

Adaptation and validation of selected stroke accuracy tests for elite Para table tennis players

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Purpose: To adapt and validate selected tests assessed the accuracy and precision of flip shots and bottom spin backhand strokes precision hitting for Para table tennis players: Manual quickness & ability Forehand (Manual Q&A FH), Manual quickness & ability Backhand (Manual Q&A BH), Alternate push test.

Methods: The study group includes 23 table tennis players (age 28.10±13.7 years, 26.1% of females), with impairment belonging to the senior national team of Poland. A battery of three specific tests evaluating stroke accuracy was assessed. The conventional Cronbach's alpha (α) and McDonald's omega (ω) coefficients were calculated to determine the tests' reliability.

Results: The highest absolute agreement was found for the Manual Q&A FH test (ICC= .838) and the lowest for the Manual Q&A BH test (ICC= .652). For most trials, the results obtained at three consecutive time points were similar ($P < .01$), and the strength of this concordance was close to .70.

Conclusions: The research on the reliability and accuracy of the specific tests confirmed the need for the indicated special technical tests on table tennis players with impairment for the three integrated classes of disabilities. Analysis of the data obtained from the tests can provide coaches with important information on the level of selected technique elements of elite Para table tennis players.

Keywords: Para athlete, Para table tennis, test adaptation and validation, stroke accuracy

Introduction

Table tennis is a physical activity that requires players to have high precision, dexterity, and motor coordination¹. One of the key skills is the precise placement of the ball to a chosen spot on the playing field executed at the right time in response to the opponent's play^{2,3}. This skill is challenging because the distance between the players and the time between successive strokes is very short. Table tennis players must quickly transition from one technical skill to another to execute precise and effective actions that bring them closer to victory in competitive sports⁴. In Para table tennis, ball speed and accuracy (ie, the capacity to hit a desired area) are the most relevant technical parameters to describe stroke performance¹. In the context of Para table tennis, these skills become particularly significant, as athletes must often deal with challenges arising from various disabilities^{5,6}.

The test protocols for motor skill and technical proficiency level in Para table tennis are still poorly established⁷. There is not a wide range of tests for players with different impairments. However, standardised tests are essential for monitoring training progress. With measurable outcomes, athletes and coaches can observe the results of their training. These tests can classify the abilities and technical levels of trained athletes and, if effective, allow coaches to evaluate their athletes' strengths and weaknesses⁸. Additionally, these tests help optimize training to enhance athletic performance; table tennis players with impairment can understand their capabilities through proper assessment, identifying weaknesses that can be improved with adequate training^{9,10}. Thus, testing is an indispensable component of the training process, as without evaluating the results, detailed

progress cannot⁸ be tracked^{11,12}.

The literature review indicates limited scientific works addressing the analysis of variables, such as accuracy and precision of strokes, in Para table tennis⁸. A synthetic compilation of tests adapted for the needs of table tennis players with impairment was conducted by Kong and Ma¹³. By analyzing the Scopus, PubMed, SPORTDiscus, and Web of Science databases, they highlighted the following studies, e.g. Wu et al.¹², Smits-Engelsman et al.¹⁴, Van Biesen et al.¹⁵⁻¹⁹.

So far, few studies have been conducted on able-bodied players²⁰⁻²³. They assessed the tests' credibility and reliability, which most often provided a secondary background for analyzing other variables, primarily involving the biomechanical analysis of the table tennis playing technique.

Only two scientific works^{24,25} attempted to determine the normative values for assessing the precision level of strokes and serves in table tennis. The proposal to develop such normative values by Gomes et al.²⁴ differentiates these levels solely based on gender and aims the senior category. On the other hand, Purashwani et al.'s²⁵ research conducted on 816 men (410 juniors and 406 seniors) does not specify values for specific age categories and does not consider the variability of levels relative to gender. So far have attempted to adapt and validate selected tests of service accuracy and precision for individuals with disabilities⁸. The attempts involved serving and returning the ball using a topspin hit. This work continues the previously undertaken research topics, focusing on adapting precision hitting tests in Para table tennis⁸. Here, the test trials focus on using fundamental hitting techniques in Para table tennis for individuals with disabilities—the forehand flip, backhand flip,

and hitting the ball with a backhand backspin¹². The research results aim to establish reference values for selected test trials assessing the special needs of Para table tennis players.

