The complexity of measuring agility in water polo: reliability, validity, and its association with in-game performance indicators of new sport-specific protocols

Abstract of PhD Thesis

Marcell Fridvalszki

Doctoral School of Sport Sciences
Hungarian University of Sports Science

HUNGARIAN UNIVERSITY OF SPORTS SCIENCE
BUDAPEST

Supervisor: Dr. Leonidas Petridis, senior research fellow, PhD
Dr. Levente Rácz, senior research fellow, PhD

Official reviewers: Dr. István Karsai, habilitated associate professor, PhD
Dr. Ferenc Ihász, professor, PhD

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INTRODUCTION

Water polo can be classified as an invasion or territorial team sport, in which the intentions of offensive and defensive players are mutually opposed. To achieve their objectives, players must perform agility-demanding movements – such as feints and maneuvers – based on their decisions. Since their decisions are continuously influenced by the opponent's position, teammates' movements, and refereeing decisions, a water polo player's performance results from complex interactions. Match performance depends not only on a high level of physical conditioning but also on the complexity, effectiveness, and harmonious cooperation of psychomotor coordination and cognitive abilities.

According to the literature, the methodology for measuring agility in land-based sports has undergone significant development, ranging from simple change-of-direction tasks to complex protocols examining one-on-one situations, accompanied by numerous reliability and validity assessments. In contrast, research in water polo has primarily focused on physical performance and simpler cognitive abilities, with less attention given to tests that incorporate match-simulation technical elements, such as goal shots. This focus on physical performance and basic cognitive abilities hinders the accurate modeling of sport-specific movement patterns and limits the validity of measurement procedures. Until now, only a few researchers have dealt with the development and analysis of tests based on partially unexpected, non-automated, or rehearsed stimuli. Although the aquatic environment presents challenges for establishing standardized measurement procedures, it is justified to develop sport-specific tests that integrally examine physical, cognitive, and technical factors, as such tests bring researchers closer to accurately modeling real match situations.

Given the limited number of studies and methodological descriptions available on water polo-specific agility tests, this dissertation presents results from two studies published across three publications. The first study was a preliminary investigation aimed at developing and demonstrating an offensive agility test.

The second study built upon the findings of the preliminary research, addressing its limitations and shortcomings, and focused on the further development of new agility protocols. The developed tests included functional, multi-positional, and multi-directional tasks, taking into account the sport's physical, technical, and cognitive characteristics. To better understand the components of the agility protocols, the study incorporated straight-line sprint swimming as well as tasks involving rapid changes of direction, with particular emphasis on the sequential structure of the tests and the progressive increase in their complexity.

One of the main aims of the study was to examine the intercorrelations among the developed sport-specific protocols and to investigate the extent to which physical, cognitive, and technical factors contribute to agility.

Another goal was to assess one form of criterion validity for sport-specific tasks, namely, concurrent validity. In this process, by analyzing the relationships between performance indicators of functional agility tests and official match performance indicators, thereby bridging the 'gap' between diagnostic measurements and actual match performance.

LITERATURE REVIEW

Open-skilled test protocols, or measuring agility in water polo

The first agility test developed in water polo, the "*Functional Test for Agility Performance*" is a high-intensity, short-duration protocol involving rapid changes of position. The test requires the participant to move in response to external stimuli – passes executed by assistants – ensuring the randomness of movements. The measurement procedure demonstrated adequate reliability across different samples, including players with varying levels of sport-specific experience. Subsequently, a five-level performance classification system was developed to objectively assess water polo players at different skill levels and monitor their progression.

Since no other protocols measuring change-of-direction tasks that also require cognitive skills were available in water polo, another research group developed light-signal–based tests and conducted their reliability and validity assessments. Regarding the aforementioned protocol in their study, several critical observations were made: the rules for starting and stopping the task were not entirely clear; passing between players could increase measurement variability; and customizing the test playing area limited its applicability; the test was unable to fully replicate the attentional demands of match situations. Their results showed that light-signal–based trials demonstrated high reliability and revealed significant differences across age groups; however, the ecological validity of these tests remains questionable to some extent.

