

Visual-spatial demands in sports: An empirical survey based study

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ABSTRACT

Visual-spatial information processing demands in sports can be understood along two key dimensions: intrinsic versus extrinsic and static versus dynamic. Different sports require varying intersecting combinations of these dimensions, often emphasizing one aspect more than another. This study aimed to classify 20 commonly practiced sports based on perceived visual-spatial demands along these dimensions. Participants rated each sport using two separate continuous scales assessing intrinsic-extrinsic orientation and static-dynamic task demands. A total of 250 participants (143 female, 107 male) completed the 40 ratings. For the intrinsic-extrinsic dimension, team sports, such as soccer or basketball, were classified as relying more on extrinsic visual-spatial skills, while technique-oriented individual sports, like dancing or gymnastics, were rated as requiring more intrinsic visual-spatial abilities. Sports such as judo and canoeing received intermediate scores along the intrinsic-extrinsic dimension. For the static-dynamic dimension, cycling, horse riding and gymnastics demonstrated intermediate scores. Except for golf, shooting, and sailing, which were rated as more static, all other sports were rated as more dynamic. Hierarchical classification and k-means clustering indicated that sports could be grouped into four clusters demonstrating intersection of intrinsic/static, intrinsic/dynamic, extrinsic/dynamic and intermediate intrinsic-extrinsic/static-dynamic dimensions. The results aligned with Uttal's framework and further supported a possible extension of it by indicating that visual-spatial demands in sports are organized along a graded continua rather than dichotomous categories, reflecting complex dimensional interactions. Future research in cognitive training and sport psychology may benefit from conceptualizing visual-spatial information processing demands in sports along continuous dimensions rather than discrete categories.

1. Introduction

Navigating the way to reach a destination via a car or a bike, walking on a crowded road, or even the simple task of picking up a mug from a table relies on the brain's visual-spatial cognition systems, which integrate perception, movement planning, and spatial awareness (Wolbers & Hegarty, 2010). Visual-spatial skills are a critical determinant of success across a wide range of activities in both academic and athletic domains (Pietsch, 2018; Pietsch et al., 2019; Uttal et al., 2013; Voyer & Jansen, 2017). These skills encompass the ability to perceive, represent, and manipulate spatial relationships, including spatial perception, spatial visualization, and mental rotation of objects or body positions (Buckley et al., 2018; Linn & Petersen, 1985; Uttal et al., 2013). Visual-spatial abilities aid in accomplishing and excelling in an individual's goals in science, technology, engineering, and mathematics (STEM), which have been proven to be a predictor of higher achievements (Uttal

et al., 2013). These skills can also help to improve performance in sport and athletic context (Pietsch, 2018; Pietsch et al., 2019).

1.1. The taxonomy of visual-spatial cognition by Uttal et al. (2013)

Uttal et al. (2013) proposed an often-cited taxonomy of visual-spatial skills that organizes them along two dimensions: intrinsic versus extrinsic and static versus dynamic. The framework was originally developed to classify and compare different kinds of spatial abilities and tasks in cognitive and educational research, with a particular emphasis on understanding how spatial training can support learning and achievement in STEM domains (Uttal et al., 2013). Although the framework was not originally developed to classify sports, it provided a theoretically grounded structure for analyzing and comparing the visual-spatial demands inherent in different sporting contexts (Pietsch, 2018).

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The *intrinsic-extrinsic dimension* refers to the reference frame of visual-spatial information (Hegarty et al., 2006; Huttenlocher & Presson, 1979; Kozhevnikov et al., 2006; Kozhevnikov & Hegarty, 2001; Uttal et al., 2013). Intrinsic visual-spatial skills involve transformations and representations within the object or the body itself, independent of the individual's position in the surrounding environment (Biederman, 1987; Hoffman & Singh, 1997; Newcombe & Shipley, 2015; Tversky, 1981; Uttal et al., 2013). In sports, this includes body-centered processes, such as sensing limb position, coordinating joint angles, maintaining posture, and mentally rotating one's own body or body segments (e.g., when a gymnast controls her/his body alignment during a somersault). In contrast, extrinsic visual-spatial skills rely on spatial relations between the individual and external objects or environmental features, such as the location of opponents, teammates, targets, or boundaries (e.g., when a soccer player positions herself/himself relative to the ball and other players) (Newcombe & Shipley, 2015; Uttal et al., 2013).

The *static-dynamic dimension* describes whether visual-spatial information remains constant or changes over time (Uttal et al., 2013). Static and moving visual input have been shown to place different demands on perceptual systems hence supporting this distinction (Scialfa et al., 1988). Static visual-spatial information involves fixed or predictable spatial configurations, allowing performers to rely on stable visual cues and preplanned movement execution. For example, in archery, performance relies on visual acuity, depth perception, eye-hand and whole-body coordination, and consistent visual response timing - skills that are particularly critical in a setting where athletes aim at a stationary target and process largely unchanging spatial information, reflecting predominantly static visuospatial demands (Strydom & Ferreira, 2010). Dynamic visual-spatial abilities, by contrast, require continuous updating of spatial representations in response to moving objects, changing body positions, or evolving environmental conditions. Many interactive and fast-paced sports, such as team sports or combat sports, place strong demands on dynamic visual-spatial skills, as athletes must track motion, anticipate trajectories, and adjust their actions in real time (Hepppe et al., 2016).

When applied to sports, Uttal et al.'s (2013) framework allows visual-spatial demands to be conceptualized not as categorical properties of a sport, but as relative emphases along these two continua. For example, gymnastics can be characterized by strong intrinsic and relatively static visual-spatial demands, as athletes execute rehearsed routines that rely heavily on internal body representations within predictable settings. In contrast, team sports, such as soccer or basketball, may be described as emphasizing extrinsic and dynamic visual-spatial skills, as players continuously perceive and respond to rapidly changing external configurations involving multiple moving agents (Pietsch, 2018). In addition, some other sports, such as combat sports, like wrestling or judo, might require a combination of high intrinsic-dynamic demands (complex body coordination and balance control) with extrinsic-dynamic demands (monitoring and anticipating an opponent's actions). Importantly, Uttal et al.'s (2013) taxonomy does not imply that any sport relies exclusively on one quadrant of the framework. This interpretation becomes particularly evident when we examine different sport types and their specific visual-spatial demands. For instance, even in sports generally characterized as extrinsically oriented, such as soccer or basketball, athletes rely heavily on intrinsic visual-spatial skills to regulate fine motor control, maintain postural stability, and coordinate limb movements. Conversely, sports commonly considered intrinsically oriented, such as dancing or gymnastics, also require continuous adaptation to external conditions, including the spatial positioning and movements of other performers or constraints imposed by the performance space. Thus, sports cannot be classified by exclusive reliance on a single pole of the intrinsic-extrinsic or static-dynamic dimensions but instead involve flexible combinations of visual-spatial demands.