The work's main objective is to adapt and validate selected precision tests for forehand and backhand flips, as well as bottom spin backhand strokes for Para table tennis players. The following hypothesis was formulated to estimate the tests' validity and reliability:

1) Para table tennis players ranked higher in world rankings in their categories are characterized by better results in special technical tests.

2) The results of special technical tests differ among integrated classes with disabilities.

Methods

Participants

The study included 23 table tennis players with an average age of 28.10±13.7 years (including 26.1% women), all part of the senior national team of Poland for individuals with impairment. The average stature of standing players was 162.71±11.60 cm and the average of body mass was 55.12±11.41 kg. The average stature of wheelchair players (sitting height) was 88.33±9.45 cm, with a body mass of 75±3.00kg. The average personal table tennis experience was 13.40±11.3 years ($W=.84$; $P=.002$) and the average number of hours of training per week was 8.80±4.4 h ($W=.89$; $P=.018$). There were six athletes in Classes 1-5, which includes wheelchair athletes, six athletes in Classes 6-10, which includes athletes who compete standing up, and four athletes in Class 11, which includes athletes with intellectual disabilities. The players had to meet the following criteria: be members of the national team for people with disabilities and possess a valid license from the Polish Table Tennis Association; have at least two years of training experience; have a health condition allowing participation in all special technical tests confirmed by medical examinations; and have a playing style requiring the use of rackets with smooth rubbers (excluding players who use non-typical rubbers, such as anti-spin, short pips, or long pips, whose play style is characterized by different techniques than the flip and chop strokes used in the special battery tests conducted). The surveyed group of athletes includes Olympic, World, and European champions, and as many as 65.2% of the athletes are ranked within the top 30 worldwide in their respective disability classes. All participants provided written informed consent to participate in the study. Parental consent was obtained for minor participants. All data was anonymized. The study was conducted in accordance with the Helsinki Declaration and received approval from the Bioethics Committee.

Methodology

A test-retest procedure was employed to calculate the reliability of the tests. The tests on table tennis players were conducted at three consecutive time points during the preparation period: T1- July 6, 2023 (Drzonków), T-2 August 6, 2023 (Bydgoszcz), and T3 - September 1, 2023 (Władysławowo). Mixed qualitative and quantitative methodologies were used in this study. In the first stage, the Delphi technique was used to determine the face validity of three tests taken from the scientific literature. It should be noted that the experts did not meet for the assessment. Delphi is a questionnaire technique that uses multiple iterations designed to develop a consensus of opinion concerning a specific topic^{23,26}. Experts could be people who possess knowledge in a particular area, who are representatives in the specific discipline, or who have relevant experience. All need to be willing to contribute their opinions. This technique was used to reach the opinion of

experts, such as high-level Para table tennis coaches and table tennis lecturers. The Delphi method was used to confirm whether the selected tests were adequate for evaluating the variables and the relevance of the tests components (i.e., the specific skills and abilities relevant to Para Table Tennis athletes). In addition to confirming alignment with the International Table Tennis Federation (ITTF) rules, the Delphi survey assessed whether the test trials, as well as the overall evaluation process, appeared to have face validity in accurately measuring the intended attributes of Para Table Tennis athletes' performance. This included examining whether the measurement methods were perceived as realistic, straightforward, and relevant to the sport's specific demands, as well as to the athletes' capabilities within the Para Table Tennis context. The expert group sample consisted of three national coaches and two university lecturers, with a minimum criterion for a coach having a national trainer certificate or a coach who has brought athletes to regional and national level competitions. As in Galas et al.⁸ the following questions were asked to the coaches: Were the measure components relevant to what is being measured? Did the measurement method seem useful for measuring the variable? Did the method of performing the various test trials comply with the game rules given by the International Table Tennis Federation (ITTF) for Para Table Tennis?

The second stage was the qualitative analysis, where the input results from expert judgment were analyzed with Aiken's formula²⁷. The final stage involved analyzing the results of the battery tests on 23 Para table tennis players using Cohen's Kappa Index. The test reliability was calculated using the test/retest procedure.