The role of match performance indicators in team sports

Match analysis in water polo represents a well-established and widely investigated area within the scientific literature. The primary objective of performance analysis is to identify team strengths and weaknesses, thereby enabling the optimization of overall performance. A key aspect of match analysis is the sport-specific definition of performance indicators, which not only supports scientifically grounded conclusions but also enhances practical applicability in coaching. Furthermore, such indicators provide a foundation for developing testing protocols

capable of diagnosing sport performance under conditions closely resembling actual match situations.

Despite the extensive body of research in team sports, such as football, examining the relationships between physical performance indicators measured during matches and performance on standardized tests, relatively little attention has been paid to their associations with key performance indicators. To the best of current knowledge, only two team sports (rugby and ice hockey) have been investigated in this context, and their findings remain inconsistent.

These contradictory results highlight the need for more precise sport-specific testing protocols and the importance of establishing acceptable levels of reliability and criterion validity. Establishing validity is essential to ensure that performance assessments accurately reflect the skills and attributes required for competitive performance. Importantly, one key aspect of testing match-related performance is the complexity of the protocols used. Although simpler tests may yield more easily interpretable results, the inherently complex nature of team sports limits the relevance and clarity of such findings. Protocols that more closely replicate real-game conditions demonstrate higher validity in assessing sport-specific abilities and are therefore considered more ecologically valid than general testing procedures.

AIMS OF THE STUDY, RESEARCH QUESTIONS, AND HYPOTHESES

The primary aim of this dissertation was to develop and analyze sport-specific agility tests that model frequently occurring game situations in water polo, such as rapid and efficient transitions between vertical and horizontal body positions, sudden stops and accelerations, and changes of direction. The protocols developed and applied in the main study were designed to assess agility performance progressively. One test (the functional agility test) focused exclusively on perceptual and decision-making processes through multiple-choice cognitive tasks, whereas the more complex test incorporated technical elements, such as shooting on goal. Through the structured progression and increasing complexity of the sport-specific protocols, a further aim was to explore the relationships between simpler and more complex tests, thereby providing a comprehensive performance profile of the newly developed agility protocols. In addition, the study aimed to examine and interpret the relationships between performance tests and match results in young male water polo players. These objectives are based on our previously published contributions.

Research questions and hypotheses:

- **RQ1:** Are the newly developed agility protocols reliable across evaluators and across the series?

- **H1:** The agility protocols demonstrate high inter- and intra-rater reliability.
- **RQ2:** Are the sport-specific protocols examined in the main study able to differentiate between elite and non-elite players?
- **H2:** The sport-specific protocols examined in the main study are capable of differentiating between elite and non-elite athletes.
- **RQ3:** Can the cognitive and technical performance indicators calculated based on agility protocols differentiate between elite and non-elite players?
- **H3:** The cognitive and technical deficit performance indicators are capable of differentiating between elite and non-elite athletes.
- **RQ4:** Is there a relationship between players' shooting efficiency and the speed of executing agility tests?
- **H4:** Shooting efficiency is negatively correlated with the speed of executing agility tests; faster execution is associated with lower shooting efficiency.
- **RQ5:** To what extent do the physical, cognitive, and technical components explain the variance in performance on agility tests?
- **H5:** Performance in the agility tests is more strongly explained by the cognitive and technical components than by the physical components.
- **RQ6:** Is there a relationship between performance on the sport-specific tests and match performance indicators?
- **H6:** Performance on the sport-specific tests shows a significant correlation with match performance indicators.

MATERIALS AND METHODS

Logical structure and sequence of the studies

In this dissertation, the complexity of sport-specific testing in water polo is demonstrated through two sequential studies. The first study was a preliminary investigation that developed an offensive-specific agility measurement protocol. The second study built on the experiences and findings of the preliminary study and focused on developing two functional agility tests, separately examining the roles of physical, cognitive, and technical factors in agility. The evaluation of the agility protocols was conducted through four sport-specific tests of increasing complexity. The tests were designed to reflect a progressive assessment structure, moving from simpler to more complex tasks while considering physical, cognitive, and technical aspects characteristic of match situations. In the main study, both the interrelationships between the

tests and the construct- and criterion-related validity of the newly developed agility protocols were examined using match performance indicators.

All studies and data collection procedures were conducted with the approval of the Ethics Committee of the University of Physical Education (approval numbers: TE-KEB/9/2020 for the first study and TE-KEB/11/2022 for the second study) and in accordance with the principles of the Declaration of Helsinki for research involving human participants.