A meta-analysis conducted by Voyer and Jansen (2017) revealed how visual-spatial skills differ across sports, with distinctions between

extrinsically and intrinsically oriented disciplines. Athletes in combat sports showed the strongest advantages in visual-spatial orientation tasks, outperforming both novices and athletes from endurance disciplines (Moreau et al., 2011). Enhanced visual-spatial skills have also been reported in (team) ball sports, such as soccer, and team handball, where the constant interaction with the opponent(s) and a rapidly changing environment requires fast visual-spatial decision-making (Hepppe et al., 2016; Jansen et al., 2012; Klotzbier & Schott, 2024; Ozel et al., 2004). Sports involving highly visual-spatial and body-oriented movement routines, such as gymnastics, similarly exhibit superior performance in spatial perception and mental rotation tasks (Feng et al., 2024; Jansen & Lehmann, 2013; Klotzbier & Schott, 2024; Ozel et al., 2002; Steggemann et al., 2011). In contrast, endurance athletes, such as runners and cyclists, show no comparable advantage and perform worse than combat sport athletes on visual-spatial tasks, likely because these sports place minimal demands on complex visual-spatial processing (Moreau et al., 2011; Ozel et al., 2002, 2004).

1.2. An ecological dynamics perspective on visual-spatial information processing in sport

While Uttal et al.'s (2013) framework provides a useful taxonomy for categorizing visual-spatial skills, it does not in itself explain how these abilities emerge and adapt during skilled action. This explanatory gap can be addressed by the theoretical framework of ecological dynamics which postulates that behavior and decision-making in sports emerge from the dynamic interaction between the athlete, the task, and the environment (Araújo et al., 2006). Rather than viewing human actions completely as the outcome of preplanned cognitive processes, this perspective emphasizes perception-action coupling, where athletes continuously adapt to changing extrinsic conditions. Therefore, it can be postulated that athletes do not simply visualize spatial relations but continuously construct them through movement, proprioceptive feedback, and environmental interaction, requiring a complex integration of both intrinsic-extrinsic and static-dynamic dimensions of visual-spatial information processing. That is, like the way visual attention flexibly prioritizes perceptual features, as proposed by the dimension-weighting account (Müller et al., 1995), athletes may also dynamically shift the emphasis placed on intrinsic or extrinsic, static or dynamic visual-spatial information depending on the situational demands. This also suggests, similar to Uttal et al. (2013), that these dimensions may operate along a continuum rather than as dichotomous categories.

Although the intrinsic-extrinsic dimension shares some conceptual overlap with the internal-external attentional focus framework, the two constructs are not equivalent (Wulf, 2013; Wulf et al., 1998). In the present framework, intrinsic and extrinsic refer to the reference frame of visual-spatial information processing and whether spatial representations are centered on the body (intrinsic) or on relations between the individual and the external environment (extrinsic). In contrast, internal and external focus of attention describe the direction of attentional focus during performance, namely whether attention is directed toward one's own body movements or toward the effects of those movements in the environment equivalent (Wulf, 2013; Wulf et al., 1998). Importantly, these dimensions operate at different levels of analysis. The intrinsic-extrinsic distinction characterizes the visual-spatial demands inherent to the task or sport, whereas attentional focus reflects a performance strategy or instructional manipulation that can be applied regardless of those task demands. As such, an athlete may adopt an external focus of attention even in tasks with high intrinsic visual-spatial demands, and vice versa. Therefore, the present framework is not intended to replace attentional focus models, but rather to complement them by providing a domain-specific characterization of visual-spatial processing requirements in sport.

In the study of cognitive processes in sports (and other forms of physical activity), a fundamental distinction is also often made between open and closed skill sports (Lai et al., 2024). This classification is based

on the predictability of the environment in which the skill is performed (Schmidt & Wrisberg, 2008). Open skill sports, such as soccer, hockey, or badminton, take place in dynamic and unpredictable contexts where athletes must constantly adapt to changes in the environment, including the actions of opponents, teammates, and external stimuli, like a ball's trajectory or the weather conditions. These situational demands closely align with extrinsic and dynamic aspects of visual-spatial skills, as identified by Uttal et al. (2013), where spatial information is located outside the body and changes happen in real-time. In contrast, closed skill sports, such as gymnastics, shooting, or golf, occur in more stable, self-paced settings, where performers can plan their movements in advance. These situational conditions represent more the intrinsic and static aspects defined by Uttal et al. (2013), which involve internal spatial representations, body-centered spatial reasoning, and minimal environmental variability. This open/closed framework provides a useful lens through which different sports' cognitive and visual-spatial information processing demands can also be understood and classified. Furthermore, Uttal's visual-spatial framework can be meaningfully integrated with the open/closed skill distinction, highlighting that different sports place distinct demands along the intrinsic-extrinsic and static-dynamic dimensions (Uttal et al., 2013).

Even though Uttal et al.'s (2013) framework provides complementary theoretical lenses for describing sport-specific visual-spatial demands, few attempts have been made to systematically apply these dimensions to the classification of individual sports. Pietsch (2018) was the first to try to classify sports categories according to the intrinsic-extrinsic and static-dynamic framework by Uttal et al. (2013). She stated that running emphasizes intrinsic-static visual-spatial demands of the task, due to its repetitive, self-directed motion, while archery relies heavily on extrinsic-static, requiring precise alignment with external targets (Pietsch, 2018). In contrast, wrestling features both intrinsic-dynamic visual-spatial demands for complex body coordination and extrinsic-dynamic for anticipating an opponent's movements. Similarly, soccer is primarily extrinsic-dynamic in her view, as players must constantly interpret and respond to the movements of teammates, opponents, and the ball (Pietsch, 2018). Some sports, such as triathlon (including swimming, cycling, and running), span multiple categories of different visual-spatial information processing, depending on the specific event (Pietsch, 2018). Although all triathlon disciplines engage both intrinsic and extrinsic visual-spatial skills, swimming may rely more strongly on intrinsic visual-spatial information. In contrast, cycling and running might often demand greater extrinsic visual-spatial information, as athletes must navigate through dynamic environments and remain aware of surrounding competitors. This categorization facilitates the understanding of sport-specific visual-spatial demands and enables possibly tailoring training accordingly.