A battery of selected tests for table tennis was used to determine the level of special fitness among players with disabilities. Two trials assessed the accuracy of flip shots: Manual quickness & ability FH (A and C) and Manual quickness & ability BH (B and D)²⁴. Another trial assessed the accuracy of the chop shot: Alternate push test (E)²⁵. A forehand (FH) is a stroke with the inside of the bat on the side of the dominant hand and a backhand (BH) is a stroke with the outside of the bat on the side of the non-dominant hand. The letters A to E refer to the five smaller pictures signed in the lower left corner of each picture (Figure 1). In the flip shot tests of ball strokes Manual Quickness & Ability I and II²⁴, the balls were thrown by a specially programmed robot with a remote oscillator and control, Tibhar Robo Pro Junior (Japan), to hit them bouncing 30 cm behind the net. The participants had to make 15 hits in one attempt with a one-minute break, aiming for squares of 30 x 30 cm, 30 cm away from the net, using forehand (A) and backhand (B). The ball thrown for class 1–5 players in wheelchairs aimed 15 cm farther, 45 cm behind the net for the forehand (C) and backhand strokes (D).

In the original article²⁴ the dimensions designated for hitting targets were not specified, nor was it indicated how many centimeters behind the net the ball should be served. Therefore, the dimensions of the designated spots were arbitrarily set to 30 x 30 cm, and the robot was programmed to serve the ball 30 cm behind the net, as specified in other tests on graphics of the same dimensions e.g., reaction speed II²⁴. Test trials Manual quickness & ability I and II have not been previously evaluated, though in a different age group and in able-bodied players²⁰, in contrast to other tests from the Gomes et al.²⁴ battery.

Selected test variants by Gomes et al.²⁴ included the use of a basic striking technique in para table tennis for individuals with disabilities—forehand and backhand flips—and the trial proposed by Purashwani et al.²⁵—hitting the ball with a backspin

