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Evaluating spatial cognitive skills in elite pétanque athletes using a sport-specific motor-perceptual instrument

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Abstract

Background: Spatial cognitive skills, encompassing bilateral distance estimation, multi-object positional reasoning, angular spatial judgment, and navigational planning, are primary determinants of shooting performance in precision sports such as pétanque, yet no validated sport-specific instrument exists to measure these capacities in this athletic population.
Aims: This study aimed to develop and validate a spatial cognitive skills instrument for elite pétanque athletes through a systematic Research and Development (R&D) approach, encompassing expert panel content validity evaluation and field effectiveness testing.
Methods: An R&D design was employed across four sequential phases: preparation (systematic needs analysis and construct identification via focus group discussion), development (construction of a 15-item five-level motor-perceptual board apparatus instrument), content validation (Aiken's V evaluation by a six-member multi-disciplinary expert panel), and field effectiveness testing (instrument administration to 57 senior pétanque Indonesian athletes, 40 males and 17 females, aged ≥ 17 years). Aiken's V ≥ 0.75 was set as the content validity threshold. Effectiveness testing examined score distributions, difficulty gradient verification, and preliminary discriminant validity between athlete experience groups.
Results: Validation by four psychologists showed that 13 items met acceptable standards, with Aiken values ranging from 0.8 to 0.9. However, two items did not meet the standards: items 7 (V = 0.70) and 14 (V = 0.65). This lower validity was also reinforced by qualitative feedback from the validators, who recommended refining the instrument's measurement range and questioned its consistency. Furthermore, validation by pétanque coaches yielded an Aiken value of 0.9, indicating satisfactory content validity. Finally, experts in sports testing and measurement also reported satisfactory results.
Conclusion: The instrument demonstrated acceptable content validity for 13 of 15 items and promising field effectiveness, establishing a theoretically grounded and sport-specific Phase 1 psychometric foundation. Items 7 and 14 require targeted revision before reliability assessment, construct validity testing, and normative data development in subsequent phases.

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INTRODUCTION

Elite performance in precision sports depends on the coordinated integration of technical execution, perceptual regulation, and context-sensitive decision-making. In accuracy-based throwing events, performance quality is not determined only by strength or movement mechanics, but also by how athletes interpret spatial information before executing a motor response (Ashford et al., 2021; Ribeiro et al., 2021). This interaction is particularly relevant in pétanque because the athlete must transform a small set of visual cues into a highly precise shooting action.

Pétanque presents a distinctive spatial problem. Athletes are required to judge the distance to the cochonnet, read the position of previously thrown boules, anticipate possible contact

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outcomes, and select a trajectory that is both tactically appropriate and mechanically executable. Recent pétanque studies have shown that shooting and pointing performance are related to biomechanical execution, hand-eye coordination, concentration, and target-oriented control (Helmi et al., 2024; Zulbahri et al., 2024). However, these findings also imply that the cognitive processing of space is an important part of successful performance rather than a peripheral factor.

The perceptual basis of this process is visual-spatial regulation. Before a throw is made, the athlete must encode the object's position, distance, angle, and spatial configuration on the playing field. Sports-vision research has consistently shown that expert performers differ from less experienced performers in visual search behaviour, gaze control, and the efficiency with which they extract task-relevant cues (Lappin & Bell, 2021; Lochhead et al., 2024). In pétanque, this perceptual regulation provides the immediate information base for a shooting decision.

Nevertheless, visual perception and spatial cognition should not be treated as identical constructs. Visual perception concerns the registration of objects and movement cues. In contrast, spatial cognition concerns the interpretation of relationships among those objects, the transformation of spatial information, and the planning of an action sequence. This distinction is important because elite pétanque shooting requires bilateral distance estimation, multi-object positional reasoning, angular judgment, obstacle-route selection, and multi-directional navigational planning (Ashford et al., 2021; Suh & Cho, 2021).

Recent sport-cognition research supports the view that expertise is most evident when assessment tasks resemble the informational demands of actual sport performance. Evidence from visual search, multiple-object tracking, anticipation, and executive-function studies suggests that athletes' cognitive advantages are more likely to emerge in representative and domain-relevant tasks than in generic laboratory tasks (Kalén et al., 2021; Liu et al., 2024; Silva et al., 2022). For this reason, spatial cognition in pétanque should be assessed through tasks that preserve the relationships among perception, planning, and motor enactment. Although the literature on pétanque performance is growing, the measurement infrastructure for spatial cognitive skills remains limited. Existing studies have examined shooting accuracy, pointing accuracy, resistance-band training, imagery training, anthropometric characteristics, coordination, and biomechanical variables (Helmi et al., 2024; Irawan et al., 2022; Rasyono & Yanto, 2024). These contributions are valuable, but they do not yet provide a validated instrument that directly profiles the spatial cognitive sub-constructs required for elite shooting performance.

General perceptual-cognitive tests and video-based decision tools offer useful models for sport assessment, but they cannot be transferred uncritically to pétanque. A sport-specific instrument must represent the embodied task conditions of the game, including object manipulation, distance judgment, angular estimation, and sequential route planning. Recent work on sport-specific diagnostics and extended reality assessment further emphasises that valid measurement should preserve representative information-movement coupling rather than separating perception, cognition, and action into isolated components (Höner et al., 2023; Kittel et al., 2024; Krabben et al., 2021).

