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Pattern Recall Skill in Handball: From Expertise Differences in Adults and Juniors to Talent Selection and Long-Term Success

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Abstract

While there has been significant exploration of perceptual-cognitive skills (e.g., pattern recall skills) in expertise and talent selection contexts, researchers have usually focused on single timepoints along the athlete development pathway. That is, differences between skill groups have rarely been investigated regarding their effects on long-term athlete development. The main aim of the four studies presented in this article was to investigate the separate steps of the Hohmann approach (2009) and, potentially, to draw direct conclusions from expertise differences to potential predictors of talent and future high-level performance. The first study involved confirming differences in pattern recall skills between expert, advanced, and novice players. Subsequently, differences between varying skill groups in two different youth age groups were analyzed (Study 2). After this, Study 3 investigated whether pattern recall skills could differentiate selected from non-selected youth players during a national try-out of the German Handball Federation. In Study 4, the highest league that the aforementioned try-out players have played within ten years was determined, and this information was used as a proxy for long-term success to check for differences in test results during the try-out ten years earlier. Collectively, these four studies reflect a dynamic and nuanced relationship between pattern recall skills and general athlete development in handball. Further, the clear differences between males and females on many relationships explored in this research emphasize the importance of differentiated data as the basis for specific athlete selection and development decisions.

Keywords

perception, talent development, cognition, perceptual-cognitive skills, expertise differences

Introduction

In high-performance athlete development, talented athletes are the “holy grail” (Baker et al., 2017). On the one hand, athlete selection and identification in many sports usually involve coaches’ subjective and intuitive decisions; i.e., the “coach’s eye” (Lath et al., 2021; Roberts et al., 2019). On the other hand, sport scientists try to identify valid and rather objective factors for inclusion in a multidimensional talent formula (Baker, et al., 2017; Bar-Eli et al., 2024). For the latter approach, Hohmann (2009) proposed two ways of identifying these factors: the ability approach and the expertise approach (see Schorer et al., 2012, for an English language explanation).

In sports, the ability approach involves administering several tests in general performance areas (e.g., technical, tactical, or motor skill tests during an athlete selection event) and examining differences between skill levels. The selection of tests is based on the performance requirements of the specific sport under examination. In contrast, the expertise approach (Williams & Ericsson, 2005) involves identifying tasks that can differentiate athletes from different performance levels (e.g., elite, sub-elite, or novices) at varying age levels and using athletes' performance on these tasks to identify talented athletes during the selection process (Schorer et al., 2008). Ultimately, the difference between these two approaches relates to whether the tests used are related to general elements of performance (e.g., cognition, visual acuity, and general indicators of power, endurance, and strength) as in the ability approach, or to highly domain specific elements (e.g., identification of specific patterns of information, pickup of specific types of postural information to allow anticipation of an opponent's forthcoming actions) as in the expertise approach.

In the past, exploration of perceptual-cognitive skills in both expertise and talent selection contexts has generally focused on single timepoints along the athlete development pathway (Baker et al., 2020). Little research has considered the potential effects of what differences in skill groups may mean for long-term athlete development. In this research program, we looked at different points of time in four studies (cf. Figure 1). In Study 1, we investigated expertise difference in adults. In Study 2, we considered differences in expertise and in youth and junior athletes. In Study 3, we checked if selected players from a talent selection had superior perceptual-cognitive performances than not-selected ones. And last, in Study 4, differences between these talents in perceptual-cognitive skill based on their ultimate level of performance are presented.

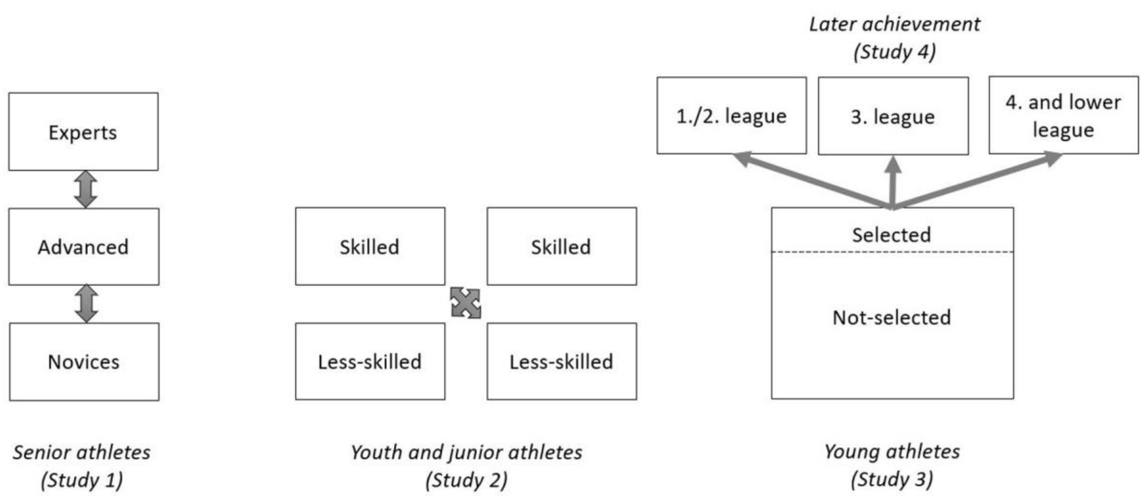

Figure 1. An overview of the four studies presented in this article.

Study 1: Expertise Differences in Pattern Recall Skill in Sports

For nearly half a century, differences between highly skilled and less-skilled athletes have been found in components of perception, knowledge, and decision-making (see Hodges et al., 2021, for a review). One skill consistently identified relates to rapidly reading patterns of information on the field of play, which presumably is valuable for making quick decisions regarding the most effective offensive or defensive actions (Roca & Williams, 2016; Williams et al., 2011). This effect is typically elicited by briefly presenting different skill groups with patterns of offensive or defensive information from their own sport and having them recall as much information as possible. With few exceptions, experts demonstrate a superior capacity to identify patterns of information from their sport compared to less skilled performers. Abernethy et al. (2005) noted the following:

> "This advantage appears to hold true regardless of whether the patterns presented are static or dynamic (Allard et al., 1980), whether the mode of presentation is visual or auditory (Starkes, 1987), and whether the elements to be recalled are opposing player positions in a team sport (Allard & Burnett, 1985), self-positions in a performance routine such as in figure skating (Deakin, 1991), or external layouts such as the configuration of balls on the table in snooker (Abernethy, et al., 1994)." (p. 706).