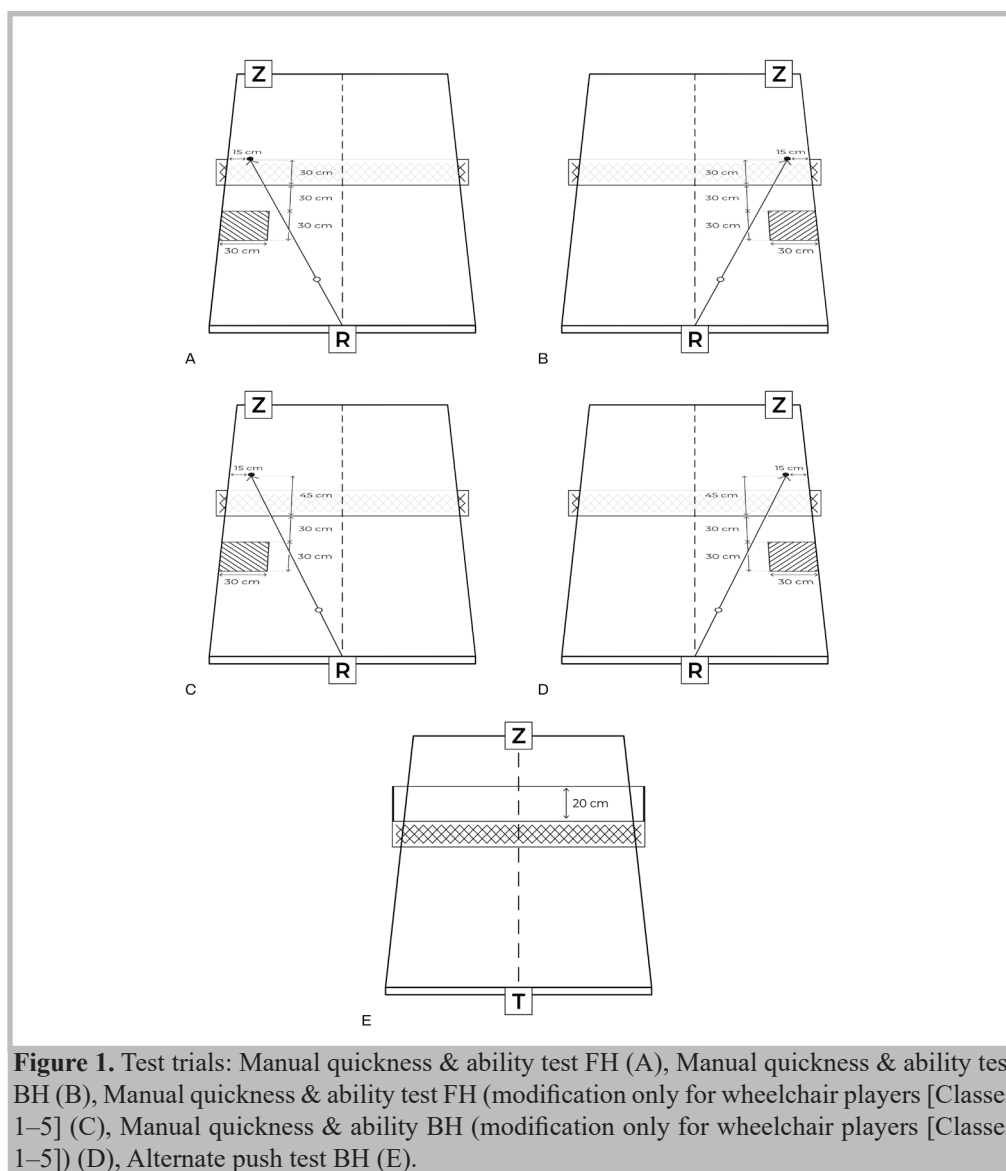


Figure 1. Test trials: Manual quickness & ability test FH (A), Manual quickness & ability test BH (B), Manual quickness & ability test FH (modification only for wheelchair players [Classes 1–5] (C), Manual quickness & ability BH (modification only for wheelchair players [Classes 1–5] (D), Alternate push test BH (E).

using a backhand stroke. This is the second attempt at validating and adapting selected tests for people with disabilities by the author Galas et al.⁸, involving different striking techniques than the first time, where the trials included serving and returning the ball with a topspin hit.

The Manual Quickness & Ability I and II tests from Gomes et al.²⁴ needed to be adapted for class 1–5 athletes in wheelchairs due to the participants' shorter arm reach. The proposed modifications were developed through detailed discussions with a panel of experts, including high-level coaches licensed from the Polish Table Tennis Association and athletes who have won medals in the Paralympic Games, World Championships, and European Championships. Video analysis of Para table tennis matches and a literature review in the field were also included^{28,29}.

In the strokes' accuracy testing, the Alternate Push Test²⁵ involved a string mounted parallel to the net at 20 cm high. The athletes had to perform as many under-cut shots with backspin as possible within 30 seconds with a master coach. One bounce was counted when the ball passed between the net and the string. Half a bounce was counted when the ball touched the string, and no bounce was counted when the ball passed over the string. The best result of two attempts within 30 seconds was considered the final result.

The trial proposed by Purashwani et al.²⁵ has so far been rarely used globally. It was used by Sharma³⁰, among others, to examine a group of 25 able-bodied table tennis players. The average score for this sample was 16.64 hits in 30 seconds.

The players were familiarized with the strategies and hardware, and the testing began shortly. All the members performed a warm-up with a square of basic workouts (15 min) and a special warm-up on the table (20 min) under the supervision of the coach, who taught them the correct way to perform the tests.

Design

All test trials were conducted on tables adapted for individuals with disabilities, certified by the ITTF, using Tibhar 3* plastic balls (Saarbrücken, Germany). The trials were implemented via direct participant observation and recorded using a Sony Handycam DCR-SR32E (Tokyo, Japan) video camera. The number of hits on the table and between the net and the tape was read on the video later. The 30 seconds in the Alternate Push Test²⁵ were measured using a CASIO HS-80TW-1EF electronic stopwatch (Tokyo, Japan), and the accuracy of the string's parallel alignment to the grid was adjusted using the JCB-CLL-R cross laser level (Pembrokeshire, United Kingdom). A specialized robot, Tibhar Robo Pro Junior (Saarbrücken, Germany), with remote control, was used for the research. The same robot has already been used by the author for other tests^{8,31,32}. Devices with similar settings were also used by other authors, including Newgy Robo Pong 2050 (Tennessee, USA)³³, Tibhar Robo Pro Master (Germany)^{21,34} and Nevgy Robo Pong 1040 (Tennessee, USA)^{17,18}. The additional tools used to conduct the skill tests were a scoresheet, a pen, a stopwatch, a chalk marker, a cord, and balls.