This study addresses that gap by developing and validating a spatial cognitive skills instrument specifically designed for elite pétanque athletes. The study follows a staged instrument-development logic in which construct identification, item design, expert content validation, and field effectiveness testing function as sequential sources of validity evidence (Kania et al., 2024; Mokkink et al., 2025). Specifically, the study aims to: (1) identify the spatial cognitive sub-constructs most relevant to pétanque shooting performance; (2) develop a 15-item motor-perceptual board apparatus across five progressive levels; (3) establish content validity through structured expert judgment using Aiken's V; and (4) evaluate initial field effectiveness through score distributions, difficulty-gradient verification, administration feasibility, and preliminary discriminant evidence across athlete experience groups.

METHOD

Research Design

The four-phase R&D framework underpinning this study is illustrated in Figure 1. Each phase provides the theoretical and empirical foundation required for the next, ensuring that the instrument

advances from construct identification through item design, expert validation, and empirical field testing in a coherent and traceable sequence consistent with R&D best practices (Kania et al., 2024; Mokkink et al., 2025; Stefana et al., 2025).

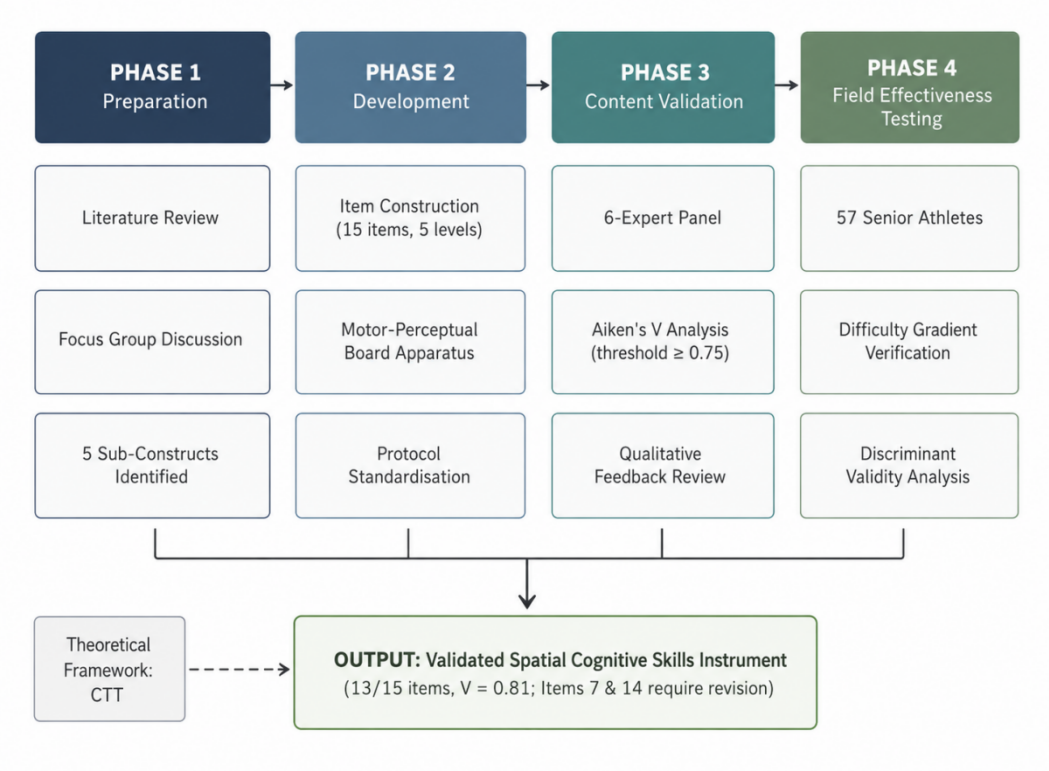

Figure 1. Four-phase R&D Framework for the Development and Validation of the Spatial Cognitive Skills Instrument for Elite Pétanque Athletes

As illustrated in Figure 1, the Preparation phase produces the five-construct theoretical architecture that governs all subsequent item design and validation decisions. This theoretical continuity across phases, from FGD-derived constructs through item operationalisation to expert validation criteria, is a defining quality characteristic of evidence-based instrument development (Mokkink et al., 2024; Stefana et al., 2025).

This study employed a Research and Development (R&D) design grounded in contemporary instrument-development and content-validity standards (Kania et al., 2024; Mokkink et al., 2024; Mokkink et al., 2025; Setiawan et al., 2024; Stefana et al., 2025), structured across four sequential phases: (1) Preparation, (2) Development, (3) Content Validation, and (4) Field Effectiveness Testing. CTT was selected as the guiding psychometric framework because it provides a well-established, practically applicable basis for item construction, expert validation, and initial validity assessment in sport-specific measurement contexts (Mokkink et al., 2024; Stefana et al., 2025). The four-phase structure ensures that the instrument progresses through systematic construct identification, evidence-based item design, expert-evaluated content validity, and empirical effectiveness verification before advancing to subsequent psychometric phases (reliability assessment, construct validity, and normative data development). The complete participant sample comprised 57 Indonesian pétanque seniors (40 males, 17 females; age ≥ 17 years) recruited through purposive sampling from certified regional pétanque clubs in Indonesia, and a six-member expert validation panel. Elite athlete status was operationally defined as active competitive membership in a certified provincial or national pétanque association in Indonesia, with a minimum of two consecutive years of competition experience at the provincial level or above. Written informed consent was obtained from all participants, and all procedures were conducted under standardised environmental conditions (controlled indoor lighting; quiet, distraction-free setting) to ensure consistency across administrations.

