Title: The Development of Perceptual-Cognitive Skills in Youth Volleyball Players.

Authors: De Waelle, S. [1], Warlop, G. [1], Lenoir, M. [1] , Bennett, S.J.[2], Deconinck, F.J.A.[1]

Affiliations

[1]Department of Movement and Sports Sciences, Ghent University, Belgium

[2]School of Sport and Exercise Sciences, Liverpool John Moores University, United Kingdom

Corresponding Author

Silke De Waelle (Silke.DeWaelle@UGent.be)

Ethical Approval

This project was approved by the local ethics committee of the Ghent University Hospital.

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Abstract

In many sports, elite players outperform novices on tests for perceptual-cognitive skills such as anticipation, decision making and pattern recall. However, the developmental trajectory of these perceptual-cognitive skills has received limited attention. Therefore, this study examined the development of anticipation, decision making and pattern recall in 202 female volleyball players aged between 7 and 26 years old. Participants were categorized into six age groups: U9, U11, U13, U15, U17 and Seniors. Using a video-based occlusion protocol, we assessed participants' ability to predict pass direction, decide the most optimal attack zone, or recall the opponents' defense positions. Results demonstrated that U17 and adult players had superior accuracy and shorter response times than younger players on all three tests. Notably, U9 players performed worse than older players on all tests. Binominal distributions showed that decision making was above chance for U17 players and adults, whereas anticipation was above chance for almost all players. Our findings indicate that age-related improvements of perceptual-cognitive skills are evident at 11 years old. However, decision making seems to develop considerably later than anticipation and pattern recall, suggesting different developmental trajectories for the different perceptual-cognitive skills. Longitudinal research regarding the development of perceptual-cognitive skills and their underlying mechanisms is warranted, as this could have important implications for talent detection and development.

Keywords: perceptual-cognitive function, decision making, pattern recall, anticipation, development, team sports

Abstract word count

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1. Introduction

In the dynamic and constantly changing environment of team sports such as volleyball, athletes have to process a substantial amount of information under severe time constraints and make split-second decisions to generate timely responses. While young athletes often seem to struggle with these severe time constraints, it is often said that expert athletes seem to "have all the time in the world" to execute their responses (Bartlett, 1947). Interestingly, though, it has been demonstrated that this advantage is not just a matter of supra-normal reaction times (Ando, Kida, & Oda, 2001; Helsen & Starkes, 1999; Vaeyens, Lenoir, Williams, & Philippaerts, 2007). Instead, this expertise seems to be based on superior domain-specific perceptual-cognitive skills, which enable individuals "to identify and process environmental information for integration with existing and ongoing knowledge to facilitate response selection" (Roca & Williams, 2016). Previous research has mainly focused on three important perceptual-cognitive skills: pattern recall/recognition, anticipation and decision making (Abernethy, Baker, & Côté, 2005; Roca, Ford, McRobert, & Williams, 2011; Runswick, Roca, Williams, McRobert, & North, 2019; Vansteenkiste, Vaeyens, Zeuwts, Philippaerts, & Lenoir, 2014). However, while several studies have described the differences between adult experts and novices, literature on the development of these perceptual-cognitive skills is scarce, and the few studies that have investigated this issue have exhibited seemingly contradictory results (Ward & Mark Williams, 2003; Weissensteiner, Abernethy, Farrow, & Müller, 2008).

Since de Groot (1965) and Chase and Simon (1973) first indicated that pattern recall skill discriminated experts from novices in chess, several studies concerning pattern recall in other sports have followed. It has been demonstrated that adult elite athletes are able to recall and recognize structured, but not unstructured patterns of play more accurately than their sub-elite or novice counterparts in numerous sports (e.g., basketball, field hockey, soccer and volleyball), thus indicating that pattern recall and recognition might be partly domain-specific skills (Abernethy et al., 2005; Borgeaud & Abernethy, 1987; van Maarseveen, Oudejans, & Savelsbergh, 2015). Pattern recognition usually requires players to make a familiarity judgement after watching a video clip of a typical game situation, i.e. indicate whether the pattern that is displayed on a screen has been previously displayed or not (Smeeton et al., 2003)[1]. Pattern recall on the other hand is commonly assessed by asking participants to watch a video clip of a typical game situation and indicate the position of a number of players on the

[1] Readers are referred to the work of North and colleagues for more detailed information on pattern recognition (North, Hope, & Williams, 2016; North, Ward, Ericsson, & Williams, 2011).

pitch from memory afterwards. While this skill has been widely investigated in adult athletes, only one study has considered it in youth athletes. Williams et al. (2003) found significantly better pattern recall performance for U13 and older soccer players compared with U11 and U9 players, potentially indicating that early adolescence is an important period for the development of this perceptual-cognitive skill.

Anticipation in sport concerns the ability to anticipate an opponent's action outcome. Expert athletes are able to anticipate an opponent's action outcome by obtaining and integrating information from two main sources: kinematic and contextual information (Cañal-Bruland & Mann, 2015; Smeeton, Hüttermann, & Williams, 2019; Williams & Jackson, 2019). Kinematic information can be extracted from the opponents' bodily movements, which is often referred to as postural cue usage. For example, skilled cricket batters can judge the type (e.g., full outswinger, full inswinger or short ball) of ball being bowled when only viewing the first phases of the bowler's actions, while lesser skilled batsmen are unable to make accurate judgments based on this limited kinematic information (Weissensteiner et al., 2008). However, even before the opponent's action unfolds, several non-kinematic or contextual information sources are available as well. These include for example playing patterns, exposure to an individual's preferences or even information about previous action outcomes (Cañal-Bruland & Mann, 2015) and can be used by expert athletes to generate timely and appropriate responses (Smeeton et al., 2019). Although different methods exist, anticipatory skill is usually assessed by displaying a video-clip of an opponent completing a typical action, in which either spatial or temporal occlusion is applied to assess where or when crucial information to predict action outcomes is being picked up. Using these techniques, superior anticipatory skills of experts compared to novices have been confirmed in a number of sports such as soccer, squash, tennis and volleyball (Abernethy, 1990; Piras, Lobietti, & Squatrito, 2014; Savelsbergh, Van der Kamp, Williams, & Ward, 2005; Vansteenkiste et al., 2014; Ward, Williams, & Bennett, 2002). Regarding the development of anticipatory skill, Weissensteiner and colleagues (2008) reported that while U20 cricket players were able to accurately anticipate ball type, U15 players did not possess the same well-developed anticipatory skills. A similar finding was reported by Abernethy (1988), who found that performance of 12, 15 and 18 year old tennis players was significantly less accurate than over 18 year old adults when having to predict ball landing locations in tennis. Only two studies have included groups of younger children. Williams and Ward (2003) found expert-novice differences for anticipation in soccer from as early as 7 years old, in a task where participants had to predict the outcome of an opponent's dribbling or passing action. Tenenbaum (2000), in contrast, found that skill-based differences in predicting ball landing location in tennis did not emerge until after 18 years old. In the main, therefore, it would seem there is some evidence that anticipation is characterized by a protracted development spanning the entire adolescence, but the actual course of this development remains unclear.