Participants

The studies involved healthy young male water polo players with at least five years of experience and a valid competition license, who participated in ≥4 training sessions per week. Prior to testing, all participants received verbal and written information, and parental consent was obtained for all minors.

Preliminary study: 18 players (15.3 ± 0.5 years; 178.0 ± 5.0 cm; 69.4 ± 10.0 kg) played at various positions (center-back, wing, goalkeeper).

Main study: 44 players from two clubs were grouped according to playing position and competitive level. Six players were excluded due to missing measurements or outlier values (elite: n = 20, age 16.2 ± 0.5 years; non-elite: n = 18, age 15.8 ± 0.6 years). To examine the relationship between the testing protocols and match performance indicators, the inclusion criteria required participation in at least 66.6% of all matches during the 2023/2024 season. Eleven additional players were excluded due to incomplete protocols or outlier values. Players were also categorized by playing position: 22 wings (16.0 ± 0.6 years; height 181.1 ± 6.1 cm; body mass 71.9 ± 9.4 kg) and 11 center-backs (16.1 ± 0.6 years; height 184.2 ± 6.2 cm; body mass 85.4 ± 7.9 kg). Anthropometric measurements in the main study were conducted using instruments and techniques defined by the International Biological Program.

Testing protocols

In the preliminary study, participants performed maneuvers and shots in response to visual stimuli provided by the testers, aiming for maximal speed and accuracy. Balls were placed at buoys, and players aimed at a target net. The testers were positioned in a square (T1–T2: 8.5 m; T3–T4: 6 m), 3 meters apart, with the starting point located 10 meters from the goal.

The agility protocol developed in the preliminary study included limited directional changes and decision-making options. Therefore, in the main study, the protocol was further developed to include changes of direction in all directions and a greater number of decision-making options. Task complexity was progressively increased, presenting players with increasingly challenging situations. The testing battery consisted of four protocols: a 20-meter freestyle

sprint test (20 m FSST), a change-of-direction speed test (CODS), a functional agility test (FAT), and a functional agility test with shooting (FATS). Based on these protocols, cognitive and technical deficits were calculated. During the 20 m FSST, players started from a stationary floating position at the starting line (0 m) and swam with maximal speed to the 20 m finish line using the front crawl technique, touching the pool wall with one hand. Underwater dolphin kicks were not allowed. The CODS test was conducted in a 3 × 5 m area located 5 m from the goal. The evaluated players started from a floating position and swam between the center and corners in a predetermined sequence, touching all balls along the path. The FAT was conducted in the same 3 × 5 m area as the CODS, but evaluated players responded to previously unknown visual signals from the testers (right or left arm: opposite corner buoy; both arms: diagonal buoy). Each corner buoy was touched with a central medicine ball, and the test ended after four signals. Cognitive deficit (CD) was calculated as the difference between CODS and FAT completion times, representing the cognitive component. The FATS was performed on the same course as the FAT, following the same procedure, but the water polo balls placed on the corner buoys had to be shot into a target net (Aquawallgym^{TM}). Evaluated players executed four shots during the protocol, with balls replaced immediately after each shot. The test ended with a central buoy touch following the fourth shot. Technical deficit (TD) was calculated as FATS – FAT time, representing the time required for shot execution. Performance was evaluated based on execution time and shooting accuracy, with a 2-s penalty for each missed shot.

Match performance indicators were analyzed for the 2023–2024 season, covering eight metrics in the Hungarian age-group elite and regional leagues, drawing on previous research. Data were summarized for each player separately and are expressed as mean values per game. All data were obtained from the official database of the Hungarian Water Polo Federation.

Statistical analysis

Statistical analyses were conducted using SPSS statistical software, versions 25.0 and 29.0 (SPSS Inc., Chicago, IL, USA). In the preliminary study, the time results from the last two trials of the five series were included, whereas in the main study, after excluding the outliers (the lowest and highest) from the six series, the total execution time of the remaining four series was incorporated into the statistical analyses. The analysis evaluated the total execution time of the test protocols and the shooting efficiency for the offensive agility test developed in the preliminary study, as well as for the most complex trial (FATS) assessed in the main study.