While Pietsch's (2018) classification represents an important first attempt to map sports onto the intrinsic-extrinsic and static-dynamic dimensions, it was based on expert judgment and has not yet been empirically validated. Little is known about how these visual-spatial distinctions are understood and applied by the general population. Conceptually, the present study is informed by a dimension-weighting account of visual-spatial processing (Müller et al., 1995), according to which perceptual dimensions are not processed categorically but are dynamically weighted depending on task relevance and contextual demands. In the context of sport, this perspective implies that intrinsic and extrinsic as well as static and dynamic visual-spatial information may be flexibly emphasized to varying degrees rather than treated as mutually exclusive categories. This view also aligns with the ecological dynamics perspective (Araújo et al., 2006; Davids et al., 2008; Newell, 1986), which conceptualizes sport performance as emerging from the continuous interaction between individuals, tasks, and environments. Therefore, building on the visual-spatial taxonomy proposed by Uttal et al. (2013) and the expert-based sport classification suggested by Pietsch (2018), the aim of this study was to examine the perceived visual-spatial demands as context-dependent constructs that may vary across sports.

To this end, a rating system was developed including 20 of the most frequently practiced sports reported by the German Olympic Sports Confederation (DOSB; *Deutscher Olympischer Sportbund e. V.*, 2024). Participants were asked to classify each sport according to the extent to which it was perceived to rely on intrinsic versus extrinsic and static versus dynamic visual-spatial demands. Identifying systematic patterns in these perceptions may contribute to a more empirically grounded classification of sport-specific visual-spatial demands. We hypothesized that perceived visual-spatial demands vary across sports along intrinsic-extrinsic and static-dynamic dimensions, yielding distinguishable intersections corresponding to intrinsic-static, intrinsic-dynamic, extrinsic-static, and extrinsic-dynamic visual-spatial demands.

2. Methods

2.1. Participants

A total of 250 participants (143 female, 107 male; mean age = 26 years (standard deviation = 8 years)) took part in the study. Participants were recruited via the University of Regensburg, the University of Paderborn, and the online research platform SurveyCircle. This recruitment approach corresponds to a convenience sampling strategy, as participants were selected based on accessibility and willingness to participate (Etikan et al., 2016). Participants recruited via the University of Regensburg and the University of Paderborn were sport science students and received course credit for their participation. The sample was diverse with respect to age and gender. The sample size is in line with recommendations from previous research to ensure sufficient statistical power and to reduce effect size bias commonly associated with smaller samples (Koch & Sollecito, 1984; Lakens, 2013; MacCallum & Hong, 1997).

2.2. Design

The present observational study employed a cross-sectional survey design to examine how individuals perceived the visual-spatial demands of different sports. As no experimental manipulation or grouping variable was introduced, participants were not randomly assigned to groups. Instead, all participants completed the same online rating task, in which they assessed the extent to which various sports rely on intrinsic versus extrinsic and static versus dynamic visual-spatial information processing. These dimensions were selected based on the established taxonomy of visual-spatial abilities proposed by Uttal et al. (2013).

2.3. Materials

The questionnaire included 20 of the most popular sports in Germany, selected based on participation rates reported by the German Olympic Sports Confederation (DOSB; *Deutscher Olympischer Sportbund e. V.*, 2024). The sports were badminton, basketball, canoeing, cycling, dancing, soccer, golf, gymnastics, team handball, hockey, horse riding, judo, sailing, shooting, skiing, swimming, table tennis, tennis, track and field, and volleyball. Including widely practiced sports increased the likelihood that participants were familiar with the activities, thereby improving the reliability of the ratings and enhancing the external validity and generalizability of the findings. Familiarity with the activities may enhance the clarity of mental representations and support more consistent subjective judgments (Tourangeau et al., 2000). In addition, because evaluating sports often involves embodied simulations of movement, using familiar sports may further contribute to stable ratings, although our study did not directly test these embodied processes (Raab & Araújo, 2019). The same was true for the individual levels of familiarity or sport-specific experience, which were also not directly assessed.

2.4. Procedure

The survey was administered online using SurveyCircle, the University of Regensburg's SONA portal, and the experimental software OpenSesame hosted on JATOS.org (see Figs. 1 and 2). The survey was conducted in German. English translations of the instructions and questionnaire items are provided in Figs. 1 and 2.

After providing demographic information (age and gender), participants rated each sport individually using a continuous slider. Ratings assessed perceived reliance on the two visual-spatial dimensions: intrinsic versus extrinsic and static versus dynamic. The slider ranged from 1 to 99, where 1 represented purely intrinsic or static visual-spatial demands, 99 represented purely extrinsic or dynamic visual-spatial demands, and 50 indicated a neutral midpoint. Participants completed 20 ratings for one dimension, followed by 20 ratings for the second dimension. To potential response biases, the order in which the different sports were presented was randomized, while the order of the two dimensions was balanced across participants. The survey required approximately 10–15 min to complete. Ethical standards were upheld in accordance with the Declaration of Helsinki. The study was evaluated by the local ethics committee of the university and determined to not require formal ethical approval. Participants were informed about the study's aims, procedures, and data protection policies, and informed consent was obtained electronically prior to participation.

2.5. Data analysis

2.5.1. Data preparation and descriptive statistics

Data analyses were conducted using Python (Version 3.12.3) and IBM SPSS. Prior to analysis, incomplete responses and statistical outliers were excluded from the dataset. Descriptive statistics were computed to summarize overall trends and frequency distributions of the visual-spatial demands ratings. The Shapiro-Wilk test was used to assess normality assumptions for the rating variables.

2.5.2. Inferential and multivariate analyses

Analyses of variance (ANOVAs) were conducted to examine differences in mean visual-spatial demands ratings. Sports (badminton, basketball, soccer, and so on) was treated as a within-subjects factor, whereas gender (female vs. male) and age group (18–25 years, 26–35 years, 36–45 years, >46 years) were included as between-subjects factors. The dependent variables were participants' slider ratings on the intrinsic-extrinsic and static-dynamic dimensions, recorded separately for each sport on a scale ranging from 1 to 99. Mauchly's test was used to

assess the assumption of sphericity, and Greenhouse-Geisser corrections were applied when this assumption was violated. Pearson correlation analyses were performed to examine the relationship between intrinsic-extrinsic and static-dynamic ratings across sports. In addition to significance testing, effect sizes were calculated and reported to facilitate interpretation of the results. Partial eta squared (η_p^2) was used as a measure of effect size for ANOVA analyses, and Pearson's r was reported for correlation analyses.

To identify groups of sports with similar visual-spatial profiles, hierarchical cluster analysis and k-means cluster analysis were conducted. Hierarchical cluster analysis was performed in IBM SPSS using squared Euclidean distances. Initially, the number of cluster solutions was examined across a range from two to 20 clusters. Visual inspection of the resulting dendrogram structure suggested a four-cluster solution. Therefore, the hierarchical cluster analysis was repeated with the number of clusters fixed at four.

