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BILATERAL TESTS FOR THE ASSESSMENT OF MANIPULATIVE SKILLS IN CHILDREN: DEVELOPMENT, RELIABILITY, AND VALIDITY

original paper
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FRANJO LOVRIC[1], IGOR JELASKA[2], CAIN C.T. CLARK[3], EMMA L.J. EYRE[3], DURDICA MILETIC[2], PETRA MANDIC[2]

[1] Faculty of Science and Education, University of Mostar, Mostar, Bosnia and Herzegovina
[2] Faculty of Kinesiology, University of Split, Split, Croatia
[3] Centre for Sport, Exercise and Life Sciences, Coventry University, Coventry, United Kingdom

ABSTRACT
Purpose. The aim of the study was to develop bilateral tests for simultaneous quantitative and qualitative assessment of manipulative skills among 7-year-old children, and to examine the reliability and validity of the tests.
Methods. A sample of 78 (35 girls) children (aged 7.34 ± 0.53 years) were tested with 3 novel bilateral tests: *Standing ball throwing*, *Bouncing the ball standing*, and *Dribbling the ball with the foot*. Subsequently, the reliability and validity of the constructed tests were investigated.
Results. Very high between-participant reliability was demonstrated through high and stable Cronbach's alpha coefficient (0.94–0.98 for all tests), while relatively small coefficients of variation (0.03–0.12 for all tests) were observed. High values of correlation between expert judges' ratings, as well as intra-class correlation, for both left and right sides indicated excellent between-rater reliability (0.84–0.99 and 0.88–0.93 across all tests, respectively).
Conclusions. The tests are reliable and valid in 7-year-old children and may be used to promote the adoption of appropriate sport and physical activities. Future research should explore the influence of further fine and gross motor skills on motor development.
Key words: psychometric characteristics, measurement, fundamental movement skills, motor asymmetry, motor competence

Introduction

The mastery of fundamental movement skills (FMS), the basic building blocks of movement, is a prerequisite for children's physical, cognitive, and social development, and is suggested to provide the foundation for an active lifestyle [1, 2], potentially to combat the global obesity epidemic [3, 4]. Although naturally developed through growth, children's free play is insufficient stimuli alone for optimal development of FMS [5], leading to a need for additional education and teaching in the field [6]. Furthermore, organised physical activity is shown to be strongly associated with FMS [7]. Current empirical data support the dogma that teaching programmes of physical education classes, globally, should be partially based on learning and mastering FMS [8, 9].

FMS are movement patterns that can be defined as locomotor or manipulative skills. While locomotor skills necessitate moving the body from one position to another (e.g., running, leaping, jumping, and galloping), manipulative skills refer either to receiving or to propulsion of an object with the hand or foot (i.e., throwing, kicking, striking, and catching) [10, 11].

In addition to locomotor and object control, competence in stability is also alluded to (i.e., balancing and twisting) [12, 13]. It is evident that in all facets of FMS, manipulative skills are recognized as an indispensable part of the basic motor knowledge. Extending beyond FMS, a large number of sporting activities will

Correspondence address: Cain C.T. Clark, Centre for Sport, Exercise and Life Sciences, Coventry University, Alison Gingell building, Priory Street, CV1 5FB, United Kingdom, e-mail: Cain.Clark@coventry.ac.uk

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primarily depend on the quality of learned and developed basic building blocks, leading towards sports-specific knowledge and competence. Despite mounting evidence for the benefit of qualifying FMS, there remains an over-predominance in focusing on the quantity of activity rather than the quality [14, 15]. Only in contemporary works has there been a trend towards a joint consideration of quantification and qualification [14, 15], which is especially recommended for the assessment of motor tasks in younger age groups [16].

There are three accepted phases of motor knowledge development: the (1) initial, (2) basic, and (3) mature one [17]. During the development phase of FMS, the integration of all components of the learned movement structures in coordinated, resulting in accurate and effective performance [18]. Individuals who have not reached the mature phase in the development of biotic motor knowledge have a limited opportunity to progress in the acquisition of specific motor skills [1, 18]. In accordance with the progressive and developmental nature of FMS and specific motor skills, the necessity of reliable and valid FMS assessment is axiomatic [19]. Notwithstanding this need, there is a distinct paucity of bilateral-specific FMS tests, and given the ipsilateral and contralateral nature of many sports, the development of valid bilateral assessments is warranted. Therefore, the aim of this study is twofold: first to construct, and subsequently to examine novel bilateral assessments of manipulative skills.