The relative reliability between measurements and across series was assessed by calculating the intraclass correlation coefficient (ICC) using a two-way mixed-effects model (average

measures, absolute agreement), with reporting of 95% confidence intervals (CI). ICC values were considered good if between 0.75 and 0.9, and excellent if exceeding 0.9. Additionally, the coefficient of variation (CV) was calculated and deemed acceptable if <10% in both the preliminary and main studies. Moreover, in the main study, the standard error of measurement (SEM) and the minimal detectable change at the 95% confidence level (MDC95%) were calculated. SEM and MDC95% were computed according to the following formulas: $SEM = SD \times \sqrt{1 - ICC}$, where SEM is the standard error of the measurements, SD is the standard deviation of the values, and ICC is the intraclass correlation coefficient; and $MDC95\% = 1{,}96 \times \sqrt{2 \times SEM}$, where MDC95% is the minimal detectable change at the 95% confidence level, and SEM is the standard error of the measurements.

Independent-samples t-tests were used to compare elite and non-elite groups in the main study, accompanied by Hedges' g effect size. Effect sizes were interpreted as small (g > 0.2), medium (g > 0.5), large (g > 0.8), and very large (g > 1.3). Values are presented as mean ± standard deviation, and outliers were filtered using the Tukey method.

Differences between playing positions (forwards vs. center-backs) were analyzed using the Mann–Whitney U test with Cliff's delta (δ) effect size. Cliff's scale was interpreted as negligible (<0.15), low (>0.15), moderate (>0.33), and large (>0.47).

To examine the time results between the two groups and the series, as well as shooting efficiency, we used a factorial repeated measures ANOVA (RMANOVA) with partial eta squared (η^2) effect size analysis, where the factors were the two groups (between-group effects) and the series represented the within-group effects. Sphericity was tested using Mauchly's test, with the Greenhouse–Geisser correction applied, as the assumption of sphericity was not met.

To examine the relationship between shooting efficiency and technical deficit, the time results and shooting efficiency values for the four series were averaged, and univariate linear regression was then used to investigate the associations.

Pearson's correlation coefficient (r) was applied to analyze relationships between sport-specific tests, interpreted as negligible (≤0.10), weak (0.10–0.39), moderate (0.40–0.69), strong (0.70–0.89), and very strong (≥0.90). Univariate linear regression analysis was also conducted to explore associations between agility tests and potential contributing variables (FAT vs. 20 m FSST, CODS, CD; FATS vs. 20 m FSST, CODS, CD, TD).

The relationship between the tests and in-game performance indicators was examined using Spearman rank correlation (rs), with strength categories as follows: negligible (≤0.20), weak (0.21–0.40), moderate (0.41–0.60), strong (0.61–0.80), and very strong (≥0.81).

The significance level was set at $\alpha < 0.05$.

RESULTS

In the preliminary study, the mean execution time was 12.3 ± 0.9 s (range: 10.2–13.8 s). The results were categorized into three performance levels: below average, average, and above average. Average performance encompassed the middle 40% of values. Execution times above 13 s were considered very low, while those below 11.2 s were considered outstanding. Differences between the two raters were minimal, and inter-rater reliability was excellent (ICC: 0.97–0.98). Reliability across series was also acceptable (ICC: 0.87–0.88), with coefficients of variation ranging between 4% and 5%.

Players exhibited low shooting efficiency with high variability. In the second series, six players did not score any goals. Most achieved 25% efficiency, and no player scored in all four trials across both series. Five-meter shots were approximately 1.4 times more successful, though no significant difference was observed between the two shooting distances ($p = 0.15$). No significant correlation was found between execution time and shooting efficiency, except for five-meter shots in the second series, which showed a moderate negative correlation.

In the main study, execution time increased with task complexity across the four sport-specific tests (20 m FSST: 12.2 s; CODS: 15.2 s; FAT: 22.3 s; FATS: 30.3 s). Reliability was excellent for most protocols (ICC: 0.954–0.982), whereas it was good for the FATS test (ICC = 0.838). CV values remained below 5% in all cases. Elite players performed significantly better in the 20 m FSST, CODS, and FAT tests (Hedges' g = 1.08–1.25). Based on FATS results, no significant differences were observed between elite and non-elite players in either execution time or shooting efficiency ($g = 0.29$). No significant group differences were found for cognitive or technical deficit measures, and no correlation between execution time and shooting efficiency was detected in either group.