Despite the consistency of results, the provision of a feasible and user-friendly methodology is one limitation to practical application for coaching and athlete selection. This study aimed to replicate expertise differences found using a structured sport-specific pattern recall test (Fischer et al., 2016; Schapschröer et al., 2016). Moreover, this study focused on female athletes, a group that has been identified as under-represented in this area. Three groups of female handball players from different skill levels participated in this study. As in previous studies, it was hypothesized that test performance would decrease with lower expertise levels.

Methods

Participants

Thirty-six females participated in this study and were classified into three groups: experts, advanced players, and novices. The novices (*n* = 11) had very little previous experience in handball. The advanced players (*n* = 11) were active players in teams from the third and fourth league in Germany. The experts (*n* = 14) played handball in the two highest leagues in Germany. All participants had normal or corrected-to-normal vision.

The study employs an ex post facto design with a secondary data analysis, which is exempt from ethics approval because of the previously conducted collection and retrospective analysis of anonymized data. Good practice standards for conducting secondary data analyses were followed according to the Declaration of Helsinki. The German Handball Federation (DHB) provided the data.

Stimulus Material

The pattern recall task comprised animations presenting different handball game situations (cf. Figure 2, next page). Animations were created with the software Easy Animations (http://easy-sports-software.com/easy-animation/) and included small common icons representing handball players. The whole animation was presented from an aerial perspective showing one half of a handball court with a size of 1920 x 1080 pixels. The animation showed the standard handball player formation including six defenders in red jerseys, six offenders dressed in white jerseys, and one goalkeeper in a green jersey. The starting screen presented a basic handball formation. When the animation started, offenders left the basic player formation and started moving on the court and passing the ball to fellow players. Defenders shifted their positions depending on and adapting to the offenders' movements. Animations ended halfway through a common tactical group attack in handball.

Apparatus and Tasks

Participants were seated in front of several touch screens (Acer Z5610, 23 inches, system software Windows 7) at a distance of approximately 0.5 m from the monitor. Within the pattern recall task, each animation had a length of two to four seconds depending on the tactics presented. The animation froze at the last frame presenting a characteristic handball move, and this frame was shown for another five seconds. Afterwards, player icons were again presented in the standard player formation from the beginning. The participant's task was to replicate the player formation of the last frame as precisely as possible. Participants used their forefinger as the cursor on the touch screen to place player icons on the court. It was possible to move only one player at a time. The twelve field players were labeled with the normal short versions of their player positions. The goalkeeper did move during the animation but was neglected in the player placement task. The ball presented in the animation disappeared in the basic player formation.

Procedure

Before commencement, participants were given basic information about the experiment and brief verbal instructions on the task and the handling of the touch screen. Participants also received written instruction concerning the experiment on the screen before the animations. Examples of the procedure were given, and an exemplary animation was presented that included a standard handball player formation and the last frame. Participants were allowed to ask questions regarding the procedure before the start of the experiment. After finishing their player placements, participants were required to save the player formation they replicated using a save button shown on the screen. After using this button, the next animation automatically started after a delay of two seconds. A total of five animations were presented in a counterbalanced order to each participant. After saving their last player placement, participants received information about their performance presented as the mean distance between the correct positions in the animation and the respective positions replicated by the participant.

Statistical Analyses and Dependent Variables

The dependent variable for the pattern recall skill was the mean radial error (MRE) of the displacement (in pixels) reflecting the distance between the correct positions in the animation and the position replicated by the participant. A one-way analysis of variance (ANOVA) was conducted with group as a between-subject factor. Effect sizes for the ANOVA are reported as *f*-values along with corresponding 90% confidence intervals (CI), which were calculated by administering the SPSS syntax by Smithson (2001) downloaded from the website of Wuensch (2017). Simple contrasts are reported between all three groups separately, with corrected Hedges' *g* as the measure of effect size, because the cell numbers were different in two comparisons. SPSS 30.0 was used for the statistical analyses, and data visualization suggestions were followed (Abernethy, 1988).

Results

As can be seen in Figure 3, a statistically significant difference was found between expertise levels, $F(2,33) = 4.32$, $p = .02$, $f = .51$, CI 90%(.14, .75), $1\text{-}\beta = .75$. Contrast analyses revealed statistically significant differences between novices and experts, $t = 2.85$, $p = .03$, $g = 1.15$, and between advanced players and novices, $t = 2.12$, $p = .04$, $g = 0.90$, but not between advanced players and experts, $t = 0.60$, $p = .55$, $g = 0.24$.

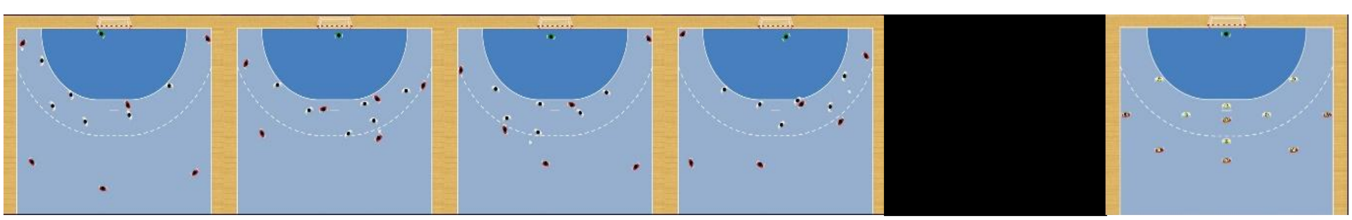

Figure 2. The pattern recall task showing half of a handball court including six player icons in red jerseys (defenders), six player icons in white jerseys (offenders), and one goalkeeper in a green jersey. The figure shows four frames from an animation shown during the experiment (left) as well as the neutral starting frame for the placement task (right).