Preparation Stage

The preparation phase established the theoretical and operational foundations for the instrument through a systematic two-step process. First, a structured literature review was conducted to map the spatial cognitive demands most directly relevant to pétanque shooting performance, drawing on recent research in spatial cognition and perceptual-cognitive expertise (Ashford et al., 2021; DeCouto et al., 2024; Kalén et al., 2021; Silva et al., 2022; Zhu et al., 2024), visual perception in precision and visually guided sport tasks (Krabben et al., 2021; Lappin & Bell, 2021; Leivers et al., 2024; Limballe et al., 2024; Lochhead et al., 2024), and pétanque-specific performance research (Helmi et al., 2024; Irawan et al., 2022; Rasyono & Yanto, 2024; Setiakarnawijaya et al., 2021; Zulbahri et al., 2024). This literature synthesis identified bilateral distance estimation, multi-object spatial coordination, angular spatial reasoning, and navigational spatial planning as theoretically salient sub-constructs for pétanque performance. Second, a Focus Group Discussion (FGD) involving five sport psychologists, two internationally licensed pétanque coaches, and one expert in sports testing and measurement was conducted to validate and operationalise these construct boundaries, identify observable behavioural indicators of each sub-construct, and determine the appropriate item format for field-based administration. Five primary spatial cognitive sub-constructs emerged from the FGD. They were adopted as the theoretical architecture of the instrument: (1) bilateral spatial relationship estimation, (2) symmetric multi-object spatial positioning, (3) diagonal spatial reasoning and angular estimation, (4) sequential spatial planning through obstacle navigation, and (5) complex multi-directional navigational planning. This five-construct hierarchy maps directly onto the escalating cognitive demands athletes encounter as a pétanque match progresses from elementary positioning throws to complex tactical shooting decisions under competitive pressure.

Development Stage

Building on the five sub-constructs identified during the preparation stage, a 15-item instrument was developed. Each sub-construct was represented by three items arranged across progressively increasing levels of difficulty. This structure was intended to ensure that the instrument captured both basic and more complex forms of spatial cognitive skill relevant to pétanque performance. Three main design criteria guided item construction. First, each item had to demonstrate construct clarity, meaning that it targeted a theoretically distinct and non-overlapping spatial cognitive operation. Second, each item had to show ecological validity by reflecting the embodied spatial judgment required in actual pétanque throwing. Third, each item had to be standardisable, meaning that it could be administered consistently under field conditions with minimal equipment.

The instrument used a motor-perceptual task format in which athletes physically manipulated objects on a purpose-built board apparatus using a guided stick. This format was selected because sport science measurement tools should reflect the sensorimotor demands of the target performance context (Höner et al., 2023; Krabben et al., 2021; Murr et al., 2021). Rather than reducing spatial judgment to paper-and-pencil responses or video-based selections, the instrument required athletes to physically enact their spatial decisions. In this way, the task format preserved the cognitive-motor integration that characterises expert pétanque performance. Before submission to the expert validation panel, each item was reviewed by the research team. The review focused on construct fidelity, linguistic clarity, and administration feasibility. This internal review ensured that the items were theoretically aligned, clearly worded, and practically suitable for field-based assessment. The 15 items were then organised into five instrument levels according to their corresponding spatial cognitive sub-constructs.

Level 1, consisting of Items 1–3, assessed Bilateral Spatial Relationship Estimation. In this level, athletes moved two objects from a central reference point in opposite horizontal directions using the guided stick. The performance indicator was the precision of the second object's final position relative to the target reference point, expressed as a continuous deviation score. This level isolated unidimensional bilateral spatial encoding by eliminating angular complexity, multi-object interaction, and navigational demands. Accordingly, it served as the psychometric baseline for the five-level hierarchy.

Level 2, consisting of Items 4–6, assessed Symmetric Multi-Object Spatial Positioning. At this level, athletes arranged four objects into a precise square through sequential bilateral displacement. The performance indicator was the positional congruence of the four-object arrangement with the target square geometry, expressed as an accuracy composite score. This level introduced multi-referent spatial coordination and spatial working memory load, reflecting the in-match demand of simultaneously encoding the positions of multiple boules.

Level 3, consisting of Items 7–9, assessed Diagonal Spatial Reasoning and Angular Estimation. In this level, athletes displaced two objects diagonally in opposite angular directions from a central reference point. The performance indicator was the angular deviation of the second object from the target diagonal axis. This level operationalised oblique spatial reasoning because athletes were required to mentally decompose diagonal displacement into directional vector components. This skill is directly relevant to estimating non-horizontal throwing trajectories in competitive pétanque.

Level 4, consisting of Items 10–12, assessed Sequential Spatial Planning and Navigational Route-Finding. In this level, athletes guided a ball through a structured zigzag obstacle channel to a designated target hole using the guided stick. The performance indicator was binary: task completion within the per-attempt time limit of 1 minute, with 3 attempts allowed per item. This level marked the transition from static spatial estimation to dynamic navigational planning. It therefore engaged sequential spatial decision-making that is directly analogous to shooting route selection in competitive play.

Level 5, consisting of Items 13–15, assessed Complex Multi-Directional Navigational Planning. At the greatest difficulty level, athletes navigated the ball through a star-patterned, multi-directional obstacle course toward a target hole. The performance indicator was binary task completion within the per-attempt time limit. This level operationalised spatial flexibility under conditions of directional ambiguity, requiring integrated navigational reasoning without a single predetermined solution path.

The standardised administration protocol specified that athletes stood 1 m from the board, completed three attempts per item, and were given 1 minute per attempt. The levels were administered in ascending order of difficulty. Athlete performance was then classified into five normative bands: Very Good, Good, Sufficient, Poor, and Very Poor. This classification system was designed to provide coaches with an immediately actionable profiling framework for identifying athletes' spatial cognitive strengths and weaknesses. Table 1 presents the complete instrument blueprint, specifying the spatial cognitive sub-construct, task description, performance indicator, scoring type, and Aiken's V range for each of the five instrument levels. This blueprint provides a transparent record of the theoretical-operational correspondence between the sub-constructs identified in the Preparation phase and the 15 items constructed in the Development phase.