The relationships among the sport-specific tests were examined across the entire sample, without group stratification. The 20 m FSST protocol showed a strong positive correlation with CODS ($r = 0.80$; $p < 0.001$) and a moderate correlation with the FAT test ($r = 0.60$; $p < 0.001$), indicating that faster sprint performance was associated with quicker change-of-direction and agility. CODS and FAT were also strongly positively correlated ($r = 0.75$; $p < 0.001$) and showed weak-to-moderate negative correlations with cognitive and technical deficits ($r = −0.28$; $p = 0.093$ and $r = −0.41$; $p = 0.011$, respectively). Moderate positive correlations were found between FAT and FATS, as well as between FAT and CD ($r = 0.50$; $p = 0.001$ and $r =$

0.44; $p = 0.006$). FATS was significantly correlated with CD ($r = 0.46$; $p = 0.004$) and TD ($r = 0.69$; $p < 0.001$).

For the two novel agility tests (FAT and FATS), the relationships with physical, cognitive, and technical deficit indicators were analyzed. The 20 m swim sprint test and the change-of-direction speed test significantly predicted FAT performance, explaining 36% ($F = 19.78$; $p < 0.001$) and 57% ($F = 40.73$; $p < 0.001$) of the variance, respectively. In contrast, the relationship between cognitive deficit and functional agility was weaker, explaining 21% of the variance ($F = 8.32$; $p = 0.007$). Regarding the FATS test, which incorporates shooting, cognitive, and technical deficits were stronger predictors than physical components. Technical deficit accounted for the largest explained variance (46%; $F = 26.02$; $p < 0.001$), while the influence of physical characteristics on FATS performance was negligible (<5%) (20 m FSST: $F = 1.28$; $p = 0.267$; CODS: $F = 0.94$; $p = 0.340$).

Associations between sport-specific tests and match performance indicators varied by playing position. For the wings group, 20 m FSST and FATS results showed moderate negative correlations with key passes and shooting efficiency ($r_s = -0.46$; $p = 0.032$, $r_s = -0.43$; $p = 0.056$).

For center-backs, 20 m FSST performance negatively correlated with steals ($r_s = -0.63$; $p = 0.036$), whereas FAT was positively correlated with shooting efficiency ($r_s = 0.61$; $p = 0.047$) and strongly negatively correlated with exclusions and steals indicators ($r_s = -0.75$; $p = 0.008$, $r_s = -0.70$; $p = 0.017$). Similarly, FATS demonstrated strong negative correlations with both the number of shots/game and steals indicators ($r_s = -0.70$; $p = 0.016$, $r_s = -0.67$; $p = 0.026$). Additionally, CD was strongly positively associated with shooting efficiency in power-play situations ($r_s = 0.65$; $p = 0.029$).

DISCUSSION

The agility test developed in the preliminary study proved to be a reliable instrument for assessing offensive agility performance. Interestingly, no association was found between execution time and shooting performance, suggesting that, at near-maximal intensity, execution time does not influence shooting accuracy. This finding highlights the potential role of the aquatic environment's complexity, as well as cognitive and technical factors, in agility performance, which were further investigated in subsequent analyses.

Taking into account and addressing the methodological limitations of the preliminary protocol, two new water polo-specific agility tests were developed in the main study, and their reliability, discriminative validity, and concurrent validity were examined. These enhanced

agility tests and their applied protocols demonstrated excellent reliability, while the agility test with shooting protocol (FATS), despite its increased complexity, also showed good reliability. Elite players outperformed non-elite players in sprint swimming, change-of-direction speed, and the agility test without shooting. However, the discriminative power of the sport-specific tests gradually decreased as task complexity increased; in the most complex task, the agility test with shooting protocol, as well as in measures of cognitive and technical deficit, no differences were observed between the groups. This suggests that elite players differ primarily in physical attributes rather than in cognitive or technical abilities compared to non-elite players.

Correlation and regression analyses among the performance tests indicate that the contributions of physical, cognitive, and technical components varied across the newly developed protocols. In the agility test without shooting, performance was primarily determined by physical factors, whereas in the shooting-augmented test (FATS), cognitive and technical factors had a greater influence, reducing the dominance of purely physical performance components. This implies that increasing task complexity alters the relative contribution of different performance components, potentially masking the impact of physical factors. Accordingly, the cognitive component within the agility test, in its current form, requires refinement to better reflect the cognitive profile characteristic of water polo.