Statistical Analysis

Table 1. Reliability, descriptive statistics and comparison of test results for all tests at the three measurement time points.

Test	Reliability				Descriptive statistics											Friedman test				Kendall test		η^2/ϵ^2
	α	ω	ICC (2,1)	P	term	M	SD	Q1	Me	Q3	Min	Max	SKE	V	W	P	T	p	W	χ^2	P	
Manual Q&A FH (number of hits)	.843	.849	.838	< .001	T1	9.81	2.53	8.00	10.02	12.00	6.00	14.00	.00	26%	.94	.195						.41
					T2	10.01	2.69	8.00	10.00	12.00	4.00	13.00	-.90	27%	.87	.008	6.58	.037**	.76	49.81	< .001	.37
					T3	10.70	2.80	9.00	11.01	13.00	5.00	15.00	-.50	26%	.94	.201						.39
					T1	10.52	2.61	9.00	10.00	13.00	5.00	15.00	-.20	25%	.97	.629						.35
Manual Q&A BH (number of hits)	.684	.708	.652	.001	T2	10.00	2.50	8.00	10.01	12.00	6.00	14.00	-.20	25%	.93	.130	4.61	.015*	.62	40.99	.008	.42
					T3	11.62	1.95	10.00	12.02	13.00	8.00	15.00	.00	17%	.96	.451						.48
					T1	22.81	2.79	21.00	23.01	26.00	18.00	28.00	.10	12%	.95	.305						.38
Alternate Push Test (number of hits)	.799	.806	.749	< .001	T2	22.33	2.66	20.00	23.02	23.00	18.00	29.00	.60	12%	.94	.240	8.77	<.001*	.68	45.09	.003	.47
					T3	24.50	3.01	23.00	25.00	26.00	18.00	30.00	-.10	12%	.97	.644						.40

Abbreviations: α - value of Cronbach coefficient; ω - omega McDonald's coefficient; (ICC) (2,1) - Interclass correlation coefficient value of interclass correlation (two-way mixed type absolute agreement); p , significance level, M - mean; SD - standard deviation; Q1 - first quartile; Me - median; Q3 - third quartile; Min - minimum value; Max - maximum value; SKE - squatness V - coefficient of variation; W - value of Shapiro–Wilk test, T - value of Friedman test; W - value of Kendall coefficient; χ^2 - value of the chi-square statistic, η^2 - measure of the strength of the effect eta square, ϵ^2 - measure of the strength of the effect epsilon square. “*” one-way repeated measures ANOVA; “**” Friedman test.

The data's normal distribution and homogeneity were verified using the Shapiro–Wilk test. A one-way analysis of variance (ANOVA) tested the significance of differences in means among more than two independent groups. When the assumption of congruence with a normal distribution was not met, the significance of differences in distributions among more than two independent groups was tested using the Kruskal–Wallis test. The significance of differences in means between more than two dependent measures was tested using an ANOVA for dependent samples. The significance of differences in distributions among more than two dependent measures was tested using the Friedman test. A nonparametric test was used to detect treatment differences across multiple test attempts. The Bonferroni correction was used for post hoc testing. Correlations between variables were checked using Spearman's rank correlation coefficient (r_s). The conventional Cronbach's alpha (α) and McDonald's omega (ω) coefficients were calculated to determine the tests' reliability. The ICC (two-way mixed effects, absolute agreement, and Kendall's W) was used to determine correlations between measurements. Objects of measurement with ICCs between .01 and .30 represent slight agreement, ICCs between .31 and .50 represent moderate agreement, ICCs between .51 and .70 represent strong agreement, and ICCs between .71 and 1.00 or .80 represent very strong agreement³⁵. The level of statistical significance was set at $\alpha = .05$ for all tests. SPSS Statistics (version 24) (IBM, Armonk, NY, USA) was used for the statistical analysis.