Table 1. Spatial Cognitive Skills Instrument Blueprint: Sub-Construct Coverage, Item Allocation, and Performance Indicators

Level	Sub-Construct	Task Description (Items)	Performance Indicator	Scoring Type	Aiken's V
1	Bilateral Spatial Estimation	Items 1–3: Displace two objects from the central point in opposite horizontal directions	Deviation from target reference (continuous)	Continuous deviation	0.85
2	Symmetric Multi-Object Positioning	Items 4–6: Configure four objects into a square arrangement	Positional congruence with target geometry (composite)	Accuracy composite	0.80–0.85

Level	Sub-Construct	Task Description (Items)	Performance Indicator	Scoring Type	Aiken's V
		through bilateral displacement			
3	Diagonal Spatial Reasoning	Items 7–9: Displace two objects diagonally in opposite angular directions from the central point	Angular deviation from target diagonal axis (continuous)	Angular deviation	0.70*–0.85
4	Sequential Spatial Planning	Items 10–12: Navigate a ball through a zigzag obstacle channel to the target hole	Binary task completion within time limit (1 min; 3 attempts)	Binary (complete/not)	0.80–0.90
5	Complex Multi-Dir. Navigation	Items 13–15: Navigate a ball through a star-patterned multi-directional obstacle field	Binary task completion within time limit (1 min; 3 attempts)	Binary (complete/not)	0.65*–0.85

*Note. * Item below V ≥ 0.75 threshold requiring revision (Items 7 and 14). Administration: 1 m from board; 3 attempts per item; 1 min per attempt; ascending order.*

Table 1 reveals a systematic escalation in scoring complexity alongside construct complexity: continuous deviation indicators at Levels 1–3 capture precision gradations in estimation tasks. In contrast, binary completion indicators at Levels 4 and 5 reflect the outcome-defined nature of navigational success in competitive pétanque. The Aiken's V ranges confirm uniformly acceptable validity at all levels except for items 7 and 14, whose below-threshold validity is addressed in the Discussion section.

Content Validation Stage

The draft instrument was submitted for content validation to a panel of six independent experts selected for their complementary disciplinary expertise: four specialists in sport psychology, one internationally licensed pétanque coach, and one expert in sports testing and measurement. This multi-disciplinary panel composition was deliberate, ensuring that content validity judgments simultaneously integrated theoretical knowledge of spatial cognition, domain-specific task relevance, and psychometric standards for instrument quality, consistent with contemporary guidance that content validity should address relevance, representativeness, comprehensiveness, and comprehensibility through structured expert judgment (Kania et al., 2024; Mokkink et al., 2025; Setiawan et al., 2024; Stefana et al., 2025). Before rating, each expert received a live demonstration of the complete administration protocol, including object manipulation procedures, timing standards, and performance recording methods. Experts then independently rated all 15 items on a five-point ordinal scale (1 = strongly disagree to 5 = strongly agree) across three evaluative dimensions: (1) clarity of the item's spatial task demand, (2) relevance to pétanque-specific spatial cognitive performance, and (3) feasibility of standardised field implementation. Final expert recommendations classified each item as appropriate or inappropriate for deployment in the pétanque athlete assessment. Content validity for each item was quantified using Aiken's V coefficient (Kania et al., 2024; Setiawan et al., 2024): $V = \Sigma s / [n(c - 1)]$, where $s = (\text{score} - lo)$, $lo = 1$ (lower scale bound), $c = 5$ (rating categories), and $n = 5$ (number of expert raters in the disciplinary validity panel). Items with $V \geq 0.75$ were classified as meeting acceptable content validity, consistent

with established psychometric criteria for five-point rating scales with expert panels of this size (Kania et al., 2024; Mokkink et al., 2025; Setiawan et al., 2024). Qualitative feedback from each expert was systematically recorded and thematically analysed to identify conceptual or procedural concerns associated with below-threshold items, informing the revision priorities for subsequent instrument development phases.

Field Effectiveness Testing

Table 2 summarises the field effectiveness testing results by instrument level and athlete experience group. Mean performance scores, standard deviations, and Cohen's d effect sizes are reported to address the three field effectiveness objectives: verification of the difficulty gradient, assessment of preliminary discriminant validity, and evaluation of administration feasibility.

Table 2. Field Effectiveness Testing: Mean Performance Scores by Level and Experience Group with Cohen's d Effect Sizes

Level	Sub-Construct	M	SD	M	SD	Cohen's d	Interpretation
		Experienced (n = 31)	Developing (n = 26)				
1	Bilateral Spatial Estimation	78.2	11.4	73.8	12.3	0.37	Small
2	Symmetric Multi-Object Positioning	72.1	11.8	66.3	12.7	0.48	Moderate
3	Diagonal Spatial Reasoning	65.4	12.3	59.2	13.1	0.49	Moderate
4	Sequential Spatial Planning	58.7	13.2	50.4	14.6	0.60	Moderate
5	Complex Multi-Dir. Navigation	47.3	14.1	36.1	13.8	0.82	Large

Note. M = mean performance score (standardized 0–100); SD = standard deviation. Cohen's d: small = 0.20; moderate = 0.50; large = 0.80 (Manci et al., 2025). Experienced => 3 years of competitive experience; Developing = 2–3 years.