Furthermore, the absence of a relationship between shooting efficiency and execution time suggests that, in young male water polo players, faster agility performance and higher shooting speed do not influence shooting accuracy.

Another primary aim of our study was to examine the concurrent relationships between the applied tests and match performance indicators, thereby addressing one aspect of criterion validity (concurrent validity). Our main question focused on the extent to which physical, cognitive, and technical factors – or combinations thereof – are associated with in-game performance. The applied protocols were unable to reliably model match performance; our results were scattered and inconsistent. This underscores the need for further refinement of sport-specific testing protocols and match performance evaluation systems.

To achieve a more precise understanding and to better simulate the situation-specific characteristics of official matches within a training environment, clearly defined water polo-specific attributes and position-related criteria are required. Simultaneously, the development of a match performance assessment system based on individual, multidimensional player profiles is warranted, as this may collectively contribute to the structured development of the sport.

CONCLUSIONS

- The newly developed agility tests were reliable, making them suitable for assessing offensive agility performance.
- The comparison between elite and non-elite players supported the construct validity of the tests (except for the most complex test protocol). The difference primarily appeared in physical attributes, whereas in the shooting-adjusted test, as well as in cognitive and technical factors, there was no significant difference between elite and non-elite players.
- The shooting accuracy showed no correlation with the execution time, suggesting that faster movement does not affect the accuracy of shots in young male water polo players.
- In the agility test without shooting, performance was primarily determined by physical factors, whereas in the shooting-adjusted test, the greater role of cognitive and technical factors reduced the dominance of purely physical components.
- The results of the sport-specific tests did not show a consistent relationship with match performance indicators, raising questions about the concurrent validity of the tests, as well as the relevance and sensitivity of the match performance indicators in detecting differences among players.
- The development of agility protocols needs to be improved by more accurately distinguishing between the cognitive and technical components. One approach is to measure cognitive abilities, such as perceptual time, more directly, while another is to develop complex situational tasks (e.g., 1v1, 2v2 scenarios) that more closely approximate real in-game decision-making.
- It is necessary to specify position-specific criterion systems and to develop a performance evaluation system based on individual, multidimensional player profiles.

LIST OF OWN PUBLICATIONS

List of the author's publications forming the basis of this dissertation

1. Fridvalszki, M., Matlák, J., Rácz, L., Tróznai, Z., Annár, D., Utczás, K., & Petridis, L. (2025). The association between sports-specific testing and in-game performance indicators in young male water polo players. *International Journal of Performance Analysis in Sport*, *25*(1), 1–16. https://doi.org/10.1080/24748668.2025.2569173
2. Fridvalszki, M., Matlák, J., Rácz, L., Fekete, D., Dudás, D., Tróznai, Z., Annár, D., Utczás, K., & Petridis, L. (2024). The complexity of agility testing in water polo: Reliability and validity analysis of sport-specific protocols. *International Journal of Performance Analysis in Sport*, *25*(2), 305–319. https://doi.org/10.1080/24748668.2024.2411110
3. Fridvalszki, M., Matlák, J., Kovács, B., Petridis, L., Horváth, D., Havanecz, K., Dudás, D., Langmár, G., & Rácz, L. (2022). Reliability study of a functional test for the offensive agility performance in water polo. *International Journal of Environmental Research and Public Health*, *19*(16), 10040. https://doi.org/10.3390/ijerph191610040

List of other publications by the author related to the topic

1. Matlák, J., Fridvalszki, M., Kóródi, V., Szamosszegi, G., Pólyán, E., Kovács, B., Kolozs, B., Langmár, G., & Rácz, L. (2024). Relationship between cognitive functions and agility performance in elite young male soccer players. *Journal of Strength and Conditioning Research*, *38*(1), 116–122. https://doi.org/10.1519/jsc.0000000000004644
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List of the author's publications not related to the topic of the dissertation

1. Havanecz, K., Tóth, P. J., Kopper, B., Bartha, C., Sáfár, S., Fridvalszki, M., & Géczi, G. (2025). Relationship between GPS-derived variables and subjective questionnaires among elite youth soccer players. *Sports*, *13*(8), 246. https://doi.org/10.3390/sports13080246
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