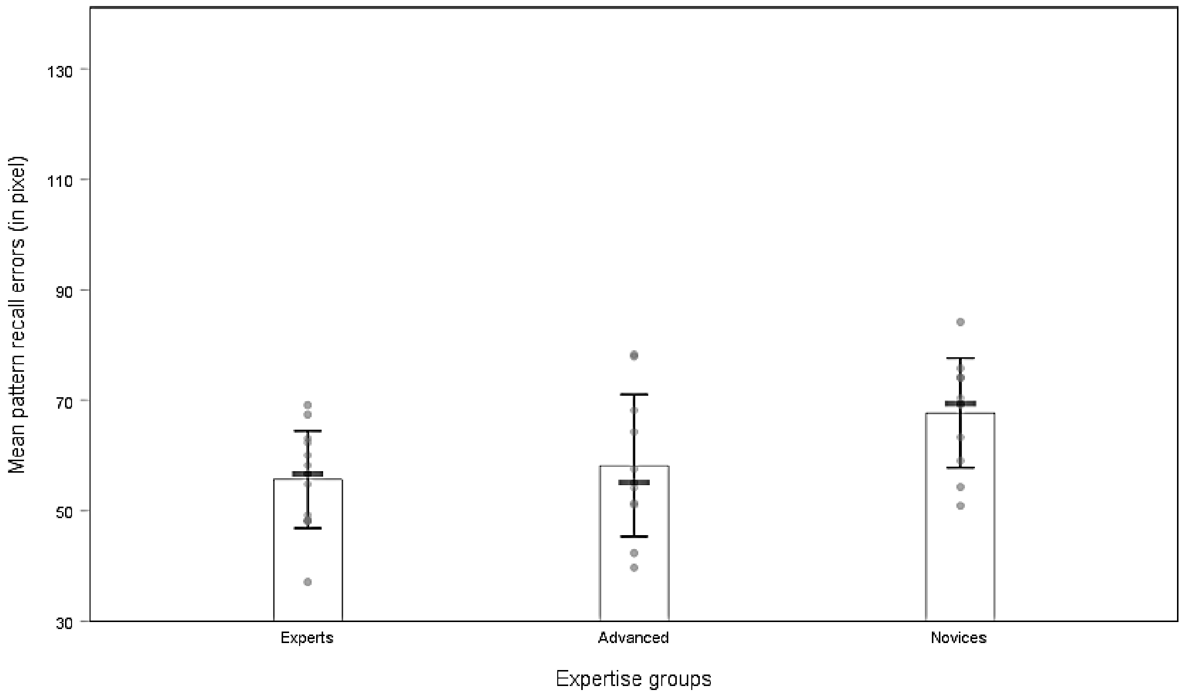

Figure 3. Error bars for the mean values of the pattern recall results (in pixel) differentiated by skill levels for female athletes in Study 1. The bold black bar indicates the medians. The black bars represent the standard deviations and the grey dots the single observations.

Discussion

As expected, a large effect for the overall expertise differences was found. More specifically, both skilled groups outperformed the novices in this task. These findings replicate the overall findings from Schapschröer et al. (2016). However, there were some differences between the studies. Schapschröer and colleagues found differences between experts and novices, similar to our results, but not between advanced players and novices like in the current study. This might be due to the exercise load Schapschröer and colleagues used while the athletes participated in their test. The present results provide support for the pattern recall test as a valid measure for eliciting skill differences for the aspect of perceptual-cognitive skills. We explore the utility of this test for examining the development of pattern recall skill with younger athletes in the next study.

Study 2: Pattern Recall Skill in Junior Athletes

While the value of perceptual-cognitive skills including pattern recall skill at the end of the athlete development journey (i.e., adult level) is clear and largely uncontested, when and how these skills develop are largely unknown since few studies have looked at these skills in young athletes. In the past, studies have shown that perceptual-cognitive skills play an important role in discriminating players from different skills levels, age groups and playing positions (Murr et al. 2018). However, few studies have examined specific perceptual-cognitive skills like pattern recall in youth athletes. In two older studies, Abernethy (1988) and Tenenbaum et al. (2000) investigated anticipatory skills and underlying perceptual skills of different age groups in badminton and tennis, respectively. These authors reported no skill-based differences before adulthood, implying those skills are acquired through years of practice. In another study investigating tactical pattern recall skills, Ward and Williams (2003) found that youth soccer (U9-U17) players improved over time with skill differences already present at the age of 9 years. Similarly, in the sport of volleyball, De Waelle et al. (2021) compared perceptual cognitive skills in different age groups (U9, U11, U13, U15, U17 and Seniors) and found that U9 players had worse skills than other players while U17 and senior players showed superior skill. Data of all age groups showed a steady improvement over time.

This research suggests perceptual-cognitive skills develop over time (potentially with an important period in early adolescence), are the result of learning and experience and that they may be helpful for athlete selection purposes (Schorer et al., 2015). Better understanding of how and when perceptual skills come 'on board' during the extensive process of athlete development in different sports would improve approaches to training and models of athlete development. The aims of this study were three-fold. First, differences in the pattern recall test between different junior age groups were investigated. Second, we explored whether skill differences could be found within one junior age group. Given findings from previous research (in other sports), we hypothesized that older and more skillful players show better results in the pattern recall test. Last, the interaction of both factors – age and skill level – were explored.

Methods

Participants

For this study, four groups of participants were recruited for each sex. The two factors were age and skill level (cf. Figure 1). In this study, junior (age 16-18 years) and youth (age 14-16 years) players were included. Within these age groups, athletes from two different skill levels were asked to participate. In total, 53 male and 51 female athletes participated in this study (cf. Table 1). All participants had normal or corrected-to-normal vision. The study employs an ex post facto design with a secondary data analysis, which is exempt from ethics approval because of the previously conducted collection and retrospective analysis of anonymized data. Good practice standards for conducting secondary data analyses were followed according to the Declaration of Helsinki. The German Handball Federation provided us with the data.

Table 1. Overview of the number and age of the participants per subgroup.

Female	Junior	Youth	**Male**	Junior	Youth
Less-skilled	12	14	Less-skilled	14	11
Skilled	14	11	Skilled	15	13

Stimulus Material

The same stimulus material as in Study 1 was used.

Apparatus and tasks

The same apparatus and task as in Study 1 were administered.

Procedure

The same procedure as in Study 1 was followed.

Statistical Analysis and Dependent Variables

Almost the same dependent variables and statistical analyses were used as in Study 1. However, instead of using a one-factorial ANOVA, a two-factorial ANOVA was administered. The between-subject factors were skill (less skilled versus skilled players) and age group (junior versus youth). Effect sizes for ANOVA are reported as f-values along with corresponding 90% CI, which were calculated by administering the SPSS syntax by Smithson (2001) downloaded from the website of Wuensch (2017). SPSS 30.0 was used for the statistical analyses and data visualization suggestions were followed (Loffing, 2022).

Results

As can be seen in Figure 4A (next page), the two-factorial ANOVA revealed statistically significant differences between female skill groups, $F(1,47) = 5.92$, $p = .02$, $f = .36$, 90%CI(.10, .59), 1-β = .68. There was neither a statistically significant difference between age groups, $F(1,47) = 0.22$, $p = .64$, $f = .07$, 1-β = .07, nor an interaction between age group and expertise level, $F(1,47) = 0.03$, $p = .87$, $f = .03$, 1-β = .05.