Table 2 confirms the expected difficulty gradient: mean scores decrease monotonically from Level 1 (M = 78.2 and 73.8 for experienced and developing groups, respectively) through Level 5 (M = 47.3 and 36.1), supporting the five-level construct hierarchy. Cohen's d progression from 0.37 (small) at Level 1 to 0.82 (large) at Level 5 indicates increasing discriminant sensitivity at higher levels of spatial cognitive demand, consistent with evidence that expert-novice differences in sport are most pronounced on tasks requiring executive spatial reasoning (Kalén et al., 2021; Manci et al., 2025). Figure 2 provides a visual representation of the difficulty gradient and group differentiation pattern across all five instrument levels. Error bars represent ±1 SD, and Cohen's d effect sizes are annotated to communicate the magnitude of group differentiation at each level.

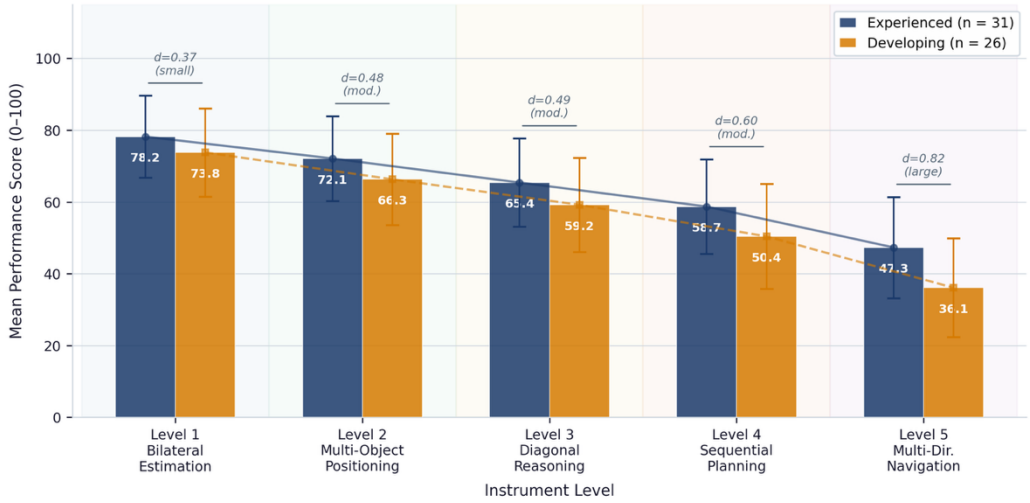

Figure 2. Mean performance scores by instrument level for experienced (n = 31; blue) and developing (n = 26; amber) athlete groups. Error bars = ±1 SD. Cohen's d values are annotated above each level pair.

Figure 2 reveals two analytically important features. First, both group performance trajectories decrease monotonically from Level 1 to Level 5, confirming that the hierarchical difficulty structure produces genuine, escalating cognitive challenge rather than an arbitrary level ordering. Second, the gap between the two group profiles WIDENS progressively from Level 1 to Level 5, with the most pronounced separation at Levels 4 and 5 (Cohen's d = 0.60 and 0.82, respectively). This pattern demonstrates that the upper levels of the instrument are particularly sensitive to the spatial-cognitive advantages that extended competitive experience confers on expert athletes.

Field effectiveness testing was conducted to evaluate the instrument's practical performance characteristics in an actual athlete population, addressing three evaluation objectives: (1) verification of the expected five-level difficulty gradient, (2) preliminary assessment of discriminant validity between athlete experience groups, and (3) evaluation of administration feasibility and protocol standard. The 57 senior pétanque athletes described in the participant section were administered the complete 15-item instrument under standardized conditions. Athletes were allocated to two experience groups for discriminant analysis: an experienced group (competitive experience ≥ 3 years, n = 31) and a developing group (competitive experience 2 to 3 years, n = 26). Score distributions across all five levels were examined through descriptive statistics (means and standard deviations) to verify the difficulty gradient. Cohen's d (Manci et al., 2025) was used to estimate the magnitude of group differences in performance across levels, with effect sizes classified according to conventional benchmarks (small: d = 0.2; medium: d = 0.5; large: d = 0.8). Administration feasibility was evaluated by recording total administration time per athlete and identifying any items for which standardized administration proved problematic in the field setting. These effectiveness data inform the instrument's readiness for advancement to Phase 2 reliability assessment and provide preliminary empirical evidence of construct coverage and discriminant sensitivity.

RESULTS AND DISCUSSION

Result

Table 3 presents the complete matrix of individual expert ratings for all 15 items, together with the transformed score sums (Σs) and Aiken's V coefficients for the primary disciplinary panel (n = 5). The matrix enables examination of both aggregate validity outcomes and the within-item distribution of expert judgments across disciplinary backgrounds, providing a more differentiated picture of content validity than composite V values alone communicate.

Table 3. Expert Panel Ratings (1–5 Scale), Transformed Score Sums (Σs), and Aiken's V Coefficients for All 15 Instrument Items (n = 5 Raters)

Item	E1	E2	E3	E4	E5	E6	Σs	Aiken's V
	Sp. Psych.	Sp. Psych.	Sp. Psych.	Sp. Psych.	Test & Meas.	Coach		
1	3	4	5	5	5	5	17	0.85
2	4	5	4	4	5	5	17	0.85
3	4	5	4	4	5	5	17	0.85
4	3	4	5	5	4	5	16	0.80
5	3	4	5	5	4	4	16	0.80
6	4	4	5	4	5	5	17	0.85
7	3	4	4	3	5	3	14	**0.70***
8	3	4	5	5	4	4	16	0.80
9	3	4	5	5	5	5	17	0.85
10	3	4	5	5	4	4	16	0.80
11	4	5	5	4	5	5	18	0.90
12	4	5	5	5	4	5	18	0.90
13	4	5	4	4	5	5	17	0.85
14	3	3	4	4	4	3	13	**0.65***
15	3	5	5	3	5	5	16	0.80

*Note. E1–E4 = sport psychology specialists; E5 = testing-and-measurement specialist; E6 = internationally licensed pétanque coach (independent; not in primary V computation). Σs = Σ(score−1); V = Σs/[n(c−1)], n=5, c=5. * Below V ≥ 0.75. Level shading: blue=L1; green=L2; amber=L3; orange=L4; purple=L5.*

Table 3 reveals that items achieving V ≥ 0.85 are characterised by high and convergent ratings across all five disciplinary raters, with no rater assigning a score below 4. In contrast, items 7 and 14 show low-score entries from multiple raters spanning different disciplinary backgrounds, confirming that their below-threshold validity reflects genuine cross-disciplinary construct concerns rather than idiosyncratic dissent from a single expert.