Results

For all tests, absolute agreement was found for the three measurements ($P > 0.05$). The highest absolute agreement was found for the Manual Q&A FH test (RICC = .838) and the lowest for the Manual Q&A BH test (RICC = .652) (Table 1). Cronbach's alpha reliability coefficients were above 0.7 for the Manual Q&A FH ($\alpha = .843$) and the Alternate Push Test ($\alpha = .799$). For the McDonald's omega coefficient, satisfactory reliability above .70 was obtained for all tests. The highest absolute strength of agreement was found for the Manual Q&A FH test ($\omega = .849$) and the lowest for the Manual Q&A BH test ($\omega = .708$) (Table 1).

The descriptive statistics for all three tests at the three measurement time points (T1, T2, and T3) are presented in Table 1. Except for one case, the distribution of the results followed a normal distribution in all the test samples ($P \leq .05$). The statistical analysis using the Friedman test indicated significant differences between scores on the Manual Q&A FH test ($T = 6.58$; $P = .037$). However, further post-hoc analysis using the multiple comparisons test for ranks of means failed to show which measures had statistically significant differences ($P \geq .05$). The statistical analysis using one-way repeated measures analysis of variance indicated a significant difference between the number of hits scores on the Manual Q&A BH test ($F = 4.61$; $P = .015$) and the Alternate Push test ($F = 8.77$; $P < .001$). Further post-hoc analysis using the Bonferroni test indicated that, for the Manual Q&A BH test, measurements taken at T1 were significantly different from those taken at T3 ($F = 15.18$; $P < .001$). In contrast, in the second case, measurements taken at T1 were significantly different from those taken at T2 ($F = 8.82$; $P < .001$), and measurements taken at T1 were significantly different from those taken at T3 ($F = 8.82$; $P < .001$).

For most trials, the results obtained at three consecutive time points were similar ($P < .01$), and the strength of this concordance was close to 0.7. The strongest concordance was found for Manual Q&A FH test results ($W = 0.76$), and the weakest for Manual Q&A BH ($W = 0.62$) (Table 1). It should be noted that the players' results improved in each test round only with the Manual Q&A FH test. Statistically significant differences were found in the distribution of scores between integrated sports classes for the Alternate Push Test at T2 ($P = .027$). Further post-hoc analysis showed that classes 1–5 were significantly different from those with an intellectual impairment ($P = .024$). The effect's strength, measured by the epsilon square, was .30. Statistically significant differences were found in the distribution of scores between groups by integrated sport class for the Alternate Push Test at T3 ($P = .035$). Further post-hoc analysis demonstrated that sport classes 1–5 significantly differed from sport classes 6–10 ($P = .042$). The effect's strength, measured by epsilon square, was .28 (Table 2).

No additional statistically significant correlations were found.

Table 2. Correlations between test results and integrated sport classes.

Term of research	Test	integrated sport classes						Kruskal–Wallis test		ε²
		1–5 class		6–10 class		11 class		T	P	
		M	SD	M	SD	M	SD			
T1	Manual Q&A FH (number of hits/15 balls thrown)	9.51	2.66	10.21	2.51	9.36	2.99	0.55	.778**	.03
	Manual Q&A BH (number of hits/15 balls thrown)	8.33	2.16	11.41	2.14	10.81	3.30	3.47	.051*	.26
	Alternate Push Test (number of hits/30 seconds)	23.22	3.31	22.83	2.31	22.53	4.12	0.07	.934*	.01
T2	Manual Q&A FH (number of hits/15 balls thrown)	10.34	2.42	9.82	2.42	10.50	4.36	1.32	.517**	.06
	Manual Q&A BH (number of hits/15 balls thrown)	9.35	2.16	10.75	2.75	9.03	1.83	1.04	.373*	.09
	Alternate Push Test (number of hits/30 seconds)	24.21	3.31	22.31	1.80	19.84	2.22	4.33	.027*	.30

	Manual Q&A FH (number of hits/15 balls thrown)	10.51	2.51	10.90	2.90	10.32	3.59	0.22	.895**	.01
T3	Manual Q&A BH (number of hits/15 balls thrown)	11.02	1.26	12.32	2.18	10.35	0.96	2.36	.120*	.19
	Alternate Push Test (number of hits/30 seconds)	27.26	2.56	23.64	2.72	23.52	2.65	3.98	.035*	.28

Note: M – mean and *SD* – standard deviation; T - value of Kruskal Wallis test; ε^2 - measure of the effect's strength epsilon square; *P* - significance level; “*” one-way repeated measures ANOVA; “***” Friedman test; T1, T2, T3 - research time points; Manual Q&A FH - manual quickness and ability forehand test; Q&A BH - manual quickness and ability backhand test.