Material and methods

Participants

The sample included 78 children (35 girls, 43 boys) with an average age of 7.34 ± 0.53 years, from the same geographical location. The final sample only involved participants who were right-handed (4 left-handed subjects were excluded), asymptomatic of ill health, without visible motor disturbances or injuries (3 subjects were excluded), and not engaged in additional sports activities outside of obligatory physical education classes (16 subjects were excluded).

Variables

Three bilateral tests for simultaneous qualitative and quantitative assessment of the degree of adoption of manipulative FMS were constructed: *Standing ball throwing*, *Bouncing the ball standing*, and *Dribbling the ball with the foot*. During motor performance, a model of error assessment was applied according to the segment of knowledge [20], which is recommended for the evaluation of motor skills, particularly among younger age groups. Consequently, each skill performance was precisely divided into four topological segments for which evaluation criteria were identified, detailed in Tables 1–3. For each test, the result of the participant was obtained by summing the segmental qualitative performance assessments (maximal score: 8) and quantitative results (maximal score: 4), so the total assessment scale equalled 12 points. The described procedure united qualitative and quantitative assessment, further facilitating inspection of each of them separately. An expert evaluation was carried out through analysis of digital records by three independent expert judges with more than 15 years of experience in physical education. The average values of all expert scores were used to define each participant's score. Description of each newly constructed test is reported below.

Test name: *Standing ball throwing* (with left hand, with right hand) (Figure 1).

Place of performance: School gym.

Equipment: Tennis ball, meter.

Starting position: Feet shoulder-width apart, arms down next to the body, tennis ball in one hand.

Performance: When signalled 'GO,' the participant steps forward with the leg opposite to the arm they use to swing with body rotation and throws the ball. The task is to throw the ball as far as possible. The task is then completed with the opposite side of the body. A familiarization period was permitted.

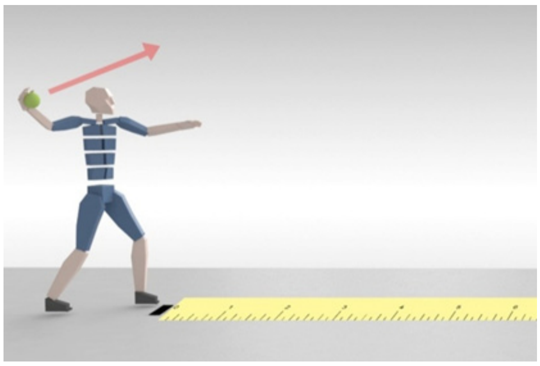

Figure 1. 3D view of *Standing ball throwing* performance

Test name: *Bouncing the ball standing* (with left hand, with right hand) (Figure 2).

Place of performance: School gym.

Equipment: Basket ball, 30 × 30 cm area marked with tape, stopwatch.

Starting position: Participant stands on their right foot, with left leg bent at the knee to 90°, holding the ball in a front arm raise, arms bent at the elbows.

Table 1. *Standing ball throwing*: judge's score card

Motor skill evaluated	Score
Swinging the throwing arm while rotating the torso	2
Rotating the torso without arm swing	1
Throws the ball without swinging or rotation	0
With a slight bend in the throwing arm, moves to front arm raise	2
During the throw, separates the throwing arm from the body	1
During the throw, the throwing arm is lowered next to the body	0
During the throw, makes a step forward with the opposite leg	2
Makes a step forward with the opposite leg before the throw	1
Throws the ball without stepping forward	0
After the throw, raises the back leg, shifting weight to the front into the step forward	2
Shifts weight from the back leg without lifting it from the ground	1
Does not shift weight from the back to the front leg	0
Quantitative assessment	
The first 20% of the results	4
The second 20% of the results	3
The third 20% of the results	2
The fourth 20% of the results	1
The fifth 20% of the results	0