A third important perceptual-cognitive skill is decision making, which can be defined as the ability to select the next best move (e.g. whether to pass to a teammate or dribble towards the goal in a soccer game) (Vaeyens et al., 2007). Decision making has shown to be of great importance during sports performance as it directly influences game outcomes (Bar-Eli, Plessner, & Raab, 2011). Over the last decades, several researchers in different domains have tried to conceptualize decision making into a theoretical model. A number of these theories have also been applied to sports, with each theory capable of explaining a number of decision-making problems that exist in sports, albeit under a different approach (e.g., simple heuristic theory, decision field theory, ecological dynamics; for an overview, see Bar-Eli et al., 2011; Raab, Bar-eli, Plessner, & Araújo, 2019). While different methods for decision making assessment exist (Marasso, Laborde, & Bardaglio, 2014), decision making is generally measured by displaying sport specific videos occluded at a certain point of interest. Athletes are then requested to select the best possible decision by means of a button press, verbal report or even by performing a sport specific movement (Piggott et al., 2019). In this respect, it has been demonstrated that expert athletes outperform novices in quickly selecting the most appropriate response (i.e. leading to the highest chance of success) in various sport-specific situations in team sports as well as racquet sports (Roca, Ford, McRobert, & Williams, 2013; Tenenbaum, Sar-El, & Bar-Eli, 2000; Vaeyens et al., 2007). To our knowledge, however, age-related changes in decision making performance in youth athletes of a broad age range, have not been investigated yet.

In summary, there is an abundance of evidence that adult expert athletes in fast and dynamic (team) sports demonstrate superior perceptual-cognitive skills, and that these skills seem to be one of the key determinants for expert performance. However, there have been very few studies on the development of perceptual-cognitive skills across the entire adolescence. A few studies have tried to retrospectively analyze the developmental activities during childhood and adolescence that contribute to expert perceptual-cognitive skill (Ford, Low, & Mcrobert, 2017; Ford & O’Connor, 2019; Roca, Williams, & Ford, 2012; A Mark Williams, Ford, Eccles, & Ward, 2011). While these studies provide valuable information about the influence of different kinds of sport-specific and non-sport-specific practice and play, they do not provide any information on the rate and timing of the development of perceptual-cognitive skill. Moreover, no single study has assessed these three key perceptual-cognitive skills directly in the same sample of youth players. This is an important omission given that some studies suggest pattern recall, anticipation and decision making are related to some degree in adult athletes (Roca & Williams, 2016; Williams & Jackson, 2019). Investigating all three skills in a large sample of youth athletes will allow to study the similarities and differences in the developmental trajectory of these three skills. Here, then, we examined sport-specific, video-based tests of anticipation, decision making and pattern recall in a young female volleyball players between 7 and 17 years old. An adult group that performed the same tasks was included for comparison. The first aim was to investigate cross-sectional differences between age groups, covering a uniquely broad age-range encompassing a part of childhood, the entire adolescent period, and early adulthood. The second aim was to determine at what age young volleyball players' ability to accurately anticipate an opponent's action, recall typical patterns of play and make correct decisions emerges, and at what age they are able to match adult athletes' abilities on these skills.

2. Methods

2.1. Participants

A total of 202 female volleyball players between 7 and 26 years old participated in this study. The youth players (7 to 17 years old) were recruited in two Flemish volleyball clubs that received a 4 out of 5-star ranking from the federation youth sports fund 2018, which ensured their youth development quality. The adult players (21 to 26 years old) were recruited from all levels of the Belgian volleyball competition. To investigate development, the participants were divided into 6 age groups: U9, U11, U13, U15, U17 and Seniors. Table 1 displays the average age, average years of experience and average amount of training for each group.

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.

2.2. Test development & procedures

Three video-based occlusion tests were developed for this study, each one designed to measure one of the three perceptual-cognitive skills mentioned above. All videos were recorded on a volleyball court with a high definition digital camera (Sony HDR-CX240e, Tokyo, Japan) with a filming rate of 30 FPS. The camera viewpoint varied between the three different tests, as each test was designed to measure a different perceptual-cognitive skill and required a different perspective. All players on the recordings were adult skilled players who received detailed instructions about where to stand, and which action to perform prior to filming the video sequences. A panel of three certified youth coaches with extensive experience assisted in deciding on the content and the structure of the video clips for each test to ensure face validity of the test.

2.2.1. Anticipation

For the anticipation test, the camera was placed in the center of the back of the field, at 1.30m above the ground. The video clips showed a free ball being tossed to the back defender on the opposing side, who played the ball perfectly to the setter’s position. The setter would then pass the ball to one out of four options: (1) long backwards pass to the outside spiker, (2) short backwards pass to the middle spiker, (3) short forward pass to the middle spiker, (4) long forward pass to the other outside spiker. Only the clips in which the setter received the ball perfectly and was able to play all options were used in the study. Around the time of the set-up, the video was occluded (i.e., a black screen was presented) in accord with three progressive temporal occlusion conditions, further referred to as viewing conditions (Abernethy & Russell, 1987). These three viewing conditions were selected together with the panel of expert coaches, based on the kinematic movement pattern of a volleyball set. The critical moments in this movement pattern are the actual reception of the ball (first ball contact) and the wrist movement that follows to give direction, implying that little to no important cues will be available before the ball contact of the setter in a perfect situation. Therefore, the decision was made to occlude the videos either at the moment of reception (i.e. at ball contact, OCC 0), right after direction is given with the wrists just before ball release (i.e. 33 ms after ball contact, OCC 33), and just after ball release, when initial ball flight information becomes available as well (i.e. 100ms after ball contact, OCC 100). Participants were asked to indicate as fast and as accurately as possible which of the four passing options was executed by the setter by pressing the corresponding button on the keyboard, using only their two index fingers. Participants first received an explanation of the tests, including a familiarization clip and two practice trials. During the test, a total of 40 clips were shown and each clip lasted about 3 to 5 seconds, with "ready?" being shown for three seconds prior to each clip. All clips were shown in a random order that differed for each participant, after each clip, participants had 5 seconds to respond. A screenshot of the test is provided in figure 1.

2.2.2. Decision making

The decision making test consisted of 4 viewing conditions, each involving a different number of opponents: (a) "2x2", 2 opponents, (b) "3x3", 3 opponents, (c) "4x4", 4 opponents and (d) "6x6", opponents. These different viewing conditions were included to provide a suitable stimulus for each stage of development (Marasso et al., 2014). This way, each age group would be able to experience at least one viewing condition at their own playing level, and floor as well as ceiling effects would be minimized. The full game (i.e. 6x6) is played from U15 onwards, and the U9, U11 and U13 play 2x2, 3x3 and 4x4 respectively. However, these last three playing forms are often incorporated in practice across all ages, and thus not unfamiliar to older groups. Furthermore, while the number of opponents and field size differs between the different playing forms, the game rules are the same across all playing forms in youth and adult volleyball.

The camera was placed approximately 2.20m above the ground (on top of a referee chair) and behind the spiker (i.e. the attacking player) to simulate the spiker's viewpoint. The video clips showed the spiker's team developing an offensive sequence and the other team's defense taking positions. The end positions of the defense players were predetermined, and the players participating in the clips knew exactly where to stand as small marks were placed on the court to indicate their positions. These marks were not visible on the test film so participants would not notice this. The players in the video clip would start in neutral or home position, and then position themselves in the correct defense positions as soon as the setter of the opposing team sets the ball. A black screen was presented two frames (i.e., 66 ms) before the spiker's ball contact, while the defense was already in position. Setting the occlusion time at 66 ms before ball contact minimized the possibility that participants were influenced by the actual decision made by the spiker in the videos. Participants were asked to imagine being the spiker and to indicate which zone in the field would render the highest possibility of scoring a point by pressing the corresponding button on the keyboard as quickly and as accurately as possible (using their index fingers). They were also told that the actions of the spiker did not necessarily represent the best choice, and that they should focus on their response regardless of the actions of the spiker. Participants first received an explanation of the tests, including a familiarization clip and two practice trials. They received a new familiarization clip before each new condition, as the size of the field, number of players and number of zones to choose from would change. For the first two conditions (2x2 and 3x3), participants could choose from 6 zones, while for the last two conditions (4x4 and 6x6) participants could choose from 9 zones, as shown in figure 2. Each clip lasted approximately 5 seconds, preceded by "READY?" being shown in the center of the screen for 3 seconds. After each clip, participants had 5 seconds to respond. All participants completed the different viewing conditions in a fixed order: 2x2, 3x3, 4x4 and 6x6. Within one viewing condition, clips were shown in a random order that differed for each participant. Table 3 provides an overview of the number of opponents, the size of the field, the number of zones to choose from and the number of clips in the test for each level or viewing condition, and a screenshot of the test is provided in figure 3.