K-means clustering was conducted in Python (JupyterLab Version 4.2.5) using the scikit-learn library. Prior to clustering, all numerical variables were standardized using z-scores to ensure comparability across variables. The optimal number of clusters ($K = 4$) was determined using the elbow method, supported by visual inspection of the within-cluster sum of squares (WCSS) plot. Clustering was performed using the k-means algorithm with the following parameters: $n_clusters = 4$, $init = 'k-means++'$, $n_init = 10$, and $max_iter = 300$. The resulting clusters were analyzed to identify patterns and differences among the categorization of sports.

Finally, participants recruited via SurveyCircle, the University of Regensburg, and the University of Paderborn were compared to assess potential group differences in visual-spatial demand ratings. All statistical tests applied a significance threshold of $p < 0.05$, with Bonferroni corrections used to adjust for multiple comparisons. This study was preregistered on OSF (doi:10.17605/OSF.IO/PMK9G). Minor deviations from the preregistered protocol along with a detailed deviation statement is available on OSF.

3. Results

The results are reported according to the two primary dimensions assessed, i.e., intrinsic vs extrinsic orientation and static vs dynamic task demands.

3.1. Descriptive statistics

Table 1 displays the mean rating value for the two visual-spatial

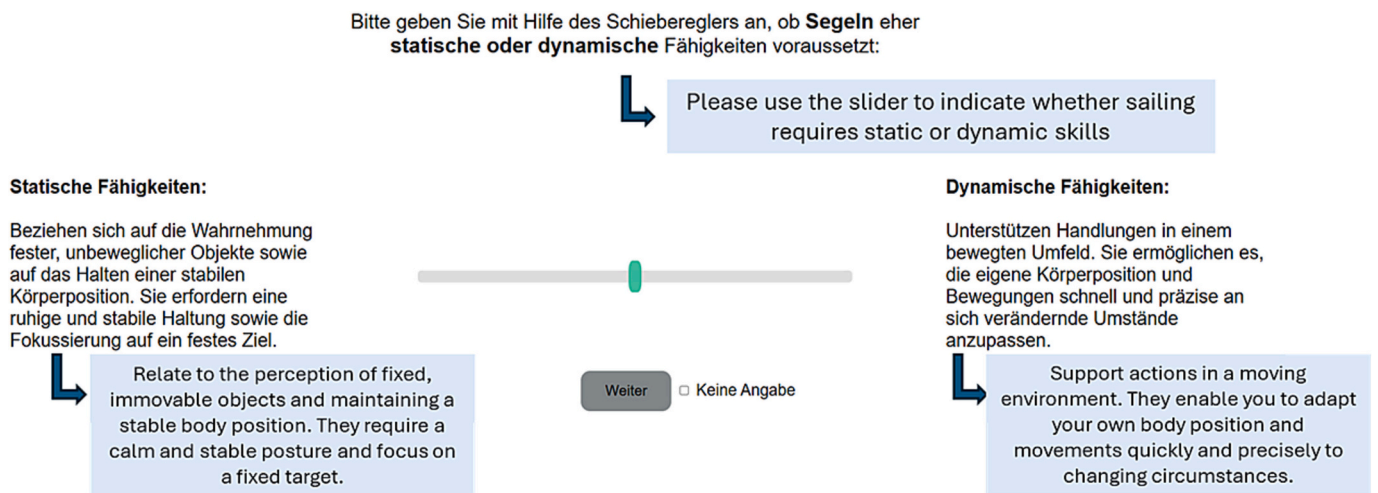


Fig. 1. Visual representation of a survey question assessing perception for the displayed sport in the static versus dynamic dimension with English translations (not shown in the original questionnaire).

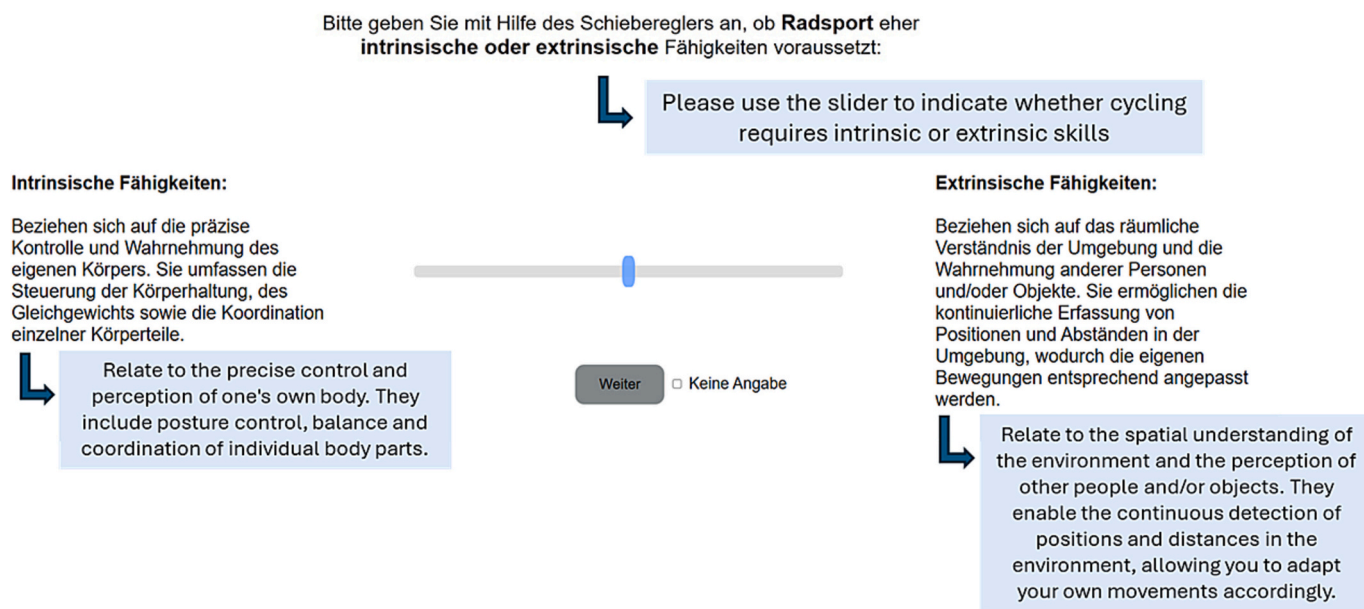


Fig. 2. Visual representation of a survey question assessing perception for the displayed sport in intrinsic versus extrinsic dimension with English translations (not shown in the original questionnaire).