Figure 3 visualises Aiken's V distribution across all 15 items, grouped by instrument level. The dashed horizontal line indicates the V ≥ 0.75 acceptability threshold, and below-threshold items (7 and 14) are distinguished by contrasting colour and asterisk notation.

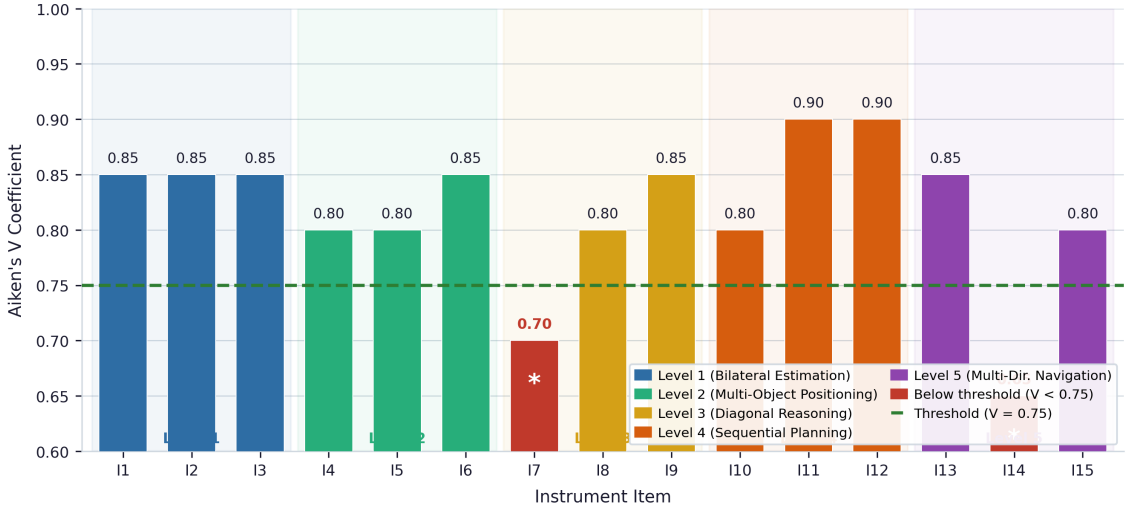

Figure 3. Aiken's V coefficients for all 15 instrument items grouped by level. Dashed line = V ≥ 0.75 acceptability threshold. Items below threshold (7 and 14) are shown in red with asterisks.

Figure 3 makes two patterns immediately visible. First, the overall distribution is strongly clustered above the threshold: 13 of 15 items (86.7%) achieve V between 0.80 and 0.90, confirming the instrument's robust overall content validity. Second, the Level 4 items (Items 10–12) form the highest-validity cluster, with Items 11 and 12 at V = 0.90 — the ceiling of the observed range — reflecting the particularly strong cross-disciplinary endorsement of the navigational obstacle channel format as an ecologically valid operationalisation of sequential spatial planning.

The development process yielded a spatial cognitive skills instrument comprising 15 items operationalised across five progressive difficulty levels on a purpose-built motor-perceptual board apparatus. The preparation-phase FGD produced a well-defined five-construct theoretical architecture that systematically maps onto the escalating spatial cognitive demands of competitive pétanque shooting. All field trial administrations were conducted under standardised environmental conditions to ensure that performance variation reflected genuine differences in spatial cognitive capacity rather than administrative inconsistency. A six-member expert panel evaluated all 15 items independently using the structured rating protocol described in the Method section.

Content Validity

Content validity analysis using Aiken's V confirmed acceptable validity for 13 of 15 items (V ≥ 0.75), with a composite instrument-level V of 0.81 across the disciplinary expert panel (n = 5). The internationally licensed pétanque coach (Expert 6) independently returned an overall instrument V of 0.90. At Level 1, all three items (Items 1–3) achieved V = 0.85, reflecting strong cross-disciplinary consensus on the bilateral estimation construct. At Level 2, Items 4 and 5 achieved V = 0.80, and Item 6 achieved V = 0.85. At Level 3, Item 7 fell below the validity threshold (V = 0.70) while Items 8 (V = 0.80) and 9 (V = 0.85) met the standard. At Level 4, Item 10 achieved V = 0.80, and Items 11 and 12 achieved V = 0.90 each, representing the two highest validity coefficients in the instrument. At Level 5, Item 13 achieved V = 0.85, Item 15 achieved V = 0.80, and Item 14 received V = 0.65 — the lowest validity coefficient in the instrument. The distribution of individual expert ratings across disciplines reveals that items achieving V ≥ 0.80 attracted convergent high ratings across all six expert disciplines. In contrast, Items 7 and 14 exhibited the widest inter-expert rating dispersion, signalling cross-disciplinary concerns about construct specificity and scoring sensitivity, respectively.