2.2.3. Pattern recall

The content of the video clips for the pattern recall test was exactly the same as the content in the decision making test, including the four different viewing conditions. However, for the pattern recall test, the clips were filmed from the back defender's viewpoint, meaning that the camera was placed in the center of the field near the back line, at 1.30m above the ground. For this test, participants had to mark the spot of each defender by putting an 'x' on a print-out version of the court (see figure 4), after the screen went black at ball contact of the spiker. The size of the field on the print-out versions was scaled 1:100, so 1 meter on the field was 1 centimeter on paper. Participants were instructed to place their 'x' as accurate as possible, no instructions about speed were given. Participants first received an explanation of the tests, including a familiarization clip and two practice trials. They received a new familiarization clip before each new condition, as the size of the field and number of players would change. All participants completed the different viewing conditions in a fixed order: 2x2, 3x3, 4x4 and 6x6. Within one viewing condition, clips were shown in a random order that differed for each participant. After each clip, participants had 12 seconds to draw their marks before the next clip started, when they were ready before that, they could manually proceed to the next clip. A screenshot of the test is provided in figure 5.

All three tests were completed within one test session. Participants either started with the pattern recall or decision making test, and always completed the anticipation test second to minimize any recall effect between the pattern recall and decision making clips. Each test session lasted about 45 minutes. After the test session, the participant or the participant's parents received an online questionnaire for information on age and experience.

2.3. Apparatus

The video clips were back projected, using a LED video projector (LG PH550G, Seoul, South Korea) with HD resolution onto a 1.07m (w) x 0.6m (l) projection screen. The projector was placed 1.5m from the screen on a table, while the subjects were placed behind the table at 2.00m from the screen (see figure 6). To facilitate immersion in the volleyball game that was displayed, participants would be standing up for the anticipation and decision making tests. However, to enable easy writing in the pattern recall test, participants were seated at the table for that test. The participant's responses for the anticipation and decision making tests were recorded using a standard Dell keyboard with a wired USB connection. OpenSesame software was used to display the videos and record the participant's responses(Mathôt, Schreij, & Theeuwes, 2012). This software is designed specifically for behavioral experiments and allows for efficient stimulus presentation with sub-millisecond timing[2].

[2] All standard keyboards are subject to timing lag. According to Damian (2010) the average lag caused by keyboards in scientific experiments is around 30ms, and Luu (2017) concluded that the variation in human performance is considerably larger than any variation due to response device imprecision. Software packages can also cause lag, and for OpenSesame, Bridges et al. (2020) showed that, for onset of visual stimuli and response times, timing lag in OpenSesame is minimal (3.85 ± 0.7 ms for visual onset and 8.27 ± 1.22ms for response time measurement).

2.4. Outcome Variables

2.4.1. Anticipation

Response Accuracy (RA). The percentage of trials where the participant correctly predicted the pass direction was calculated per viewing condition and across all trials for each participant.

Response Time (RT). The time between the moment the setter received the ball and the participant's keyboard press was calculated in milliseconds. For each participant, mean RT was calculated per viewing condition as well as the mean RT across all trials.

2.4.2. Decision Making

Response Accuracy (RA). Percentage of trials where the participant chose the best option. To decide which zone(s) in the field would render the highest chance of scoring a point, a panel of three expert coaches all judged every scenario and decided in the optimal zone of the field i.e. the zone in which scoring was almost certain. Only the trials where all three coaches agreed were used in the test. Accordingly, RA represents the percentage of trials where the participant chose the optimal zone and thus made the most appropriate decision. The percentage of trials where the participant made the most appropriate decision was calculated per viewing condition and across all trials for each participant.

Response Time (RT). The time between the end of the video and the participant's keyboard press was calculated in milliseconds. For each participant, mean RT was calculated per viewing condition as well as the mean RT across all trials.

2.4.3. Pattern Recall

RE (Radial Error). Print-outs were scanned and digitized using a custom-made script in Matlab. The radial distance (RD) of the reported location and actual location was computed for each player, using the following formula:

$$RD = \sqrt{(x_0 - x_1)^2 + (y_0 - y_1)^2},$$

where (x_0, y_0) and (x_1, y_1) are the coordinates of the actual and reported location, respectively. The RDs of all players were then averaged, and scaled to the length of the diagonal of the field to allow comparison across the different small-sided games. For each participant, mean RE was calculated per viewing condition as well as the mean RE across all trials.

2.5. Data analysis

Before performing other analyses, data was checked for a possible speed-accuracy trade-off on the decision making and anticipation task. Significant negative correlations were found between response time (RT) and response accuracy (RA) in both instances ($r_{DM} = -0.610$, $p < 0.001$; $r_{ANT} = -0.492$, $p < 0.001$), indicating that quicker responses tend to be associated with a better accuracy, and not the other way around. This implies that there is no indication for a speed-accuracy trade-off in this study (Liesefeld & Janczyk, 2019). Although no a priori power analyses were conducted, it is relevant that the sample size of the current study was approximately double that of previous similar studies investigating the development of perceptual-cognitive skill (Abernethy, 1988; Tenenbaum et al., 2000; Weissensteiner et al., 2008). Moreover, post hoc power analyses were conducted to assure that non-significant effects were not due to insufficient sample size.

RA and RT on the decision making and anticipation tests, as well as radial error (RE) on the pattern recall test, were analyzed separately using a mixed factor ANOVA in which age group was the between-participants factor and viewing condition the within-participants factor. The sphericity assumption for repeated measures ANOVA was checked using Mauchly's test of sphericity, and if violated, the Greenhouse-Geisser correction procedure was used to adjust the degrees of freedom. Significant effects were followed up using pairwise comparisons based on the estimated marginal means and Bonferroni post hoc tests. The level of significance was set at $p < 0.05$.

Furthermore, we assessed whether participants demonstrated above-chance performance for decision making and anticipation based on a binomial distribution, i.e. taking into account the probability of success on a single trial and the number of trials per condition. When performance is significantly above chance ($p < 0.05$) according to binomial distributions, it can be assumed with 95% certainty that the participant was not guessing. This was done for each individual participant in order to then calculate the percentage of participants that scored significantly above chance in each age group. To reduce the risk of making Type I errors, the Benjamini & Hochberg correction was applied to the initial alpha level ($p < 0.05$) to control for the false discovery rate (for an overview see Benjamini, Drai, Elmer, Kafkafi, & Golani, 2001; Cramer et al., 2016). The above-chance percentages are reported relative to the adjusted alpha level.

3. Results

3.1. Anticipation

Response Accuracy: ANOVA. The results are presented in Figure 7. Significant effects were found for age group, $F(5,196) = 43.34, p < 0.001, \eta_{p^2} = 0.52$, occlusion condition, $F(1.94, 380.51) = 226.08, p < 0.001, \eta_{p^2} = 0.45$, and the age group x occlusion condition interaction, $F(9.71, 380.51) = 8.42, p < 0.001, \eta_{p^2} = 0.18$. Post hoc tests revealed that the U9 and U11 groups were less accurate than all other groups on all conditions, except for the OCC 100 condition, where the U11 showed similar accuracy levels compared to the U13 and the U15 groups. The U17 and adult groups outperformed all groups on the OCC 0 and OCC 33 condition, but only outperformed the U9 and U11 groups on the OCC 100 condition. All groups' accuracy significantly increased from the OCC 0 to OCC 33 conditions, but only the U9 and U11 groups showed an increase in accuracy from the OCC 33 to the OCC 100 condition.