Table 1
Descriptive statistics of the mean rating value for the visual-spatial dimensions.

| Sport | Intrinsic vs extrinsic | | Static vs Dynamic | |
|-----------------|------------------------|-----------|-------------------|-----------|
| | Mean | Std. Dev. | Mean | Std. Dev. |
| Badminton | 67.69 | 21.01 | 78.28 | 17.68 |
| Basketball | 73.73 | 19.46 | 83.86 | 15.56 |
| Soccer | 76.40 | 18.28 | 85.52 | 13.83 |
| Golf | <u>40.94</u> | 28.26 | <u>27.07</u> | 21.32 |
| Team handball | <u>72.51</u> | 19.81 | <u>85.06</u> | 14.33 |
| Hockey | 72.55 | 19.51 | 82.66 | 14.76 |
| Judo | 50.22 | 27.31 | 67.18 | 25.62 |
| Canoeing | 48.41 | 25.80 | 55.17 | 26.00 |
| Track and field | <u>28.94</u> | 22.59 | 67.97 | 25.92 |
| Cycling | <u>41.70</u> | 25.36 | 51.38 | 26.78 |
| Horse Riding | <u>45.54</u> | 26.17 | 51.15 | 27.98 |
| Shooting | <u>38.50</u> | 30.35 | <u>13.14</u> | 17.94 |
| Swimming | <u>27.18</u> | 21.96 | 65.61 | 27.40 |
| Sailing | 59.93 | 25.54 | <u>47.91</u> | 26.31 |
| Skiing | 43.87 | 23.89 | 65.07 | 25.86 |
| Dancing | <u>22.61</u> | 21.74 | 73.03 | 23.30 |
| Tennis | 66.98 | 21.27 | 79.93 | 16.27 |
| Table Tennis | 66.86 | 20.94 | 72.24 | 21.31 |
| Gymnastics | <u>20.24</u> | 19.98 | 52.04 | 29.17 |
| Volleyball | 71.65 | 19.40 | 82.68 | 14.41 |

Note. Intrinsic versus extrinsic and static versus dynamic (both ranging from 1 to 99). Values closer to the intrinsic and static pole in are underlined.

dimensions across the different sports, respectively. For the intrinsic-extrinsic dimension, badminton, basketball, soccer, team handball, hockey, sailing, tennis, table tennis, and volleyball were rated as more extrinsic, and golf, canoeing, track and field, horse-riding, shooting, swimming, dancing, gymnastics, skiing and cycling as more intrinsic, while judo fell in between with a rating of 50. For the static-dynamic dimension, golf, shooting, and sailing were rated as more static, whereas all other sports were rated as more dynamic.

3.2. Inferential analyses

ANOVA for the intrinsic-extrinsic dimension indicated main effect for sports [F(19,4712) = 163.217; p < 0.001; $\eta^2_p = 0.379$] and a significant interaction of sports x gender [F(19,4712) = 2.716; p < 0.001; $\eta^2_p = 0.010$]. Posthoc tests revealed significant gender differences for

golf (p = 0.003), swimming (p = 0.011), track and field (p = 0.036), shooting (p = 0.024), and cycling (p = 0.048) (Table 2). Accordingly, male participants rated cycling, golf, shooting, swimming, and track and field to be more intrinsic than female participants. No significant gender differences were observed for the remaining sports.

For the static-dynamic dimension, ANOVA demonstrated main effect for sports [F(19,4712) = 196.898; p < 0.001; $\eta^2_p = 0.424$] and a significant interaction of sports x gender [F(19,4712) = 2.152; p < 0.001; $\eta^2_p = 0.008$]. Posthoc tests revealed significant gender differences for horse riding (p = 0.030), shooting (p = 0.004), soccer (p = 0.002), table tennis (p = 0.030), and tennis (p = 0.021) (Table 2). Female participants ranked horse riding and shooting to be more dynamic than male participants, whereas male participants perceived soccer, tennis, and table tennis to be more dynamic than female participants. No significant gender differences were found for the remaining sports.

ANOVA revealed no significant differences in between age groups. In addition, no significant interaction effects were observed for age group and sports.

3.3. Clustering results

3.3.1. Hierarchical cluster analysis

When taking a closer look at Table 1, it appears that certain sports seem to be represented within different clusters. To examine this impression statistically (i.e., the possible clustering of different sports along the two dimensions), a hierarchical cluster analysis was

Table 2
Gender-based significant differences between participants.

| Dimension | Sport | η^2 | p-value | Post-hoc comparisons |
|-----------|-----------------|----------|---------|-----------------------|
| IE | Golf | 0.034 | 0.003 | Male > Female intrin. |
| IE | Swimming | 0.025 | 0.011 | Male > Female intrin. |
| IE | Track and Field | 0.017 | 0.036 | Male > Female intrin. |
| IE | Shooting | 0.018 | 0.024 | Male > Female intrin. |
| IE | Cycling | 0.016 | 0.048 | Male > Female intrin. |
| SD | Soccer | 0.038 | 0.002 | Male > Female dynam. |
| SD | Tennis | 0.021 | 0.021 | Male > Female dynam. |
| SD | Table Tennis | 0.018 | 0.030 | Male > Female dynam. |
| SD | Horse Riding | 0.018 | 0.030 | Female > Male dynam. |
| SD | Shooting | 0.031 | 0.004 | Female > Male dynam. |

Note. IE: Intrinsic vs extrinsic dimension; SD: Static vs dynamic dimension.

performed. In the first step, the cluster solution space was set from 2 (minimum number of cluster solutions) to 20 (maximum number of cluster solutions). For the clustering, the linkages between groups are displayed by a dendrogram using squared Euclidean distances as a measure (Fig. 3). Visual inspection of the dendrogram structure (Fig. 3) suggests that the different sports were grouped within four clusters. Therefore, the hierarchical cluster analysis was repeated while the cluster solution space was set to four clusters. The assignment of sports to these four clusters can be seen in Fig. 4.

3.3.2. K-means cluster analysis

K-means clustering revealed four distinct clusters of sports based on participants' intrinsic-extrinsic and static-dynamic ratings (Fig. 4). The first cluster contained golf and shooting, rated as intrinsic-static (Fig. 4). The second cluster consisted of soccer, basketball, team handball, volleyball, hockey, tennis, badminton, and table tennis, which were rated as extrinsic-dynamic (Fig. 4). The third cluster comprised of skiing, judo, canoeing, cycling, sailing, and horse riding, all rated as, with characteristics intermediate between intrinsic versus extrinsic and static versus dynamic leaning more toward dynamic. The fourth cluster included dancing, track and field, swimming, and gymnastics, perceived as intrinsic-dynamic (Fig. 4).

3.4. Exploratory analysis

3.4.1. Sample analysis

Participants from SurveyCircle, the University of Paderborn, and the University of Regensburg were also compared to analyze potential group differences in their ratings. No significant differences were found between the three participant groups. This analysis was conducted to ensure that data from the different recruitment sources could be pooled without introducing systematic bias.

