dynamic visual cognition (e.g., multiple object tracking) might also be important for our test of sport-specific decision making. Lastly, other sport-specific perceptual-cognitive skills such as anticipation and pattern recall, which have been found to develop earlier than decision making,[7] could also contribute to the decision making process.[34] Further research exploring the relations between these additional factors and the ones investigated in this study could thus provide additional insights towards the development of decision making skill. With regard to talent development, our results demonstrate that decision making abilities are in full development between 7 and 17 years old, fueled by the development of visual cognition and becoming more acquainted with the dynamics and context of the game through experience. Hence, coaches should not hesitate to include decision making exercises in their training sessions, even from a young age onwards, as athletes might only benefit from it.

In conclusion, this study is the first to demonstrate that the development of decision making capabilities in young team sports athletes is independently mediated by sport-specific experience and the development of visual cognition. However, the importance of these early developmental changes in decision making capabilities towards an athlete’s future career remains unclear. Indeed, the link between perceptual-cognitive development during childhood and expert-novice differences in adulthood has yet to be made. Moreover, the trainability of decision making through its underlying mechanisms has not been addressed in youth players. Based on our finding that visual cognition influences decision making in youth athletes, combined with the knowledge that visual cognition is trainable in children and adolescents,[38] we suggest that future research should further investigate the development of perceptual-cognitive skills and its underlying factors in youth athletes in different kinds of sports.

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