Response Accuracy: Above Chance Performance. Table 3 shows the percentage of participants who scored above chance per age group and per condition. It can be seen that the number of participants scoring above chance increases gradually with increasing age, reaching the maximum of 100% in the U17 and Senior groups. From U13 onward, more than 90% of the participants scored above chance on the OCC33 and the OCC100 condition, while on the OCC0 condition, it is only from U17 onward that more than 90% of the participants scored above chance.

Response Time. Significant effects were found for age group, $F(5,196) = 29.48, p < 0.001, \eta_{p^2} = 0.43$, and occlusion condition, $F(2,392) = 4.56, p = 0.011, \eta_{p^2} = 0.02$, but not for the age group x occlusion condition interaction. Post hoc tests (see figure 8) revealed that the U9, U11 and U13 groups were slower than all other groups, regardless of condition. The U17 and adult groups were faster than all other groups. Participants showed significantly slower response times on the OCC0 condition compared to the OCC100 condition, regardless of age group. Response times did not differ between OCC0 and OCC33, and between OCC33 and OCC100.

3.2. Decision Making

Response Accuracy: ANOVA. The results are presented in Figure 9. Significant effects were found for age group, $F(5, 196) = 34.37, p < 0.001, \eta_{p^2} = 0.47$, viewing condition, $F(2.76, 541.14) = 213.74, p < 0.001, \eta_{p^2} = 0.52$, and the age group x viewing condition interaction, $F(13.80, 541.14) = 4.09, p < 0.001, \eta_{p^2} = 0.09$. Post hoc tests revealed that the U17 and adult groups made significantly more accurate decisions than all younger groups on all viewing conditions, and that the youngest players (U9) made significantly less accurate decisions than all other groups except U11. Decision making accuracy of all groups except U9 was significantly differed between the viewing conditions, with the highest accuracy in the 2x2 viewing condition and the lowest accuracy in the 4x4 viewing condition.

Response Accuracy: Above Chance Performance. Table 4 shows the percentage of participants who scored above chance per age group and per condition. Overall, there seems to be a gradual increase in number of players scoring above chance, with very low numbers in the youngest and up to 94% in the oldest age groups. The largest increases across age groups can be seen in the 2x2 and 6x6 condition. Furthermore, in that last condition, 57% of U17 players score above chance, while for the adult group, almost all players (94%) score above chance.

Response Time. The results are presented in Figure 10. Significant effects were found for age group, $F(5, 196) = 31.35, p < 0.001, \eta_{p^2} = 0.44$, viewing condition, $F(2.64, 517.70) = 30.98, p < 0.001, \eta_{p^2} = 0.14$, and the age group x viewing condition interaction, $F(13.21, 3.12) = 3.11, p < 0.001, \eta_{p^2} = 0.07$. Post hoc tests revealed that the U9 group was slower than all other groups on the 3x3 and 6x6 conditions, and that the adult group was significantly faster than all other groups in all viewing conditions except 4x4. There were no differences in response times between U11, U13 and U15 groups on any of the viewing conditions. For all groups except the U9 group, response times significantly differed between viewing conditions, with the slowest response times for the 4x4 viewing condition.

3.3. Pattern Recall

Radial Error. The results are presented in Figure 11. Significant effects were found for age group, $F(5, 191) = 60.642, p< 0.001, \eta_{p^2} = 0.61$, viewing condition, $F(2.83, 545.30) = 229.347, p<0.001, \eta_{p^2} = 0.55$, and the age group x viewing condition interaction, $F(14.17, 541.37) = 5.501, p < 0.001, \eta_{p^2} = 0.13$. Post hoc tests revealed that the U9, U11 and U13 groups were less accurate than the older groups on all viewing conditions, except for the 2x2 conditions, where the U13 group reached similar accuracy levels compared with the older groups. All groups showed a decrease in radial error with an increasing number of opponents on the field except the U9 and U11 groups, where the radial error in the 2x2 condition was smaller than in the 3x3 condition.

Post hoc power analysis showed that, for all investigated effects (i.e. all main and interaction effects), a power of 1.00 was observed, indicating that the risk of type II errors (i.e. false negatives) is minimized, and that it is unlikely that non-significant effects were due to insufficient sample size. The reason for this high observed power is the strong within-participants design with highly correlated within-conditions ($r = 0.92$ for anticipation, $r = 0.72$ for pattern recall and $r = 0.88$ for decision making), as well as the large sample size with on average 30 participants per group, all contributing to the assumption that the sample size of the current study was indeed sufficient to detect even the smaller effect sizes with a high degree of statistical significance ($p < 0.001$ for almost all effects).

4. Discussion

The current study aimed to explore the developmental trajectory of three different perceptual-cognitive skills in youth volleyball players. Proficiency levels of decision making, pattern recall and anticipation were assessed in 202 female volleyball players aged between 7 and 26 years old. In general, the results indicate that performance on all three perceptual-cognitive skills increases with participant age. More importantly, increases in performance seem to emerge as early as 10 years old, with U11 players already showing better performance than U9 players, and even a small proportion of U9 players showing above-chance performance. Although all three skills demonstrate this early onset of development and a clear increase in performance with increasing age, a number of distinct differences between the developmental trajectories of anticipation, pattern recall and decision making are observed.

While some studies have suggested that anticipation develops relatively late (i.e. in late adolescence/early adulthood) (Abernethy, 1988; Tenenbaum et al., 2000; Weissensteiner et al., 2008), our results demonstrated that the majority of U9 and U11 players already show above-chance accuracy, and are thus capable of predicting set-up direction when provided with initial ball flight information (i.e. OCC100 condition). The finding that the majority of U9 and U11 players (78% and 80%) are able to use ball flight information to predict the future ball trajectory is consistent with work by Benguigui, Broderick and Ripoll (2004) suggesting that the maturation of motion prediction capabilities occurs around the age of 10 (Benguigui, Broderick,

& Ripoll, 2004). In another study, Benguigui and colleagues also demonstrated that children as young as 7 years use adult-like strategies to extrapolate the trajectory of an occluded object (Benguigui, Broderick, Baurès, & Amorim, 2008). Similarly, the majority of the 7 and 8 year old participants in the current study were capable of predicting pass direction and length when initial ball flight information was available. However, when only kinematic information from the opponent's bodily movements was available, as in the OCC 0 condition, U9 and U11 players generally failed to reach above-chance accuracy. That said, 17% and 36% of the U9 and U11 players did show above-chance performance when provided with this limited information. This emphasizes the importance of taking into account individual developmental trajectories with regard to talent identification and talent development, although further research is required to examine whether these participants are also more likely to outperform their peers on a later age.

In contrast with the U9 and U11 players, the U15 and older players do not seem to benefit from the additional ball flight information provided in the OCC100 condition. Neither response times nor accuracy levels of the older groups are affected by the availability of ball flight information, indicating that players gain sufficient information from early kinematic information. Combined, these findings may suggest a shift in strategy to anticipate the set-up length and direction, where players base their anticipatory judgements on the kinematic information from the setter, and consequently do not need or use initial ball flight information. This demonstrates well-developed anticipatory skills already being present in U15 players, which seems to contradict the findings of Weissensteiner and colleagues, where U15 cricket players were unable to predict the type of ball being bowled based on kinematic information from the bowler (Weissensteiner et al., 2008). However, our results are in line with the findings of Williams and colleagues in soccer, demonstrating that even young players are already capable of accurately anticipating an opponent's next move (Ward & Mark Williams, 2003). In fact, with 100% of the U17 group in the present study showing above chance performance, and the U17 group demonstrating adult-like levels of performance on the majority of measures for speed as well as accuracy, our results suggest that the development of anticipation might already level off around the age of 16. This seems to challenge the hypothesis by Tenenbaum and colleagues that skilled anticipation tends to develop mainly around early adulthood (Tenenbaum et al., 2000).