Table 2. *Bouncing the ball standing*: judge's score card

Motor skill evaluated	Score
Bounces the ball standing on one leg	2
Bounces the ball standing on one leg moving their foot	1
Bounces the ball with the opposite leg touching the ground	0
Bounces the ball in the area marked for leading	2
Bounces the ball partly disrespecting the marked area	1
Bounces the ball out of the marked area	0
Bounces the ball in the rhythm and height of the hips	2
Bounces the ball partly in the rhythm misbalancing the level of the ball leading	1
Fails to keep the rhythm and the level when bouncing the ball	0
Bounces the ball by pushing it in elbow joint and wrist	2
Bounces the ball pushing it in elbow joint without depreciation in the wrist	1
Fails to bounce the ball	0
Quantitative assessment	
The first 20% of the results	4
The second 20% of the results	3
The third 20% of the results	2
The fourth 20% of the results	1
The fifth 20% of the results	0

Performance: When signalled 'GO,' the participant puts the ball down with their right hand and starts bouncing. Standing on one leg, the subject performs 6 bounces of the ball into the bounded space. The task is repeated with the left hand. A familiarization period was permitted.

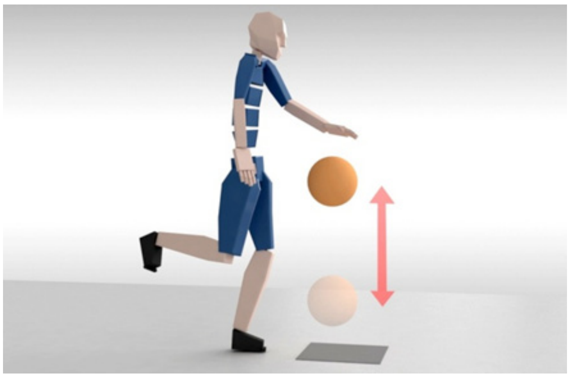

Figure 2. 3D view of *Bouncing the ball standing* performance

Test name: *Dribbling the ball with the foot* (with left leg, with right leg) (Figure 3).

Place of performance: School gym.

Equipment: Soccer ball, cones, tape.

Starting position: Participant stands in parallel position, arms next to the body, feet shoulder-width apart, a 10-metre track is demarcated with two cones, with a soccer ball at the starting cone.

Performance: When signalled 'GO,' the participant dribbles the soccer ball with the dorsal portion of their foot. The task is repeated with the left foot. A familiarization period was permitted.

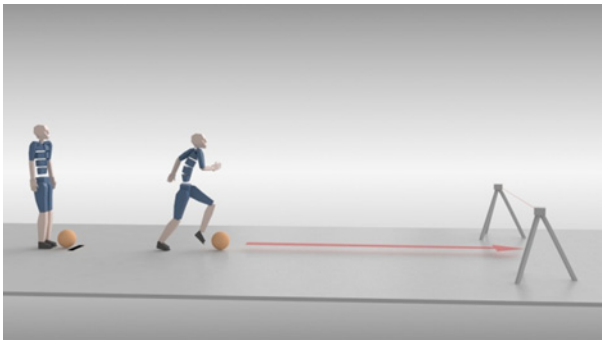

Figure 3. 3D view of *Dribbling the ball with the foot* performance

Table 3. *Dribbling the ball with the foot*: judge's score card

Motor skill evaluated	Score
Performs the task in a straight line	2
Slightly deviates from the straight line	1
Straight line is visibly deteriorated	0
Whilst running, performs the task continuously controlling the ball	2
Partially disturbs the pace and continuity of performance	1
The pace and continuity of performance are visibly deteriorated	0
Dribbles the ball with upper foot	2
Partially dribbles the ball with upper foot	1
Does not lead the ball with upper foot	0
Whilst dribbling, alternately watches the ball and the direction, with the arms bent to the elbow	2
Whilst dribbling, alternately watches the ball and the direction, with an irregular position of the upper part of the body, arms to the body	1
Whilst dribbling, watches the ball constantly during leading	0
Quantitative assessment	
The first 20% of the results	4
The second 20% of the results	3
The third 20% of the results	2
The fourth 20% of the results	1
The fifth 20% of the results	0