3.4.2. Correlational analysis

Pearson's correlation further revealed significant moderate positive

correlations in badminton ($r = 0.348, p < 0.001$), judo ($r = 0.319, p < 0.001$), table tennis ($r = 0.304, p < 0.001$), and hockey ($r = 0.302, p < 0.001$), showing that participants who rated the activity as more extrinsic also tended to perceive it as more dynamic. Slightly smaller but still significant correlations appeared in team handball ($r = 0.277, p < 0.001$) and soccer ($r = 0.265, p < 0.001$), indicating that in these sports, participants who rated the activity as more extrinsic also tended to perceive it as more dynamic. No correlations were found in skiing, sailing, track and field, golf, swimming, dancing, and horse riding, suggesting perceived independence between these dimensions in these sports.

4. Discussion

The present study aimed to investigate how individuals perceived the visual-spatial demands of different sports along two dimensions: intrinsic vs. extrinsic and static vs. dynamic. We examined whether the participants categorized the twenty selected sports according to the established theoretical frameworks of visual-spatial abilities. Existing classifications of sports by visual-spatial demands such as by Pietsch (2018), though comprehensive and detailed, are the result of expert-based classification systems. What has been unclear so far is whether similar distinctions emerge when individuals evaluate the visual-spatial demands of sports from their own perspective. To address this, we conducted a survey with sport science students from two universities and additional participants recruited via the online platform SurveyCircle, who together form a heterogeneous sample with broad familiarity and interest in sports. Within this sample, we examined how the perceived visual-spatial demands of a wide range of sports relate to the distinctions proposed in Pietsch's (2018) taxonomy. We did not find systematic differences in visual-spatial ratings between sport science students and participants recruited via SurveyCircle, so we interpret the findings without distinguishing between these recruitment groups.

Taken together, the ratings suggest meaningful variation in perceived visual-spatial demands across different types of sports, which

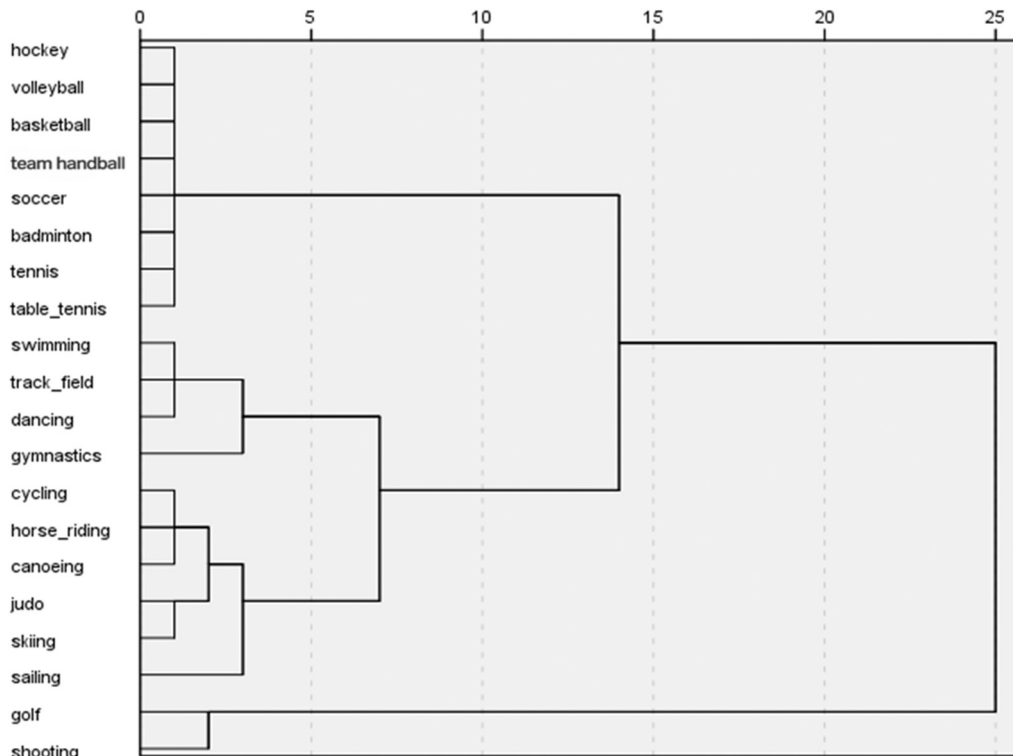


Fig. 3. Dendrogram of the average linkage (between groups of sports).