Pattern recall also seems to develop mainly during adolescence. Our findings show that pattern recall skill reaches a plateau somewhere between U15 and U17, with both groups showing adult-like performance, which seems to be slightly earlier than anticipation. Furthermore, while calculating chance levels is not possible due to the characteristics of the pattern recall test, the relative radial errors up to 25% of the size of the field in the U9 and U11 groups indicate that they are not capable of making accurate judgements on player positions, as these errors are twice as big as those in the U17 and adult groups. In fact, qualitative inspection of the responses in these younger groups demonstrated a lack of depth translation, as all player position marks were placed near the net. The reduction in radial error in U13 players compared to U9 and U11 does, however, indicate a remarkable improvement in the capacity of recalling structured patterns of play around the age of 12. These findings are again in line with the results of Williams and colleagues, who also found significant increases in recall accuracy from U13 onwards, suggesting an important developmental phase for pattern recall skill during adolescence. Interestingly, this improvement in pattern recall performance coincides with rapid development of both working memory capacity as well as processing speed, two essential factors for pattern recall (Fry & Hale, 2000; Huizinga, Dolan, & van der Molen, 2006). However, it is worth noting that the task requires more than memorizing a number of random locations in a single plane as assessed in typical working memory tasks. Previous research has shown that experts outperform novices in recalling structured, but not unstructured patterns of play (Borgeaud & Abernethy, 1987). Increasing the number of players on the field automatically requires a more structured playing pattern in order to optimally organize the defense strategy. Therefore, a more pronounced structure in combination with integration of information on relations between players provides a plausible explanation for the superior performance in the viewing conditions with a higher number of players on the field, and indicates that pattern recall might be a domain-specific skill. This is also in line with the findings from North and colleagues (2009) with regard to pattern recognition, where they demonstrated that experts indeed use this relational information between players to make familiarity judgement on playing patterns (North, Williams, Hodges, Ward, & Ericsson, 2009). The present results, showing a reduction in radial error with increasing number of players from U13 onwards, indeed seem to indicate that the participants use this knowledge about structured patterns of play in volleyball. Hence, while pattern recall seems to start its development slightly later than anticipation, this skill shows a rapid development during early adolescence and an early plateau around 14-15 years old.

Lastly, the developmental improvements in decision making seem to begin considerably later than those in anticipation and pattern recall. In fact, individual player results indicate that, even though the majority of U13 players demonstrate above chance performance in the relatively easy 2x2 condition, less than 30% of the younger players (U9 to U15) and only 57% of the U17 players are able to select the best action above chance in the more challenging 6x6 condition. This is substantially less than the 94% of adult players demonstrating above-chance performance in this condition. However, the fact that U17 players are on average as accurate as the adult participants on all conditions does indicate the presence of well-developed decision making skills in a proportion of U17 players, which was also demonstrated by Vaeyens and colleagues in soccer (Vaeyens et al., 2007). Nevertheless, while adults' decision making accuracy is on average not superior to the accuracy of the U17 group, they do demonstrate significantly faster response times in almost all conditions. The fact that U17 players show inferior performance compared to adult players with regard to the temporal component of decision making abilities highlights the protracted development of this skill. The late onset of the development of decision making is supported by the fact that less than 30% of the players in younger groups (i.e. U15 and younger) demonstrate above-chance performance in the 4x4 and 6x6 condition, illustrating that the majority of participants in these groups are not yet capable of accurately selecting the optimal decision in more challenging situations. Hence, in contrast to anticipation and pattern recall, decision making seems to improve mainly in late adolescence and continues to develop into adulthood. These findings seem to be consistent with the suggestion that pattern recall and anticipation underpin skillful decision making (Roca & Williams, 2016). Furthermore, the complexity of this skill might provide a plausible explanation for its late development compared to anticipation and pattern recall.

With respect to the decision making test, an interesting finding was the low accuracy in the 4x4 condition for all groups. Even in the U17 and Senior groups, less than 30% of the players show above chance performance. The possible explanation for this inferior performance in the older groups is twofold. Firstly, 4x4 is an uncommon and unfamiliar playing pattern and only the U13 play competition in this format. Secondly, with only 4 players defending 9 zones, larger spaces are left undefended than in the 6x6 condition, which makes decision making more difficult in a 4x4 condition. The finding that the U9 players do not show this drop in performance in the 4x4 condition perhaps supports the notion that they are not acquainted with the typical structured patterns of play, which indicates that decision making, like pattern recall, seems to be a highly domain-specific skill in which relational information and structure of patterns play an important role.

Together, our findings from volleyball athletes suggest that the ability to accurately anticipate an opponent's next move is the first perceptual-cognitive skill to reach above chance accuracy levels at the age of 11. This is followed by the ability to accurately recall structured patterns of volleyball play at age 13. The ability to select the next best move emerges last, around the age of 16. Next to the fact that different perceptual-cognitive skills might be underpinned by different mechanisms (Gorman, Abernethy, & Farrow, 2015; Roca et al., 2013), the order in which players seem to reach above chance and adult-like accuracy levels might also reflect the complexity of the task, and associated with that, the amount of information processing required. The anticipation task requires information to be processed on the kinematics of one player only, while the pattern recall and decision making tasks require information on two to six players, depending on the viewing condition. In addition, while participants might be presented with the same amount of information in the latter two tasks, pattern recall merely demands recalling player positions, whereas decision making involves additional analysis of player positions in order to decide where best to play the ball. Another difference between the pattern recall and decision making task relates to the time constraints. While the participants were allowed to take all the time they needed during the pattern recall test, the decision making test was to be executed as fast as possible, thus imposing a strict time constraint. Thus, the decision making task was arguably more complex than pattern recall, and might have required more advanced development of this skill in order to reach adult levels. Generally, these findings highlight that perceptual-cognitive skill development is characterized by a period of accelerated adaptation in early adolescence (between 10 to 13 years old), which continues to improve into adulthood.

Although the combination of three perceptual-cognitive skills tests on a sample of young athletes within a very broad age range is unique and provides much needed insight, a few limitations of this study should be acknowledged. Firstly, cross-sectional studies provide only indicative evidence when it comes to developmental changes, whereas longitudinal studies provide more compelling insight into this matter. Secondly, the method (video-based) may be considered as a less ecologically valid approach because perception and action are “uncoupled” (Araùjo, Davids, & Hristovski, 2006; Travassos, 2012) That said, a number of studies have shown that the results from such laboratory-based tasks are indeed replicable in a natural setting (Abernethy, Gill, Parks, & Packer, 2001; Farrow & Abernethy, 2002; Farrow, Abernethy, & Jackson, 2005). Moreover, using laboratory-based tasks enables researchers to accurately compare groups of participants under standardized and reproducible test conditions(Williams, Fawver, & Hodges, 2017). A similar comment holds for the design of this study. Presenting all playing conditions to all age groups, may be perceived as somewhat “artificial”. As addressed in the methods section, this was largely done to provide a feasible task for each age group. Furthermore, this design allowed better comparison across age groups. Also, we do acknowledge that the results are influenced by familiarity with a given form of play and/or the player's action capabilities at a certain age and the results should be interpreted with this in mind. Another important limitation of this study is that no detailed account of practice history of the participants was available. The nature of practice is likely to be different for the different age groups. For example, U9 and U11 training will be focused more on technique, thereby developing knowledge about the kinematics of different techniques and possibly enabling anticipation development, while U17 practice might focus more on tactical aspects of the game and facilitate decision making development. Future research should incorporate this information to gain insight in the influence of practice modalities and developmental activities on perceptual-cognitive skill development. Finally, it is important to remark that this study used chronological age to study development, not biological age. This might have obscured some of the findings, as the biological maturation of certain brain regions might influence perceptual-cognitive skill development (Gerván, Soltész, Filep, Berencsi, & Kovács, 2017; Wright, Bishop, Jackson, & Abernethy, 2010). However, studies have shown that the average difference in neuroanatomical maturation between individuals of the same chronological age is limited to roughly 1 year for individuals between 12 and 20 years old, and even less for younger children (Brown et al., 2012). Since the age categories in the present study spanned 2 years in chronological age, differences in biological age are not likely to greatly affect our findings.