Experimental procedure

All measurements were conducted in the same school gym, under the same conditions, and at the same time of day, to ameliorate the effect of diurnal variation. The parents/guardians were asked to confirm their child's health status prior to participation. Measurements were conducted on three successive days; during a single day, the subjects were measured three times in one test, firstly on their right side, and subsequently on their left side. The participants' trials were recorded in the mediolateral plane by a digital camera (HC-V770K Full HD Camcorder, 1080p, 20 × digital zoom); after all recordings were collected, three expert judges (researcher, practitioner, and teacher) rated all performances in accordance with judge's score cards, as detailed in Tables 1–3.

Data processing methods

For both measured sides, all data were presented as mean ± standard deviation, minimal and maximal result. The Kolmogorov-Smirnov test was used to confirm the normality of distribution prior to further inferential statistical tests. Because of construct validity assessment, exploratory factor analysis was applied, and factor structure matrix of the judges' scores was presented together with absolute and relative amount of variability of the judges' ratings related to single factors. Between- and within-participant reliability were assessed by using Cronbach's alpha (Cα) and coefficient of variation (CV), respectively. Furthermore, the intra-class correlation coefficient (ICC) and average correlation among the judges' ratings (IIR) were applied for between-rater reliability. All calculations were performed with the Statistica 13.2 data analysis software system (Dell Inc., Tulsa, OK, USA). For all tests, the level of statistical significance was set as $\alpha = 0.05$, with 95% confidence intervals presented when appropriate.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the authors' institutional review board or an equivalent committee.

Informed consent

Informed consent has been obtained from the parents/guardians of all individuals included in this study.

Results

Very high between-participant reliability was demonstrated through high and stable Cα coefficient (0.94–0.98 for all tests), while relatively small observed CVs (0.03–0.12 for all test) indicate appropriate within-participant reliability for all tests (Tables 4–6). High values of IIR, as well as ICC, for both left and right sides point at excellent between-rater reliability (IIR: 0.84–0.99, ICC: 0.88–0.93 across all tests) (Tables 4–6).

Discussion

A general observation is that boys tend to be more physically active than their female counterparts [21, 22], and generally display better object control skills than girls; however, evidence on sex differences in locomotor skills is much more equivocal [15, 23, 24], exemplifying the need for a specific locomotor testing battery. Contentiously, many studies show that girls outperform boys in locomotor skills [25–27], whilst a comparable number of studies assert that boys have equal [28, 29] or higher locomotor skill competence [30]; nevertheless, methodological issues or lack of specificity may be contributing to the discord across the literature. The present study proposes a new ontology, where reliable bilateral assessment of manipulative skills is focussed upon.

As detailed in Tables 4–6, very high between-participant reliability is identified through high and stable Cα coefficient, while relatively small observed CVs indicate appropriate within-participant reliability for all tests. High values of IIR, as well as ICC, for both left and right sides point at excellent between-rater reliability (IIR: 0.84–0.99, ICC: 0.88–0.93 across all tests). This suggests that the judges had adequate preparation with clearly defined evaluation criteria for these tests [31]. The results of the present study, in terms of reliability, are similar to the widely known and eponymous Test of Gross Motor Development, 2nd edition (TGMD-2) [20]. The TGMD-2 refers to 12 FMS, including locomotor and object control skills, and takes approximately 20 min to administer [20]. It is a qualitative measure in which each skill is scored against performance criteria prescribed in an accompanying manual (3–5 criteria per skill). Ratings in each item are, perhaps somewhat cumbersomely, summed to compute scores for locomotor and object control skills (each score ranging from 0 to 48). The psychometric properties of the TGMD-2 have been evaluated and the manual reports excellent test-retest reliability and inter-rater reliability ($r > 0.85$), as well as a good internal

Table 4. Reliability and validity of the constructed *Standing ball throwing* test at three measurement points for both the left and right side