For male athletes, a two-factorial ANOVA revealed no statistically significant differences between expertise groups, $F(1,48) = 2.65$, $p = .11$, $f = .23$, 1-β = .35 (cf. Figure 4B). Furthermore, there were no statistically significant differences between age groups, $F(1,48) = 2.23$, $p = .14$, $f = .21$, 1-β = .30, nor an interaction between age group and expertise level, $F(1,48) = 1.04$, $p = .31$, $f = .15$, 1-β = .17.

Discussion

Results from this study indicated skill main effects for female but not male athletes. There are multiple potential reasons for these different effects. For example, performance demands of female versus male handball may be appreciably different (e.g., female handball may emphasize pattern recall skills more than in male sports), particularly at this stage of the athlete development pathway. Alternately, the test may not have been sensitive enough to identify differences in males, which may also explain the lack of statistically significant effects between age groups.

Ultimately, however, these results emphasize the importance of gathering more data from female athletes for understanding development and skill acquisition in this population, an area that has been considerably under-studied (Baker et al., 2020). Moreover, our findings suggest continued utility for the present pattern recall test for exploring differences in perceptual-cognitive skill across athlete development.

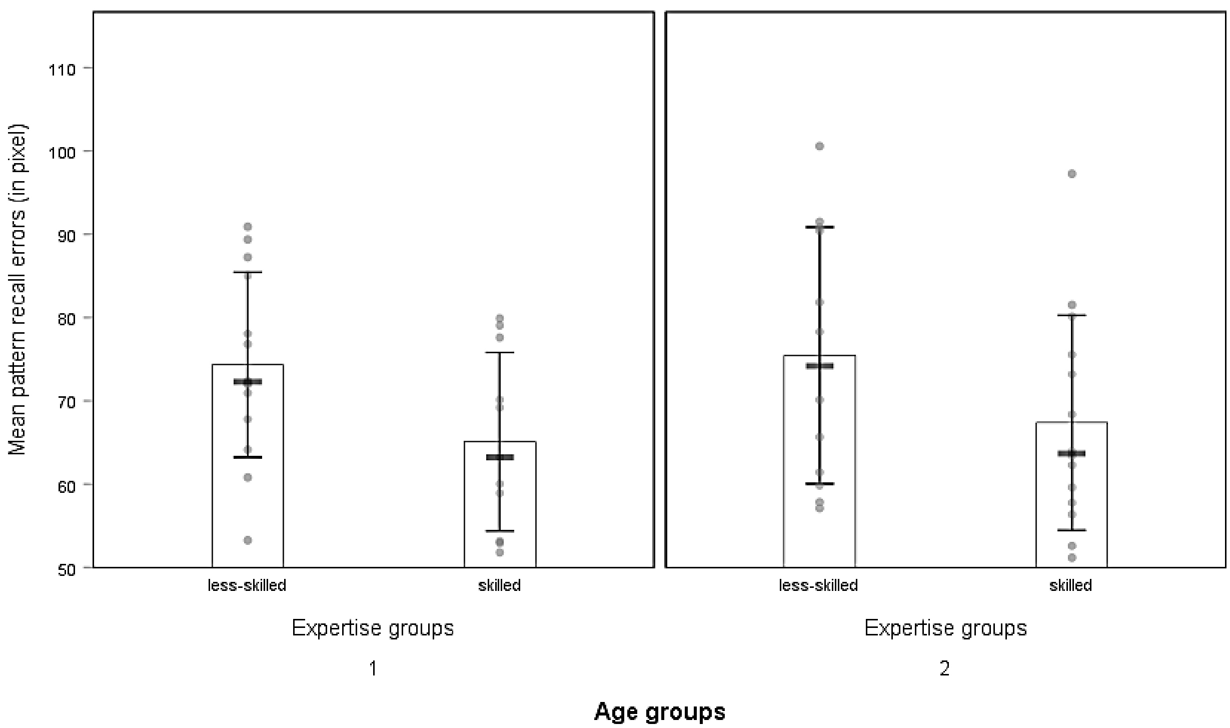

Figure 4A. Error bars for the mean values of the pattern recall results (in pixel) differentiated by age group (left: B-youth and right: A-youth) and skill levels for female athletes in Study 2. The bold black bar indicates the medians. The black bars represent the standard deviations and the grey dots the single observations.

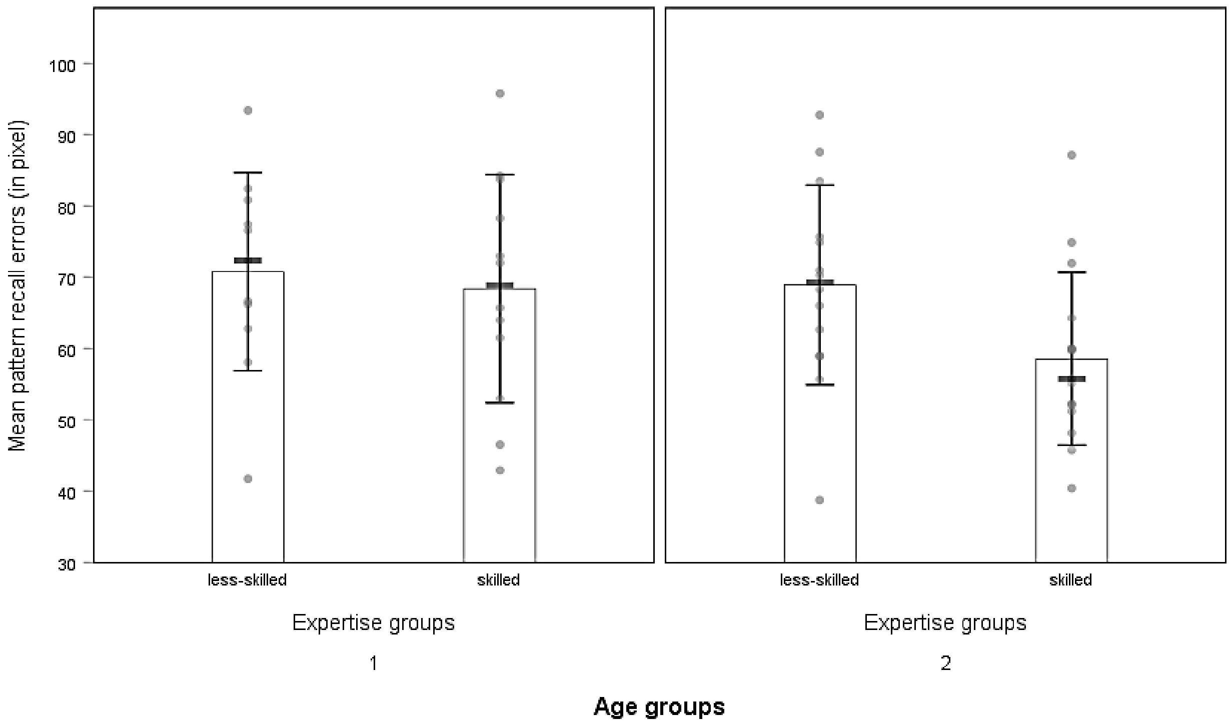

Figure 4B. Error bars for the mean values of the pattern recall results (in pixel) differentiated by age group (left: B-youth; right: A-youth) and skill levels for male athletes in Study 2. The bold black bar indicates the medians. The black bars represent the standard deviations and the grey dots the single observations.