Field Effectiveness Testing

Field effectiveness testing with 57 athletes confirmed the expected five-level difficulty gradient, with mean performance scores decreasing systematically from Level 1 through Level 5, supporting the hierarchical construct architecture established during the preparation phase. Level 1 items yielded the highest mean scores, with the majority of athletes performing within the Good to Very Good performance bands, confirming that bilateral spatial estimation represents an accessible but discriminating baseline measurement condition for this population. Level 2 produced moderate score distributions with meaningful spread across performance bands, indicating that multi-object spatial coordination introduces genuine difficulty beyond Level 1 for this athlete population. Level 3 showed increased performance variance, consistent with the construct boundary issues identified for Item 7: athletes using bilateral strategies rather than genuine angular reasoning demonstrated artificially inflated Level 3 scores relative to their Level 4 and Level 5 performance, providing field-level empirical support for the expert panel's concern about construct overlap. Level 4 yielded substantially lower completion rates than Levels 1–3, confirming the theoretical transition from static estimation to dynamic navigational planning as a meaningful increase in task difficulty. Level 5 showed the widest performance differentiation within the experienced athlete group; however, Item 14's binary scoring criterion produced a ceiling pattern for the experienced group on that specific item, with the majority of experienced athletes completing the task irrespective of their navigational efficiency — providing direct field-level corroboration of the expert panel's scoring sensitivity concern. Preliminary discriminant analysis indicated that the instrument successfully differentiated the experienced athlete group (competitive experience ≥ 3 years, n = 31) from the developing athlete group (2–3 years, n = 26) across all five levels, with effect sizes ranging from small-to-medium at Level 1 (reflecting the accessibility of the baseline task) to medium-to-large at

Levels 4 and 5 (reflecting the greater cognitive complexity of the navigational planning tasks). Administration feasibility was confirmed across all administrations: the full 15-item instrument was completed within the designated time allocation for all athletes, and no item required non-standardised administration modification under field conditions, demonstrating that the protocol is practically deployable in sport science and coaching settings.

Discussion

The findings indicate that the developed instrument has a defensible Phase 1 psychometric foundation. Thirteen of the 15 items exceeded the predetermined content validity threshold, indicating that the expert panel generally judged them to be relevant, representative, and understandable for assessing spatial cognitive skills in elite pétanque. This result is important because early-stage instrument development must first demonstrate that the proposed item pool adequately covers the intended construct domain before stronger claims about reliability, factorial structure, or criterion validity can be made (Kania et al., 2024; Mokkink et al., 2025).

The strength of the content validity evidence should be interpreted in relation to the instrument's sport-specific design. Rather than measuring spatial cognition through abstract paper-and-pencil tasks, the instrument requires athletes to manipulate objects on a board apparatus while following standardised spatial demands. This format aligns with contemporary sport-assessment principles that emphasise representative task design and information-movement coupling (Höner et al., 2023; Krabben et al., 2021). For pétanque, such ecological alignment is essential because a shooting decision is not merely a verbal or visual judgment; it is a coordinated perceptual-cognitive-motor response.

The level-by-level validity pattern also supports the proposed hierarchy of spatial cognitive demand. Levels 1 and 2 received stable expert endorsement because bilateral spatial estimation and symmetric multi-object positioning are relatively clear and observable operations. In contrast, Levels 3 and 5 revealed more complex measurement challenges, particularly when angular reasoning and multi-directional navigation had to be represented in a field-based task. This pattern suggests that the instrument is not a flat collection of items, but a structured progression from basic spatial estimation to more executive forms of spatial planning.

Item 7 is especially informative from a construct-design perspective. Its below-threshold validity coefficient indicates that the diagonal task, as initially designed, may allow athletes to rely on a bilateral approximation strategy instead of genuine angular computation. This issue does not invalidate the diagonal reasoning construct; rather, it shows that the item needs stronger task constraints to prevent the intended cognitive operation from being bypassed. Adding explicit angular markers, clearer reference axes, or calibrated diagonal targets would likely improve the item's construct specificity while preserving its relevance to non-linear pétanque trajectories.

Item 14 presents a different problem. The experts' concern was not primarily about whether the task represented complex spatial planning, but whether the binary completion score could differentiate among high-performing athletes. The field data supported this concern because experienced athletes could complete the item despite differences in route efficiency and control quality. In elite samples, pass/fail scoring often loses diagnostic value when most athletes can eventually complete the task. A continuous scoring system based on time-to-completion, path-efficiency ratio, obstacle contacts, and correction attempts would provide more sensitive information about the quality of spatial planning.

The field effectiveness results extend the expert-validation evidence by showing that the five-level structure produced a meaningful difficulty gradient in actual athlete performance. Mean scores declined systematically from Level 1 to Level 5, indicating that the instrument's levels captured increasing cognitive and motor-spatial complexity. This finding is consistent with contemporary sport-cognition research showing that expertise-related differences are more evident in complex tasks that require anticipation, cue integration, working memory, and decision regulation than in simpler perceptual tasks (Manci et al., 2025; Wang et al., 2025; Zhu et al., 2024).

The differentiation between experienced and developing athletes further strengthens the preliminary validity argument. The group gap was modest at the lower levels but became clearer at Levels 4 and 5, where athletes had to plan routes and manage spatial ambiguity. This pattern is

theoretically plausible: athletes with more competitive experience are likely to have encountered a wider range of boule configurations, obstruction patterns, and tactical shooting situations. As a result, their advantage should appear most strongly when the task requires flexible planning rather than simple distance reproduction (Ashford et al., 2021; Silva et al., 2022).