The correlation analysis performed using Spearman's test exhibited no statistically significant associations between: player age and individual test scores on the three test dates ($P \geq .05$); frequency of training and test scores on the three test dates ($P \geq .05$); player training years and test scores on the three test dates ($P \geq .05$); and player ranking and test scores on the three test dates ($P \geq .05$).

Discussion

This study aimed to adapt a set of stroke precision tests to the needs of players with impairment. This paper presents an adaptation of three further tests, determining the precision of the flip forehand and flip backhand strokes and after hitting the ball with a bottom rotation backhand for the needs of Para table tennis players. Those techniques are basic in Para table tennis. According to the study's results, the presented battery tests indicated good content validity and reproducibility; they could measure the selected ability level of any table tennis player with impairment. Furthermore, the ICC test displayed good results, so the table tennis skill battery test is needed to measure the indicated skills of Para table tennis athletes (Table 1). According to Heale et al.³⁶, Cronbach's $\alpha > .70$ shows high reliability. The key results demonstrated that the proposed set of specific tests for Para table tennis players is stable and can measure stroke accuracythe strength of this concordance was close to .70 (Table 2).

The presented tests of stroke precision have the advantage of including the measurement of table tennis skills often used by players during matches and training. The presented table tennis tests as a testing and training tool in technical skills do not require any highly sophisticated equipment and may offer valuable information to the coaches about their players' technical level. These tests have been used for almost two decades^{24,25} to identify talent in able-bodied table tennis players and have not yet been adapted for tennis players with impairment. Research is also lacking on their reliability. The first attempt to adapt a set of specific tests of accuracy and precision in table tennis to players with impairments was presented by Galas et al.⁸ among others. The assessment of technical skills conducted with standardized and validated tools, such as efficiency tests, enables the appropriate interindividual and group assessment of progress or regression.

The content validity was determined by giving the designed tests to the experts, including the table tennis coaches and the lecturer. The experts were asked to assess the accuracy of the flip forehand and backhand strokes and after hitting the ball with a bottom rotation backhand using various indicators, including clarity, safety, implementation, and accuracy.

Similarly to the study by Galas et al.⁸ correlations were calculated between the Para table tennis players' scores on the individual test trials and the selected independent variables to

confirm the criteria and content validity of the tests presented; those included the players' age, their frequency of training, years of training, integrated sports classes, and place in the current world ranking of Para table tennis players. The presented results are a basis to recommend that the proposed tests are suitable for all groups of players with impairments; however, statistically significant differences were observed only between classes 1–5 and classes with intellectual impairment. The differences were related to the Alternate Push Test at T2 and T3. This may be due to the challenges of adapting tests for specific sports to the motor or intellectual limitations of a person with a impairment.

The Para table tennis player's world ranking depends on many variables, hence the lack of significant correlation with the results of test trials assessing the selected strokes' accuracy. This result was confirmed by the studies of Galas et al.⁸, Haryanto et al.⁹ and Van Biesen et al.^{17,18}. The arbitrary choice of the study group (the Polish senior Para table tennis national team), characterized by homogeneity and internal consistency, means that the variables—age, table tennis experience, and training volume—cannot be directly related to the level of precision in the analyzed trials. The functional difficulty of the analyzed test samples, which refers to the difficulty level of a given task in relation to the performer's proficiency in that task or the conditions under which skill acquisition takes place, was also similar in the studied group. This observation might explain the low correlations between test results and indicated variables.

This study's results indicate that the presented battery tests for Para table tennis players have satisfactory content validity. This does not mean that these tests' usefulness has been unambiguously proven. However, such usefulness would be warranted if the tests' current relevance allows for further research to determine whether they are authentic and suitable for future use in Para table tennis.

Future research should investigate the relationship between the Para table player's movement kinematics and the performance of individual strokes regarding sensorimotor coordination. The topspin forehand is a complex, multi-joint movement, with multiple muscles working in different phases in different ways within a coordinated kinematic chain. The introduction of such studies will allow for the parameterization of tests and the indication of appropriate training methods to improve performance and for a better understanding of the detailed conditions affecting the accuracy of shots in Para table tennis^{12,31–33,37–39}.