In conclusion, the current study shows that perceptual-cognitive skills of youth team volleyball players increase throughout adolescence, and moreover that there are early signs of differentiation in anticipation around 10 years of age. Individually mapping the development of anticipation, pattern recall and decision making skills in the same sample of participants represents an important departure away from the typical focus on adult experts towards the promising young athlete. It is envisaged that this approach will allow for more detailed and in-depth knowledge on the nature, underlying mechanisms and development of expert perceptual-cognitive skill, which could ultimately impact upon elite performance in sports.

Disclosure of Interest

The authors whose names are listed above certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Tables

Age Group	Mean Age (SD) (in years)	Mean Experience (SD) (in years)	Amount of training per week (SD) (in minutes)	n
U9	8.41 (0.90)	1.68 (0.99)	180.00 (104.5)	23
U11	10.13 (0.64)	2.39 (1.57)	245.00 (24.49)	25
U13	11.65 (0.76)	3.75 (2.00)	288.65 (59.73)	37
U15	13.59 (0.78)	4.29 (2.47)	307.69 (66.27)	42
U17	15.63 (0.93)	6.45 (3.21)	326.15 (67.15)	42
Senior	23.66 (1.66)	14.63 (3.32)	309.09 (61.56)	33
TOTAL				**202**

Table 1. Average age, experience and amount of training for each age group.

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

Table 2. Overview of the characteristics of each viewing condition.

Viewing condition		OCC 0	OCC 33	OCC 100
Chance level: Probability (P)		P=25%	P=25%	P=25%
% of participants scoring above chance				
(p<0.05)	U9	17.4	65.2	78.3
	U11	36.0	64.0	80.0
	U13	70.3	91.9	97.3
	U15	76.2	92.9	95.2
	U17	100	100	100
	S	100	100	97

Table 3. Percentage of participants scoring above chance for each group on the anticipation test.

Viewing condition		**2x2**	**3x3**	**4x4**	**6x6**
Chance level: Probability (P)		**P=33%**	**P=22%**	**P=11%**	**P=14%**
	U9	8.7	4.3	4.3	13.0
	U11	32.0	24.0	4.0	16.0
	U13	62.2	40.5	5.4	13.5
	U15	66.7	33.3	14.3	28.6
	U17	76.2	61.9	26.2	57.1
	S	97.0	66.7	27.3	93.9

Table 4. Percentage of participants scoring above chance for each group on the decision making test.

Figure Captions List

Figure 1. Screenshot of the anticipation test.

Figure 2. Representation of the zones on the field for the decision making test.

Figure 3. Screenshot of the decision making test.

Figure 4. Response example for the pattern recall test.

Figure 5. Screenshot of the pattern recall test.

Figure 6. Schematic overview of the test set-up.

Figure 7. Response Accuracy (% correct) for the Anticipation test per Age Group per Viewing Condition

Note. Means for the same viewing condition with the same letter index are not significantly different at $p < 0.05$.

Figure 8. Mean Response Time (in ms) on the Anticipation test per Age Group.

Note. Means for the same viewing condition with the same letter index are not significantly different at $p < 0.05$.

Figure 9. Mean Response Accuracy (% correct) on the Decision Making test per Age Group and Viewing Condition

Note. Means for the same viewing condition with the same letter index are not significantly different at $p<0.05$.

Figure 10. Response Time (in ms) on the Decision Making test per Age Group per Viewing Condition.

Note. Means for the same viewing condition with the same letter index are not significantly different at $p<0.05$.

Figure 11. Radial Error (%) on the Pattern Recall test per Age Group per Viewing Condition.

Note. Means for the same viewing condition with the same letter index are not significantly different at $p<0.05$.