Study 3: Cross-sectional Analysis of Pattern Recall Skill in Athlete Selection

The process of athlete selection in youth sports is obviously complex. In most cases, selections are based on subjective observations; i.e., coach's eye (Lath et al., 2021) and/or more objective assessments of various factors (e.g., anthropometrics or technical, tactical/perceptual-cognitive or psychological skills). While there may be advantages to both types of approaches, research has shown that the combination of both appears to be best (Höner et al., 2021; Sieghartsleitner et al., 2019).

A scoping review of talent research in sport (Baker et al., 2020) found that perceptual-cognitive skills were examined the most frequently (over a quarter of all research studies). However, these types of skills are assessed using a range of methodological approaches (e.g., self-report questionnaires or observation sheets). In a systematic review of studies using psychological talent predictors in soccer, Murr et al. (2018) found superior results for selected compared to non-selected players for anticipation and situational probability but not for pattern recall skills. In another study, Kolman et al. (2022) used the Tactical Skills Questionnaire in Tennis (TSQT; comprising measures of anticipation and positioning, game intelligence and adaptability, decision-making, and recognizing game situations) to examine national and regional tennis players, noting statistically significant differences were found for all subscales except for anticipation and positioning (p = .07). Rikberg and Raudsepp (2011) compared the ‘game intelligence’ (i.e., decision-making, positioning, anticipation, and timing skills) of selected and non-selected volleyball players using both coach observations and a video test. They found statistically significant differences in both tests reflecting better results for selected players. In a related study in basketball, Rösch et al. (2021) found that tactical decision-making skills discriminated elite players from the German U16 national team from novices.

All this is to say that assessments of perceptual-cognitive or tactical skills have been useful in athlete selection contexts in multiple sports. However, tests are often highly specific to the sport under examination, and studies from one sport may not be particularly relevant to a different sport. For the purposes of this investigation, no research has examined perceptual-cognitive skills (i.e., pattern recall skill) in the context of athlete selection in handball during a talent camp. Using the method designed in Study 1, we explore the relevance of pattern recall in skilled athlete selection.

Methods

Participants

For this study, data was collected in 2010 at the yearly try-out and athlete section event of the German Handball Federation DHB. For the female athletes, 222 participated in this test between the ages of 13 and 15 years. Of these, 39 players were nominated for the next level of athlete development at the end of the try-out. From the 227 males, 60 were selected for the next round of athlete development. Their age ranged from 14 to 16 years. All participants had normal or corrected- to-normal vision. As with Studies 1 and 2, this study employed an ex post facto design with a secondary data analysis, which is exempt from ethics approval because of the previously conducted collection and retrospective analysis of anonymized data. Good practice standards for conducting secondary data analyses were followed according to the Declaration of Helsinki. The German Handball Federation provided us with the data.

Stimulus Material

The same stimulus material as in Study 1 was used.

Apparatus And Tasks

The same apparatus and task as in Study 1 were administered.

Procedure

The same procedure as in Study 1 was followed.

Statistical Analysis and Dependent Variables

The dependent variable for pattern recall was the mean radial error (MRE) of the displacement (in pixels) for every single player between the original picture of basic handball player formation and the reproduced picture by the participant as a measure of accuracy. A t-test for independent samples was conducted with group as the between-subject factor. Effect sizes for t-tests for independent samples are reported as d-values along with corresponding 95% confidence intervals. SPSS 30.0 and were used for the statistical analyses and we followed suggestions for the visualization of our data by Loffing (2022).

Results

As can be seen in Figure 5A, female athletes who were nominated had a smaller mean performance in the accuracy of recall. However, both groups revealed a proportionally greater dispersion. Therefore, the *t*-test for independent samples did not reach statistical significance, $t(220) = 0.80$, $p = .18$, $d = 0.16$, 95% CI (-0.19, 0.50).

The same pattern of results was found for the male athletes (Figure 5B). Selected players performed better than the not selected, but dispersions were large. Not surprisingly, the *t*-test for independent samples did not reach statistical significance, $t(225) = 1.38$, $p = .08$, $d = 0.21$, CI 95%(-0.09, 0.50).

Discussion

For female and male athletes participating in an athlete selection event, no statistically significant differences were found between players nominated for the next level by coaches in comparison to players who were not nominated. There are various potential reasons for these findings. For example, players who participated in this event had considerable variability in their performance, and this within-group variability increased the difficulty of finding statistically significant effects. While the source of this heterogeneity is unknown (e.g., differences in handball experience), it is not surprising that adolescent players of both sexes showed high variability in perceptual-cognitive performance at this age. A second explanation may be that the development of pattern recall skills is not that important for performance outcomes in handball at this age. At this level, other factors may explain the nominated athletes' superior performance; e.g., technical skills (Koopmann et al. [2020]) and pattern recall skills might not be very relevant for current performance. Given their relevance for later performance (Fischer et al., 2016; Schapschröer et al., 2016), one would assume these skills develop later in a player's career. A third possible reason might be accuracy of nominations by the coaches. Given recent work on the *coach's eye* and biases in athlete selection (Lath et al., 2020; Lath et al., 2021; Roberts et al., 2019), the use of the nomination status as a criterion variable may be problematic, introducing false error, at least compared to other outcomes. For example, a superior criterion variable might be the ultimate level of performance of the players (e.g., at the peak of their careers). We explore this in the next study.