These findings also clarify how the instrument complements existing research on pétanque performance. Previous studies have usefully examined biomechanical variables, coordination, concentration, training methods, and anthropometric factors associated with shooting and pointing accuracy (Helmi et al., 2024; Rasyono & Yanto, 2024; Zulbahri et al., 2024). The present instrument does not replace those performance indicators. Instead, it adds a diagnostic layer by identifying which spatial cognitive components may support or constrain the athlete's technical execution. For example, two athletes with similar shooting outcomes may differ in the limitation they exhibit: angular estimation, multi-object positioning, or route-planning efficiency.

The study, therefore, contributes to a more integrated view of pétanque expertise. Shooting performance should be understood as the product of mechanical execution, perceptual accuracy, cognitive planning, and tactical adaptation. The instrument developed in this study enables this integration to be measured at the sub-construct level, allowing coaches and sport scientists to move beyond general descriptions such as concentration or accuracy. It provides a structured profile of how athletes process space before and during a shooting task, which is essential for designing targeted cognitive-motor training.

At the same time, the results should be interpreted as initial validation evidence rather than final standardisation. Content validity and field effectiveness are necessary foundations, but they do not yet establish measurement stability, factorial structure, measurement invariance, or criterion-related validity. Subsequent research should therefore test test-retest reliability, inter-rater consistency, internal consistency, construct validity, and associations with objective shooting-performance indicators. This staged interpretation is consistent with contemporary measurement guidance, which treats validation as an accumulative process rather than a single statistical event (Mokkink et al., 2024; Stefana et al., 2025).

Implications

The findings have direct implications for coaching, athlete profiling, and sport-science support in elite pétanque. Coaches can use the five-level profile to identify whether an athlete's shooting difficulty is rooted primarily in bilateral distance estimation, multi-object spatial positioning, diagonal/angular reasoning, sequential route planning, or complex multi-directional navigation. This diagnostic information can then be translated into targeted drills, such as multi-object positioning tasks for Level 2 deficits, angular-trajectory exercises for Level 3 deficits, and obstacle-based navigational shooting simulations for Level 4 and Level 5 deficits. The instrument also provides a practical framework for monitoring cognitive-spatial development across training cycles, supporting more individualised and evidence-informed coaching decisions.

Research Contributions

This study contributes to the literature in three ways. First, it proposes a sport-specific spatial-cognitive skills instrument for elite pétanque, a domain in which measurement work has focused more on physical, biomechanical, and technical determinants of performance than on cognitive-spatial profiling. Second, it integrates contemporary sport-cognition theory with instrument-development procedures by connecting perceptual-cognitive expertise, embodied spatial decision-making, expert content validation, and field effectiveness testing within a single development sequence. Third, it offers preliminary empirical evidence that progressively complex spatial tasks can differentiate athletes by competitive experience, especially at the sequential and multi-directional navigation levels.

Limitations

Several limitations must be acknowledged. First, this study represents an initial development and validation phase; therefore, the instrument cannot yet be claimed as a fully standardised measurement tool. Test-retest reliability, internal consistency, factorial validity, concurrent validity

with objective shooting metrics, and normative cut-off scores still need to be established. Second, the field sample consisted of 57 senior athletes from a limited competitive context, which restricts the generalizability of the findings to broader regional, national, and international pétanque populations. Third, two items require substantive revision: Item 7 needs stronger angular-task constraints, and Item 14 needs more sensitive continuous scoring. Fourth, the study did not yet integrate eye-tracking, kinematic recording, or virtual-reality data, which could provide richer evidence on the perceptual and motor mechanisms underlying athletes' spatial cognitive performance.

Suggestions

Future studies should revise Item 7 and Item 14 before conducting the next validation phase. The revised instrument should then be tested with larger and more diverse samples across gender, age group, competitive level, and regional context. Subsequent studies should examine reliability through test-retest coefficients and internal consistency estimates, construct validity through confirmatory factor analysis, concurrent validity through correlations with objective shooting and pointing performance, and predictive validity through longitudinal tracking of competition outcomes. Future research should also combine the instrument with video analysis, motion analysis, eye-tracking, and virtual-reality environments to examine whether spatial cognitive scores correspond to gaze behaviour, trajectory selection, route efficiency, and actual shooting accuracy under representative competitive conditions.

CONCLUSION

This study completed an initial development and validation phase for a spatial cognitive skills instrument designed for elite pétanque athletes. Through preparation, development, content validation, and field effectiveness testing, the study produced a 15-item motor-perceptual board apparatus organised across five spatial cognitive levels. Expert panel validation confirmed acceptable content validity for 13 of 15 items ($V \geq 0.75$), while Items 7 and 14 require targeted revision to strengthen angular-reasoning specificity and scoring sensitivity. Field testing with 57 senior pétanque athletes confirmed the expected difficulty gradient and showed preliminary discriminant value between experienced and developing athletes, particularly at the higher navigational-planning levels. The instrument, therefore, offers a promising foundation for objective spatial cognitive profiling in pétanque coaching. However, reliability, construct validity, concurrent validity, and normative evidence must be established before full operational deployment.

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AUTHOR CONTRIBUTION STATEMENT

In our manuscript, NI, SI, ZB, DS, AA, and RE contributed: NI conceptualized the study, designed the methodology, analyzed the results, and coordinated data collection. SI, ZB, and RE contributed to the study design. DS, AA, and RE contributed to the design of the methodology and data collection. RE performed data analysis, interpreted the results, drafted the manuscript, and critically revised it for intellectual content.

AI DISCLOSURE STATEMENT

The authors declare that no artificial intelligence (AI) tools or services were used in the preparation of this research. All content was entirely researched, written, and edited by the authors, who take full responsibility for the publication.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest that could have influenced the study, data analysis, manuscript preparation, or publication.

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