Figure 1

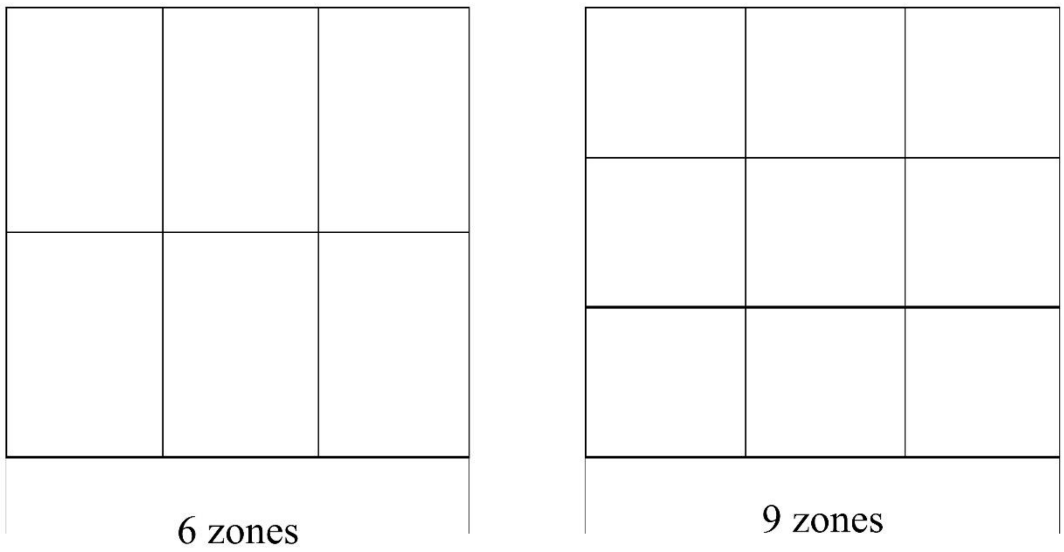


Figure 2

Figure 3

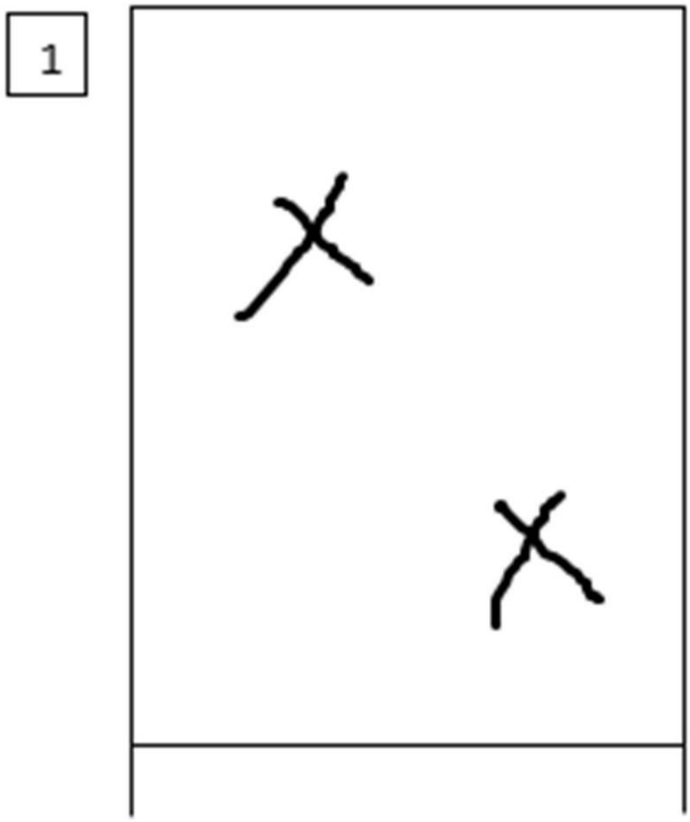


Figure 4

Figure 5

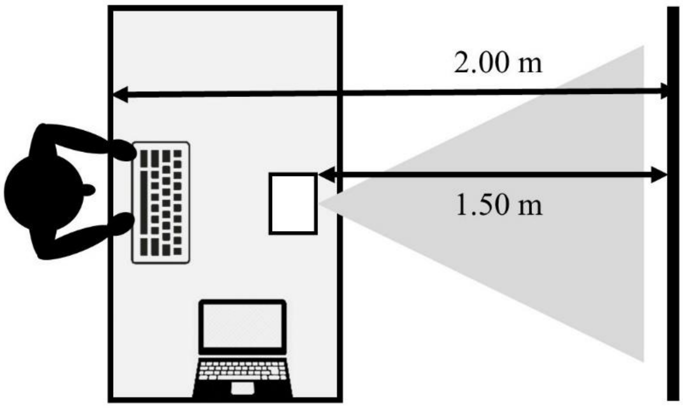
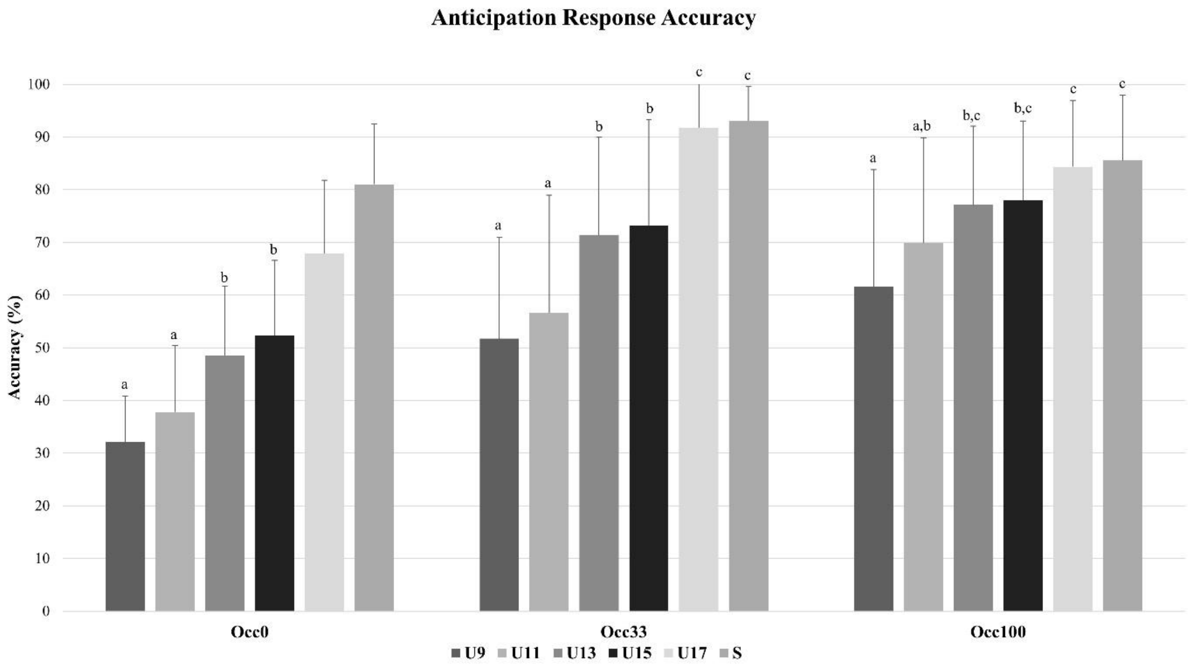


Figure 6



Anticipation Response Accuracy
Accuracy (%)
100
90
80
70
60
50
40
30
20
10
0
a
a
b
b
a
a
b
b
c
c
a
a,b
b,c
b,c
c
c
Occ0
Occ33
Occ100
U9
U11
U13
U15
U17
S

Figure 7

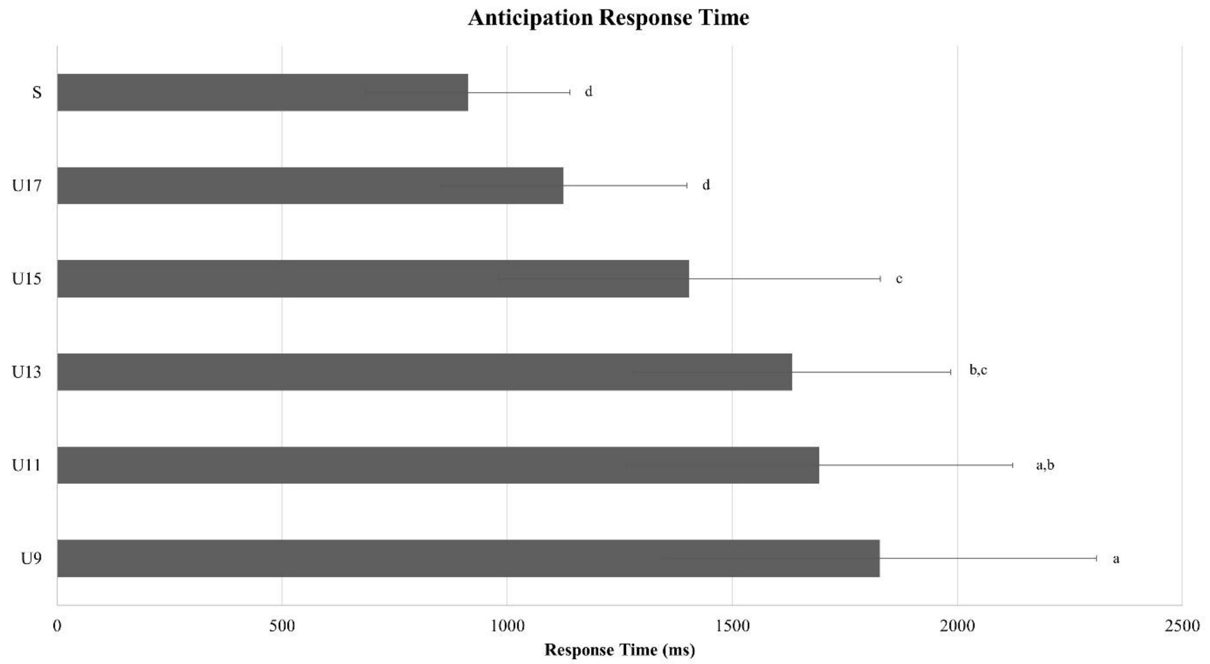
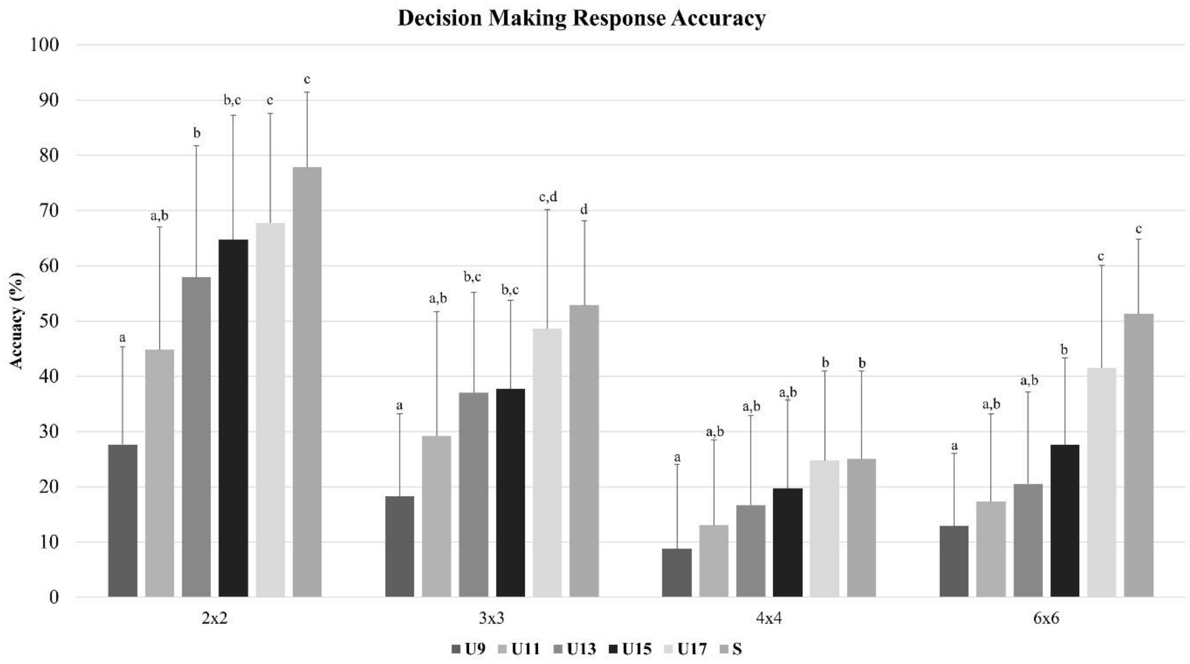