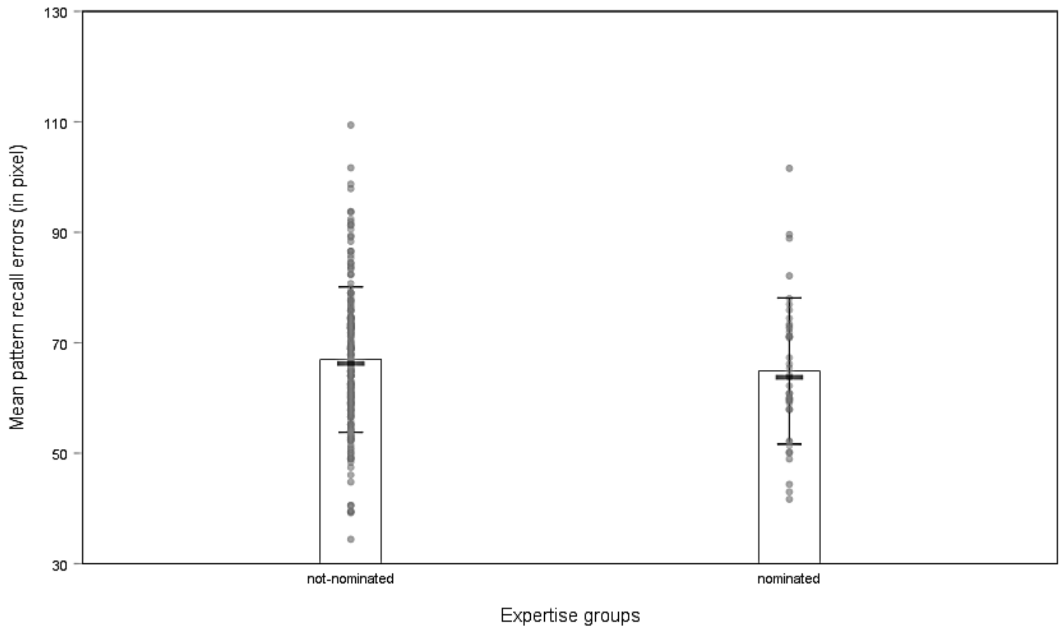

Figure 5A. Error bars for the mean values of the pattern recall results (in pixel) differentiated by nomination for female athletes in Study 3. The bold black bar indicates the medians. The black bars represent the standard deviations and the grey dots the single observations.

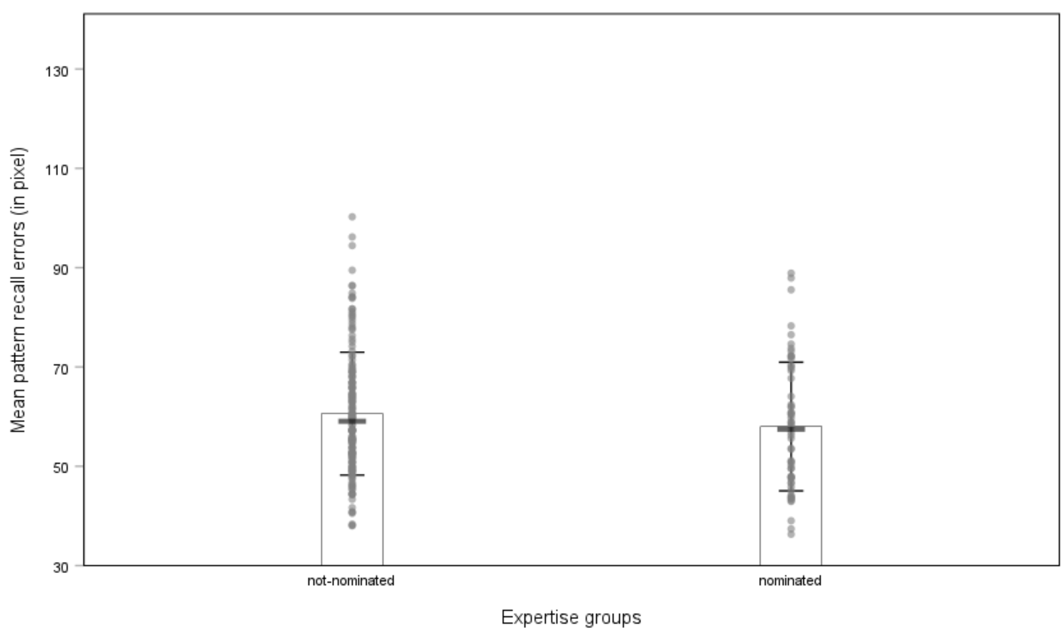

Figure 5B. Error bars for the mean values of the pattern recall results (in pixel) differentiated by nomination for male athletes in Study 3. The bold black bar indicates the medians. The black bars represent the standard deviations and the grey dots the single observations.

Study 4: Longitudinal Analysis of Perceptual-Cognitive Skills as Long-Term Talent Predictors

As presented in Study 3, cross-sectional studies suggest some value for perceptual-cognitive skills for athlete selection and development purposes. However, to uncover the underlying processes, and determine these assessments' long-term validity, longitudinal studies are needed. Of the 20 longitudinal studies in talent research identified in a systematic review by Johnston et al. (2018), only two looked at perceptual-cognitive skills in a broad sense. Elferink-Gemser et al. (2007) examined a combination of variables in field hockey and found that tactical variables discriminated elite and sub-elite youth players on three assessment occasions. Similarly, Falk et al. (2004) found that selected junior water polo players were superior in terms of game intelligence (i.e., coach observation of decision making, positioning, anticipation and timing) based on three testings. In a longitudinal study looking at young handball players' perceptual-cognitive skills using a similar approach to the present study, Raab and Farrow (2015) found differences between skill groups and playing positions, which the authors concluded emphasized the importance of pattern recall performance in expertise development.

Since the systematic review by Johnston et al. (2018), a few other longitudinal studies have assessed perceptual-cognitive/tactical skills in different sports. In soccer, Höner et al. (2021) and Murr et al. (2018) found that tactical skills, kicking skills and sprint were most predictive of the players' success three seasons later in U12 to U15 German soccer players. In basketball, Guimarães et al. (2021) found better tactical skills for better players using a multidimensional approach to measure five age-cohorts quasi-longitudinally. Relatedly, in baseball, Liu et al. (2020) found that pre-seasons scores on smooth pursuit accuracy and oculomotor processing speed assessments significantly predicted batters' highest attained league levels during the season. In handball, Schorer et al. (2021) found tactical skill measures assessed in young players at the German talent selection camp differentiated players who ended up being more successful from less successful players as adults. While this longitudinal study on perceptual-cognitive/tactical skills in youth handball gives initial support to their value for athlete selection decision-making, the methodological approach of game observations and notational analyses is rather indirect. More direct assessment of perceptual-cognitive skills such as the pattern recall of handball-specific contexts may provide new insights and is the focus of this study.