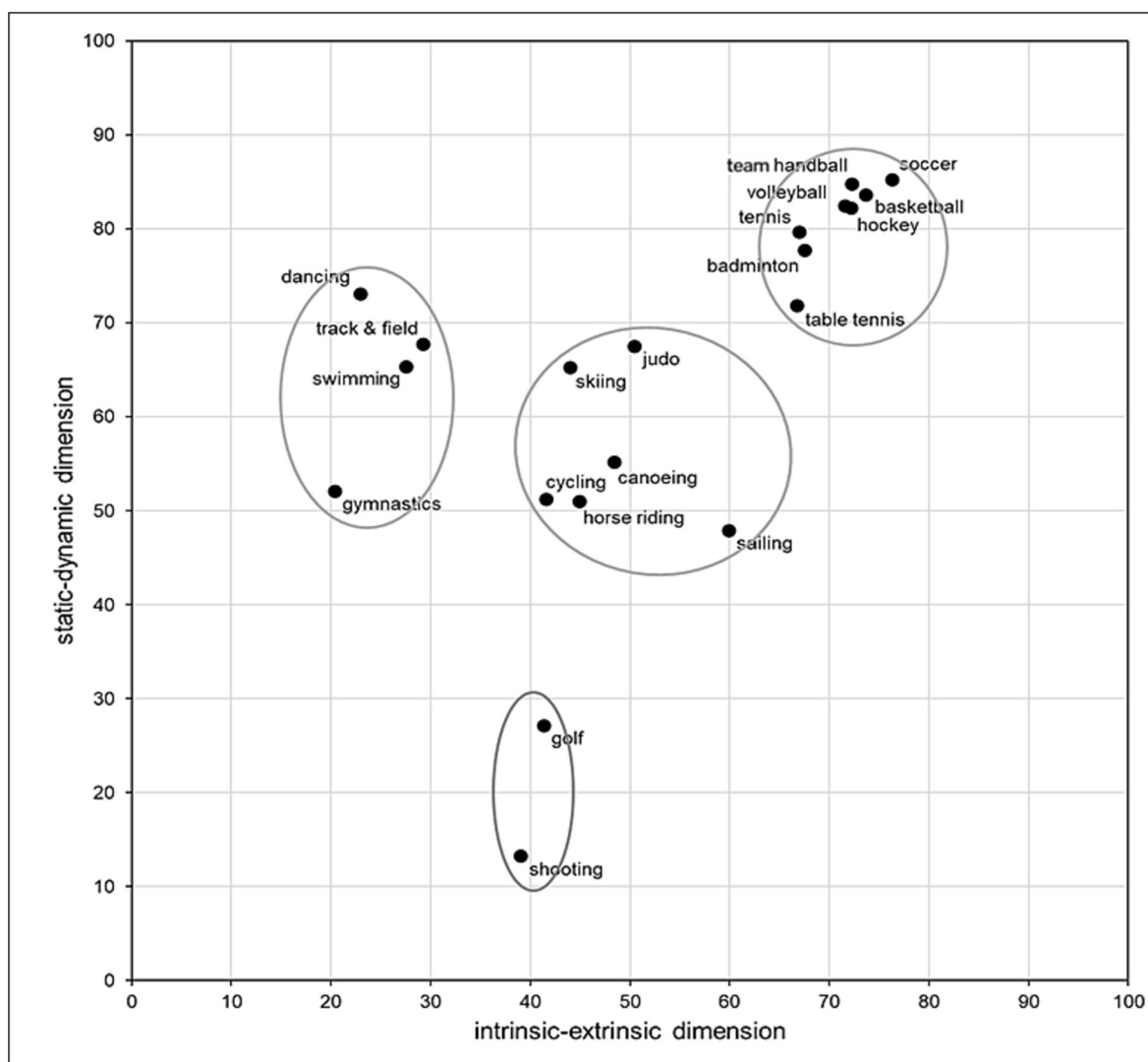


Fig. 4. Cluster structure of sports.

Note: As demonstrated by hierarchical and k-means cluster analyses as they yielded comparable solutions; the figure illustrates the resulting cluster configuration.

is consistent with Pietsch's (2018) visual-spatial taxonomy for sports and its basis in Uttal et al.'s (2013) intrinsic-extrinsic, static-dynamic framework for spatial abilities. In particular, the need for external focus and dynamic reaction in team sports, such as soccer or basketball, has also been emphasized in the past (Abernethy et al., 1999; Matos & Godinho, 2006; Pietsch et al., 2019; Williams et al., 1999). They are characterized by rapid exchanges and continuous adjustments to opponents' actions, which demand a higher level of extrinsic and dynamic visual-spatial information processing as demonstrated in our findings. By contrast, the prominence of self-referential feedback, for example kinesthetic cues, judges' form scores, tilts sports, such as dance or track and field, toward the intrinsic pole of the dimension, even though they are unmistakably movement-rich. This supports models that associate intrinsic visual-spatial demands with self-referential movement planning and internal body mapping (Hegarty & Waller, 2005; Perrin et al., 2000; Pietsch, 2018; Pietsch et al., 2019). Although these disciplines involve vigorous movement, performance is judged more by internal factors, such as body awareness, technique, and aesthetic execution, rather than by direct confrontation with an opponent, which further matches the perceptions revealed in this study.

Skiing, canoeing, and judo demonstrated an intermediate intrinsic-extrinsic rating indicating a general perception of the balance between intrinsic visual-spatial demands (edge control in skiing, feel for water in

canoeing) and extrinsic visual-spatial feedback integration (race times, head-to-head bouts in judo) as being more evenly split. This supports the view that visual-spatial demands in such sports fluctuate with context, performance phase, and interaction demands. This is consistent with ecological dynamics and constraints-led perspectives, which propose that skill and perception-action coupling emerge from the continuous interaction of performer, task, and environmental constraints rather than fixed categorical characteristics (Araújo et al., 2006; Davids et al., 2008; Newell, 1986).

Gender was included as an independent variable in the analyses in an exploratory (rather than theoretically driven) manner, to examine potential differences in how visual-spatial demands of sports are perceived across demographic groups. This decision is informed by prior research suggesting that visual-spatial processing and sport-related experiences may vary as a function of gender (Notarnicola et al., 2014). The significant sports and gender interactions suggest that gender had a limited but detectable influence on how some sports were rated on the intrinsic-extrinsic and static-dynamic dimensions. This may reflect differences in prior exposure, sport participation, or familiarity with specific activities, although the present data do not allow a direct test of these possibilities. Importantly, the effects were small and did not extend across all sports. Moreover, the absence of age-related differences and age and sports interactions suggests that these judgments were relatively stable across

age groups in the current sample. Together, these findings suggest that perceptions of visual-spatial sport demands are shared across participants, with only limited gender-specific variation.

4.1. Visual-spatial processing demands in sports as dimensionally weighted

Taken together, the convergence and divergence between expert-based and participant-based classifications suggest that visual-spatial demands may not be fixed properties of sports but instead reflect flexible combinations of multiple visual-spatial information sources. A central contribution of the present findings is their strong alignment with a dimension-weighting account of visual-spatial demands perception (Müller et al., 1995). According to this framework, perceptual dimensions are flexibly weighted depending on task relevance rather than processed in an all or none fashion (Müller et al., 1995). Building on this framework, the present findings suggest that dimension-weighting operates not only at the level of basic perceptual features, but also at the level of sport-specific visual-spatial demands, shaping how different sports are conceptualized in terms of their visual-spatial information requirements.

In the current data, most sports were rated between the extreme poles of the intrinsic-extrinsic and static-dynamic continua, indicating that participants implicitly attributed varying degrees of importance to multiple visual-spatial information sources within a single sport. This pattern suggests that visual-spatial demands were perceived as dynamically weighted combinations of intrinsic and extrinsic, as well as static and dynamic, information rather than as fixed or categorical properties of a sport. Importantly, this graded pattern was evident even in sports traditionally considered prototypical examples of one dimension. For instance, team sports, such as soccer and team handball, were rated as predominantly extrinsic and dynamic, yet not exclusively so, reflecting the acknowledged role of intrinsic body-centered control in skill execution. Conversely, sports, such as dance and gymnastics, commonly associated with intrinsic and static visual-spatial demands, were perceived to involve extrinsic and dynamic components as well. These findings provide empirical support for the notion that visual-spatial demands in sports reflect adaptive dimension-weighting, rather than categorical classification.

The dimension-weighting interpretation is also conceptually consistent with ecological dynamics, which emphasizes perception-action coupling and the continuous interaction between athlete, task, and environment (Araújo et al., 2006). From this perspective, athletes are not thought to rely on fixed internal representations but instead dynamically recalibrate perceptual information sources as situational constraints evolve. The present findings suggest that such recalibration is not only a feature of skilled performance but is also reflected in how observers conceptualize the visual-spatial demands of different sports. The intermediate ratings observed for sports, such as judo, skiing, canoeing, and cycling, further support this view. These sports were perceived as requiring a balance between intrinsic and extrinsic visual-spatial information, likely reflecting shifts in task constraints across competitive contexts, skill levels, or performance phases. Such flexibility aligns with ecological dynamics models that describe behavior as emergent and context-dependent, reinforcing the interpretation that visual-spatial demands in sport are not static but continuously reweighted (Araújo et al., 2006).