Anticipation Response Time
S
U17
U15
U13
U11
U9
d
d
c
b,c
a,b
a
0
500
1000
1500
2000
2500
Response Time (ms)

Figure 8



Decision Making Response Accuracy
Accuacy (%)
100
90
80
70
60
50
40
30
20
10
0
2x2
3x3
4x4
6x6
a
a,b
b
b,c
c
c
a
a,b
b,c
b,c
c,d
d
a
a,b
a,b
a,b
b
b
a
a,b
a,b
b
c
c
U9
U11
U13
U15
U17
S

Figure 9

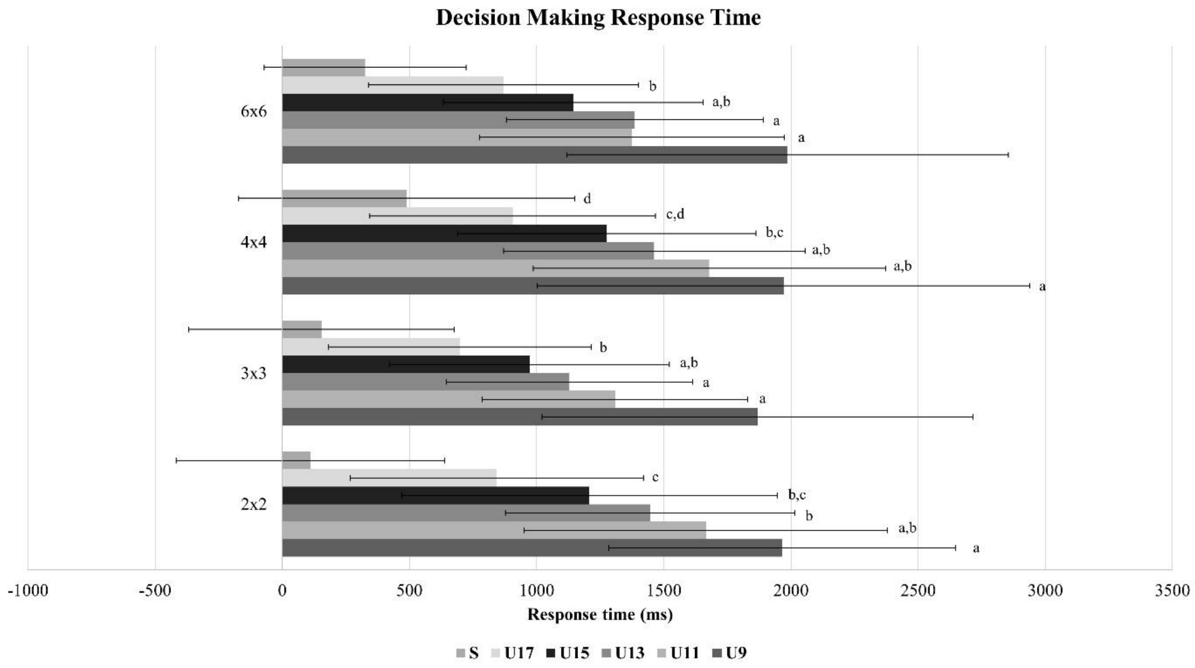
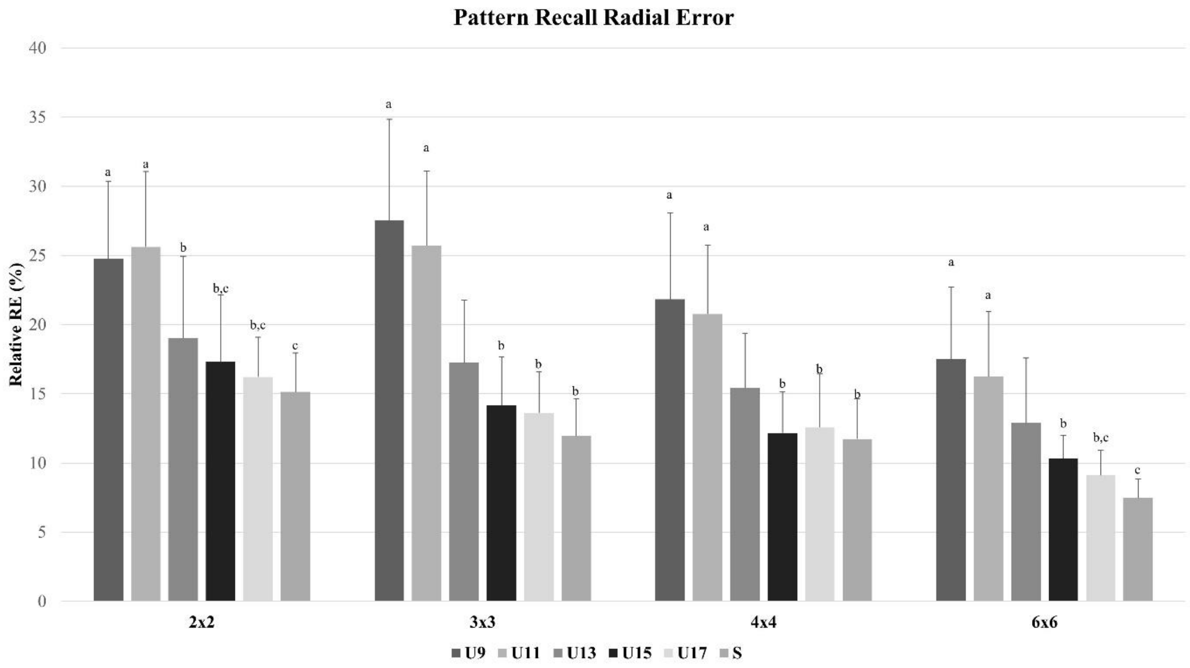

Decision Making Response Time
6x6
4x4
3x3
2x2
b
a,b
a
a
d
c,d
b,c
a,b
a,b
a
b
a,b
a
a
c
b,c
b
a,b
a
-1000
-500
0
500
1000
1500
2000
2500
3000
3500
Response time (ms)
S
U17
U15
U13
U11
U9

Figure 10



Pattern Recall Radial Error
Relative RE (%)
40
35
30
25
20
15
10
5
0
a
a
b
b,c
b,c
c
b
b
b
a
a
b
b
b
a
a
b
b,c
c
2x2
3x3
4x4
6x6
U9
U11
U13
U15
U17
S

Figure 11