Methods

Participants

For this study, performance of participants was followed up and re-analyzed. For all of them, the highest league level was searched on internet sites. Of the female athletes, 139 out of 222 players could be found ten years after the talent section had occurred. Of these, 24 had reached the first or second highest league in Germany as adult players, 20 had played in the third league and 95 participated in the fourth league or lower. For the male athletes, data for 162 was found. Of these, 40 reached the first two leagues in Germany, 29 played at the third league and 93 players played in the fourth and lower leagues.

Stimulus Material

The same stimulus material as in Study 1 was used.

Apparatus and Tasks

The same apparatus and task as in Study 1 were administered.

Procedure

The same procedure as in Study 1 was followed.

Statistical Analysis and Dependent Variables

The dependent variable for pattern recall was the mean radial error MRE of the displacement (in pixels) for every single player between the original picture of basic handball player formation and the reproduced picture by the participant as a measure of accuracy. A one-factorial ANOVA was conducted with reached expertise level as a between-subject factor. Effect sizes for ANOVA are reported as f-values along with corresponding 90% confidence intervals, which were calculated by administering the SPSS syntax by Smithson (2001) downloaded from the website of Wuensch (2017). One-sided simple contrasts were used to check for differences between groups, and corrected effect sizes Hedges' g are reported. SPSS 30.0 and were used for the statistical analyses and we followed suggestions for the visualization of our data by Loffing (2022).

Results

As can be seen in Figure 6A, the higher league levels were related to smaller mean distances. This resulted in a significant difference between expertise levels for females, $F(2,136) = 3.79$, $p = .02$, $f = .24$, CI 90%(0.06, 0.36). Contrast analyses revealed significant differences between novices and experts, $t(136) = 2.71$, $p < .01$, $g = .62$, but not between advanced players and experts, $t(136) = 1.26$, $p = .11$, $g = .38$, or novices, $t(136) = 0.97$, $p = .16$, $g = .24$.

For the male athletes, descriptive results can be seen in Figure 6B and revealed the same pattern of results. However, the main effect between expertise levels for males was not statistically significant, $F(2,159) = 1.66$, $p = .19$, $f = 0.14$, $1\text{-}\beta = .20$. Contrast analyses revealed significant differences between novices and experts, $t(159) = 1.77$, $p = .04$, $g = .33$, but not between advanced players and experts, $t(159) = 1.32$, $p = .09$, $g = .32$, or novices, $t(159) = 0.06$, $p = .48$, $g = .01$.

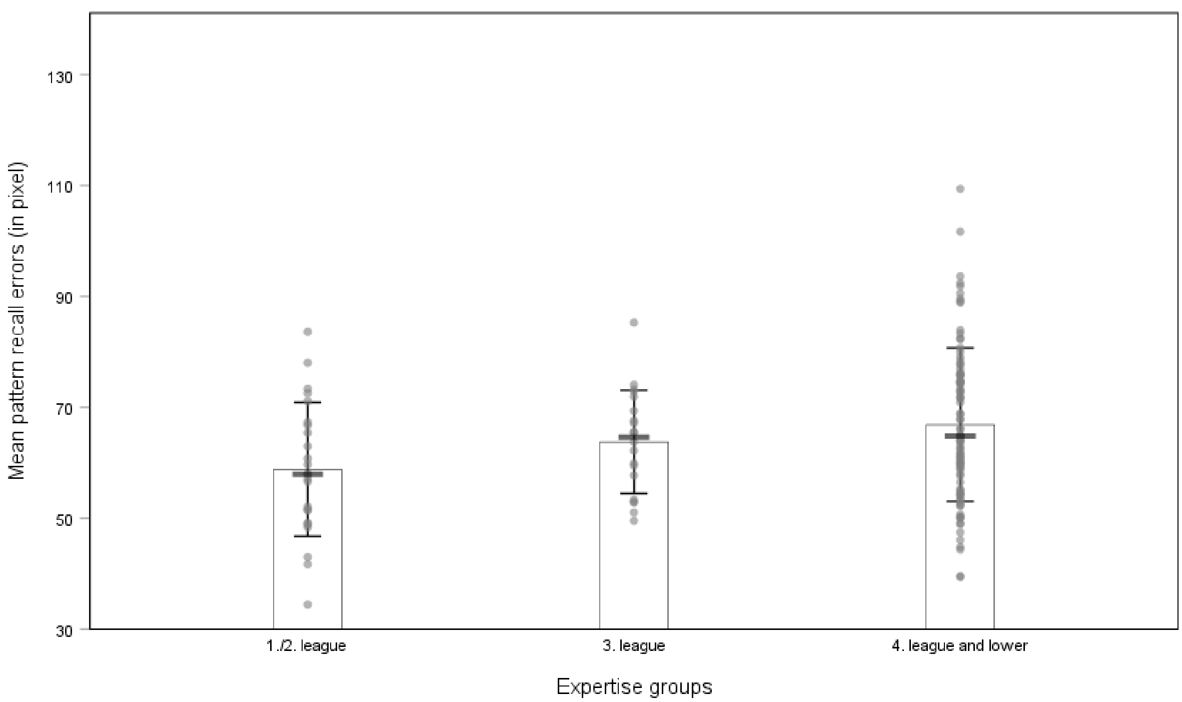

Figure 6A. Error bars for the mean values of the pattern recall results (in pixel) differentiated by league level for female athletes in Study 4. The bold black bar indicates the medians. The black bars represent the standard deviations and the grey dots the single observations.