The findings of this study should be considered along with their limitations. The sample size of each sports class was small due to the limited number of Para-athletes available in Poland. In the 2023–2024 season, only 227 players in Poland held licenses for table tennis. The presented line of research is worth further investigation in Para table tennis in other countries. International tournaments, offering further research opportunities, take place several times a year in various locations worldwide.

Another significant limitation of the research is the lack of up-to-date and reliable norms against which the obtained results in the analyzed test samples can be compared. The only available studies indicating normative values to assess the level of selected components of special fitness among able-bodied athletes do not allow for such an attempt because, in the case of the tests conducted by Gomes et al.²⁴, the division was made only based on gender. In contrast, the study by Purashwani et al.²⁵ was conducted only within a group of men, among juniors. In both cases, there is a lack of differentiation based on important variables, such as the stage of sports training, age category, training experience, or training frequency. In individual tests, it is essential to differentiate the reference values based on the difficulty level of the tasks performed. Significant differences were observed in this regard, especially in the Reaction Speed tests, where the first attempt aims to hit only the opposite half of the table, a rectangle of 137 x 76.25 cm. On the other hand, the second attempt aims to hit 30 x 30 cm squares arranged in the corner of the table. In practically every trial, detailed references are lacking regarding the exact point of impact of the ball on the player's half of the table and the technical parameters for programming the specialized robot to standardize the tests.

The results of the research presented in this article indicated that, for Para table tennis players, differentiation based on disability classifications is an essential element. The limited group of participants allows for data analysis only within integrated groups of grades 1–5, 6–10, and 11. However, it is also important to keep in mind that the classification system in table tennis is complex and detailed. In this regard, even within the indicated integrated groups, significant differences are observed concerning the type of disability^{8,40}. For example, among wheelchair competitors, class 1 athletes may have limited control over their upper limbs, affecting their ability to perform serves, returns, and strokes to different parts of the table, especially when executing shots like flips or playing the ball with backspin. These limitations may arise from various causes, such as severe cerebral palsy, serious spinal cord injuries, or other conditions that affect muscle control and coordination. In comparison, class 5 athletes have significantly better body balance and stability. They can make quick position changes and perform various strokes from different parts of the table, even when the balls fly just over the net. Their mobility limitations may be caused by moderate forms of cerebral palsy or mild spinal cord injuries^{8,40}.

Practical applications

There is an urgent need to implement the research presented in this article, as developing objective methods to assess the level of special fitness in table tennis players with impairment is extremely important in training practice. Knowledge in this area can be utilized to classify and assess the development of athletes with disabilities to improve individual technique, create development plans and pathways in a tactical context, or assist in monitoring the overall level of physical readiness. Furthermore, it enables the development of recommendations for coaches aimed at optimizing and monitoring the training process, as well as indicating potential compensatory and corrective actions in the process of developing essential motor coordination skills in table tennis, such as the ability to differentiate movements, time-space orientation, balance maintenance, and rapid reaction.

It is also worth mentioning that future research will aim to explore the mechanisms of motion control during strikes (e.g., biomechanical or physiological). These studies will not only enable the assessment of strike precision and the parameterization

of trials but also contribute to a deeper understanding of the phenomenon under investigation, thereby increasing the value and practical application of the acquired knowledge.

The next step should be the creation of an algorithm for the development of normative values to assess stroke accuracy levels in Para table tennis for the test samples analyzed. The existing standards developed by Gomes et al.²⁴ and Purashwani et al.²⁵ are outdated and unreliable. Further research in this vein is recommended to systematize and clarify these issues.

Conclusions

In conclusion, the presented tests are the first attempt to adapt and validate a selection of stroke accuracy tests for use by Para table tennis players. The battery of the specific tests appears to be a simple and reliable procedure that could be easily used by coaches with trained Para table tennis players and should be taken into account when setting basic goals in the training plan. There is a need for standardized testing in Para table tennis coaching practice. There is a need for further research to develop an algorithm of normative values to assess the accuracy levels of Para table tennis strokes for the analysed tests.

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Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Ethical Committee approval

Bioethics Committee of the Karol Marcinkowski Medical University in Poznań (no. 543/18).

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The authors have no conflicts of interest to declare.

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Author-s contribution

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