When compared with Pietsch's (2018) expert-based classification, the present results show both convergence and divergence. Broad patterns such as the extrinsic-dynamic characterization of team sports and the intrinsic emphasis of aesthetic and precision sports were largely consistent across studies (Pietsch, 2018). However, notable differences emerged for several disciplines, including martial arts, dance, swimming, and skiing (Pietsch, 2018). These differences highlight the value of integrating expert classifications with the perspective of a more general population. The present findings suggest that visual-spatial

classifications benefit from empirical grounding and that perceived demands may shift depending on contextual interpretation. This supports the need for ongoing reassessment of sport classifications, particularly when they can possibly be used to inform training design or cognitive assessment.

4.2. Extending the dimensional framework

From an ecological dynamics' perspective, such continuous variation reflects the adaptive coupling between perception and action, where athletes constantly recalibrate the relative influence of intrinsic and extrinsic information in response to situational constraints (Araújo et al., 2006). Together, these perspectives suggest that visual-spatial processing in sport is inherently flexible and context-dependent, rather than fixed at one pole of either dimension.

To illustrate this graded view more concretely both scales can be divided into three segments, resulting in a more fine-grained taxonomy divided into 9 fields of visual-spatial processing demands. Values between 1 and 33 represent tasks closer to the intrinsic (or static) pole, 66–99 reflect tasks toward the extrinsic (or dynamic) pole, and 33–66 indicate sports in which both intrinsic/static and extrinsic/dynamic visual-spatial information are important and receive roughly similar weighting. This notion of flexible emphasis also aligns with dimension-weighting accounts proposed in visual perception (Müller et al., 1995), which suggest that attention dynamically assigns greater or lesser weights to perceptual dimensions depending on task relevance. By analogy, athletes may continuously reweigh intrinsic and extrinsic visual-spatial information according to the situational demands. Sports that fall near the middle of each continuum may therefore involve a balanced weighing mechanism, in which both internally generated (intrinsic/static) and externally derived (extrinsic/dynamic) visual-spatial information are processed with comparable priority.

Recognizing these "middle zones" provides a more nuanced understanding of the perceptual complexity of real-world sports and helps explain why participants' judgments did not cluster at the extremes. In doing so, the present findings suggest an extension of Uttal et al.'s (2013) framework by reframing intrinsic-extrinsic and static-dynamic processing as continuous, jointly weighted dimensions rather than discrete categories. Future research could test whether these perceptual gradations correspond to measurable differences in attentional weighting, decision strategies, or performance adaptability across sports.

4.3. Practical implications

The present findings have practical implications for sport-specific cognitive-motor training. If visual-spatial demands are best conceptualized as weighted combinations of multiple dimensions, training programs should reflect this complexity rather than targeting isolated skills. Athletes in predominantly extrinsic-dynamic sports may further benefit from training intrinsic body awareness, whereas athletes in intrinsically oriented disciplines may benefit from exposure to externally driven and variable visual-spatial challenges. The identification of intermediate zones along both continua further suggests that sports cannot be meaningfully reduced to discrete categories.

4.4. Future research

Future research should confirm and refine these distinctions using systematic qualitative and quantitative approaches. Expert interviews, observational analyses, rating scales, and behavioral performance measures may help operationalize graded intrinsic-extrinsic and static-dynamic demands beyond perceptual classification. Such work could inform coaching practices, talent identification, and the design of practice environments aligned with athletes' motivational profiles.

4.5. Limitations

While this study offers valuable insights into the cognitive visual-spatial categorization of sports, several limitations must be acknowledged. The reliance on self-reported perceptions introduces potential subjectivity and bias, as participants' ratings may be influenced by personal experience, familiarity, or preconceptions rather than objective visual-spatial demands. Self-report measures are known to be vulnerable to cognitive and situational biases, such as miscomprehension, recall error, and social-desirability or self-serving tendencies, which can distort appraisals of internal states and performance-related constructs (Saw et al., 2015).

Furthermore, sport-specific experience of the participants was not controlled or measured, which might have influenced participants' judgments differently depending on their level of exposure. Research indicates that sport expertise modulates visual-spatial processing, postural control, and sensory integration, meaning that experienced athletes may construe the same visual-spatial demands differently from novices (Buscemi et al., 2024; Thalassinou et al., 2018). Systematic reviews of sports-expertise and visual-attention studies also highlight that failure to account for expertise level can confound comparisons of perceptual and cognitive performance across groups (Mann et al., 2007). Lastly, the selected sports were chosen based on high national participation to ensure familiarity. However, this could still exclude niche or emerging sports with distinct visual-spatial profiles, particularly because public-policy and cultural structures tend to favor mainstream, high-participation activities (Bergsgard, 2025).

5. Conclusion

This study contributes to the growing body of research on cognitive visual-spatial processing in sports by examining how individuals categorize various disciplines along the dimensions of intrinsic versus extrinsic and static versus dynamic visual-spatial demands. The findings indicate that perceptions of these demands in sports are consistent with the theoretical framework of visual-spatial skills by Uttal et al. (2013). However, they reveal complex and overlapping patterns that go beyond binary classifications and fall on a continuum. Team-based, fast-paced sports were rated as more extrinsic and dynamic, while individual, form-driven sports were associated with intrinsic and dynamically changing visual-spatial abilities. Sports showed the involvement of both poles of the two dimensions to varying degrees, suggesting that visual-spatial demands in sports exist along a continuum. The findings further support an extension of the current framework in which visual-spatial information processing demands in sport are conceptualized as dimensionally weighted combinations of multiple visual-spatial dimensions, rather than as fixed dichotomous categories. These findings have further practical implications for sport-specific cognitive-motor training, suggesting that visual-spatial demands should be addressed as integrated and multidimensional rather than isolated skills. Instead of training, for example, spatial orientation, object tracking, and decision-making in separate drills, coaches and practitioners could design tasks that simulate the dynamic, multi-dimensional nature of real-world sports situations. In this way, athletes practice perceiving, processing, and acting on visual-spatial information simultaneously, which may enhance transfer to actual game performance. Future research could integrate neurocognitive measures, behavioral assessments, or longitudinal tracking to deepen our understanding of how these perceptual categories align with performance outcomes.

CRedit authorship contribution statement

Bhagyashree Singh: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Matthias Weigelt:** Writing – review & editing, Visualization.

Miro Ebert: Writing – review & editing, Software, Methodology, Investigation, Conceptualization. **Petra Jansen:** Writing – review & editing, Supervision, Resources, Methodology, Conceptualization.

Declaration of competing interest

We have no conflicts of interest to disclose.

Data availability

Data will be made available on request.

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