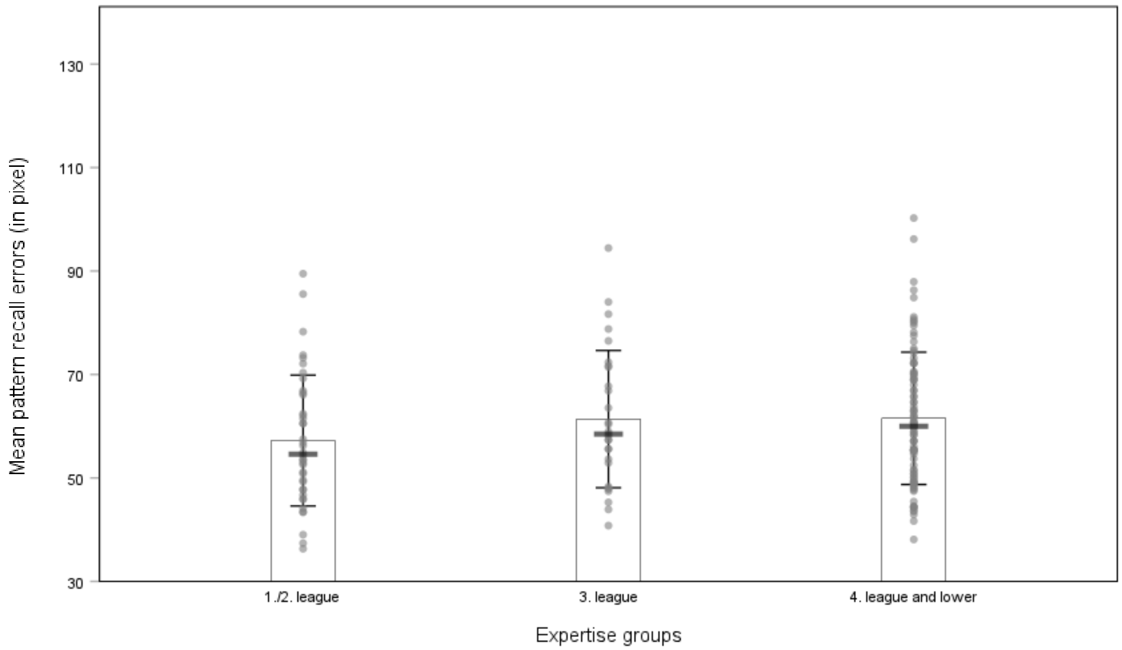

Figure 6B. Error bars for the mean values of the pattern recall results (in pixel) differentiated by league level for male athletes in Study 4. The bold black bar indicates the medians. The black bars represent the standard deviations and the grey dots the single observations.

Discussion

This study adds to a sparse body of evidence examining the predictive value of early assessments of perceptual-cognitive skills (in this case a pattern recall test) on performance as adults. For male and female athletes, there were statistically significant contrasts between players who reached the top professional leagues and those who reached the fourth or lower leagues. These results were similar to previous findings by Raab and Farrow (2015). While for the male athletes this difference was small, it was a medium-sized effect for the females. These results may seem unimpressive initially; however, when perceived relative to the myriad reasons affecting whether athletes succeed or drop-out over longer time periods, effects of this size are expected. The factors affecting an athlete’s progression are diverse (Baker et al., 2017), both within the overall sample and between the male and female groups. This likely influenced the test power and results. Additionally, the assumption that every player has the same profile and/or follows the same trajectory needs to be reconsidered. There may be athletes in the professional leagues who made it there despite their poorer performance in this test because they were outstanding in other areas like speed or technical skill (i.e., compensation phenomenon). Future research would need to collect a larger sample to be able to differentiate between players with different makeups. Moreover, it seems logical to assume there would be variability in this makeup across differing playing positions as suggested by Raab and Farrow (2015). This was not accounted for in the present study because at the talent selection players are supposed to be allrounders as field players. The specialisation for specific positions happens at later ages.

As suggested above, the difference between the sexes in these analyses is noteworthy and may reflect differences in the developmental pathways for males and females. For instance, the pathway to the national team for females is more restrictive as club structures are not as professional as those in the male pathway, which has an established system of academies at the club level (Schorer et al., 2012). Once again, these results emphasize the need for sex-specific research not only in handball.

General Discussion

The present study aimed to test and validate a structured sport-specific pattern recall test and use this test to assess pattern recall skills in male and female handball players from different skill levels. Results of this multi-study investigation highlight the utility of assessing specific perceptual-cognitive skills during athlete development to understand the nature of perception and cognition in this population, as well as to understand how these skills develop over time. In particular, our findings support the validity of a standardized and easy to administer test for the collection of this data in handball players. Moreover, our results also suggest some value for these skills in predicting future success (Study 4), at least at a preliminary level.

The most consistent finding across this investigation was the differences between male and female samples. These sex differences highlight the limitation in handball research, and sport more generally, when it comes to female-specific research. As noted by Baker et al. (2020), only 10% of work over the past three decades has focused on female-only samples. Importantly, results of the current study challenge the assumption that results from one group can be broadly applied to other groups, especially without a clear understanding of what makes those groups similar and different.

The exploration of differences between skill and age groups in Studies 2 and 3 suggest perceptual-cognitive skills emerge at different rates and at different times across the athlete development pathway. Moreover, results indicate pattern recall skills are not equally relevant for performance or selection at every stage of development, or, potentially, for each athlete. The high dispersion within the groups on this skill emphasizes that although perceptual-cognitive skills are important, they are not equally relevant for all athletes at the same stage of development, which emphasizes the importance of a multi-dimensional assessment of players and the lack of a 'one-size-fits-all' approach to athlete development.

However, despite our intriguing results, some limitations in our design are noteworthy. First, while the idea of these studies was to compare skill groups of the same levels across the stages of athlete development, there were differences between the groups across the studies. In Study 1, experts were compared to advanced players and novices. In contrast, in Study 2 only skilled versus less-skilled players were compared within specific age groups. Finally, for studies 3 and 4, the best players in Germany at the point of selection (i.e., between 13 and 15 years of age) were considered. Given that a clear categorization for younger age groups is difficult (Baker et al., 2005; Swann et al., 2015), and the importance of perceptual-cognitive skill likely varies across development, comparing these groups is at least slightly problematic. In particular, because the young players from Studies 3 and 4 ended up playing at various leagues within Germany, the heterogeneity between these players might be larger than we expected.

A second limitation is that while we have longitudinal data at the start of talent development and one point during their peak performance age, the processes influencing the players between these years is not known. Future research would benefit greatly by following players over their entire athlete development pathway using various skill tests and assessments.

Conclusions

The results of these four studies add to a developing, but still sparse, evidence-based research on the value of perceptual-cognitive skills across an athlete's development. While there were notable limitations to our design, the objectives of these studies were ambitious (i.e., to test and validate a structured sport-specific pattern recall test and use this test to [longitudinally] assess pattern recall skills in male and female handball players from different skill levels). Collectively, our results emphasize the dynamic nature of perception across development and the importance of context-specific data (e.g., female-only samples) for improving our understanding of athlete development. Greater attention to these areas will ensure reduction of pervasive and persistent gaps in our knowledge base.

Authors' Declarations

The authors declare that the data can be requested via email from the first author on reasonable request.

The authors declare that there are no personal or financial conflicts of interest regarding the research in this article.

The authors declare that the research reported in this article is in accordance with the Ethical Principles of the *Journal of Expertise*.

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