	1st measurement right	2nd measurement right	3rd measurement right	1st measurement left	2nd measurement left	3rd measurement left
Cα		0.98			0.96	
CV		0.03			0.09	
ICC	0.91*	0.88*	0.91*	0.92*	0.90*	0.93*
95% CI	0.87–0.95	0.86–0.91	0.86–0.94	0.89–0.96	0.88–0.93	0.89–0.96
IIR	0.98*	0.94*	0.97*	0.96*	0.97*	0.94*
95% CI	0.96–0.99	0.92–0.97	0.95–0.99	0.93–0.99	0.95–0.99	0.92–0.99
S1	–0.99	–0.98	–0.99	–0.99	–0.99	–0.97
S2	–0.99	–0.97	–0.99	–0.99	–0.99	–0.98
S3	–0.99	–0.98	–0.99	–0.99	–0.99	–0.98
Var	2.95	2.87	2.93	2.93	2.95	2.88
V%	98.49	95.65	97.66	97.55	98.24	95.89
KS-p	< 0.15	> 0.20	< 0.20	> 0.20	< 0.20	> 0.20
M	5.85	4.31	5.82	4.08	6.33	4.38
σ	3.42	2.40	3.39	2.54	3.50	2.64
Min	0.00	0.00	0.00	0.00	1.00	0.00
Max	12.00	9.00	12.00	12.00	12.00	11.67

* significant at $p < 0.05$
Cα – Cronbach's alpha coefficient, CV – coefficient of variation, ICC – intra-class correlation coefficient, 95% CI – 95% confidence interval, IIR – average correlation between expert judges' ratings, S1, S2, S3 – factor structure matrix coefficients, Var – variance accounted for by the factor, V% – proportion of variance accounted for by the factor, KS-p – significance of Kolmogorov-Smirnov test, M – mean, σ – standard deviation, Min – minimum result, Max – maximum result

Table 5. Reliability and validity of the constructed *Bouncing the ball standing* test at three measurement points for both the left and right side

	1st measurement right	2nd measurement right	3rd measurement right	1st measurement left	2nd measurement left	3rd measurement left
Cα	0.98			0.94		
CV	0.06			0.09		
ICC	0.93*	0.93*	0.93*	0.89*	0.91*	0.92*
95% CI	0.90–0.95	0.91–0.96	0.91–0.95	0.83–0.95	0.89–0.94	0.90–0.96
IIR	0.95*	0.95*	0.96*	0.95*	0.94*	0.92*
95% CI	0.91–0.99	0.93–0.99	0.94–0.98	0.92–0.97	0.92–0.97	0.89–0.97
S1	–0.98	–0.98	–0.98	–0.99	–0.99	–0.99
S2	–0.99	–0.98	–0.99	–0.99	–0.99	–0.99
S3	–0.98	–0.99	–0.99	–0.99	–0.99	–0.99
Var	2.90	2.99	2.92	2.94	2.96	2.66
V%	96.83	96.41	97.42	98.32	98.57	98.51
KS-p	< 0.15	> 0.20	< 0.05	> 0.20	< 0.10	> 0.20
M	5.17	4.44	5.18	5.34	6.48	6.61
σ	3.01	2.90	3.14	3.42	3.06	2.87
Min	0.00	0.00	0.00	0.00	0.00	0.00
Max	11.67	10.00	10.67	11.00	12.00	11.67

* significant at $p < 0.05$
Cα – Cronbach's alpha coefficient, CV – coefficient of variation, ICC – intra-class correlation coefficient, 95% CI – 95% confidence interval, IIR – average correlation between expert judges' ratings, S1, S2, S3 – factor structure matrix coefficients, Var – variance accounted for by the factor, V% – proportion of variance accounted for by the factor, KS-p – significance of Kolmogorov-Smirnov test, M – mean, σ – standard deviation, Min – minimum result, Max – maximum result

Table 6. Reliability and validity of the constructed *Dribbling the ball with the foot* test at three measurement points for both the left and right side

	1st measurement right	2nd measurement right	3rd measurement right	1st measurement left	2nd measurement left	3rd measurement left
Cα	0.95			0.94		
CV	0.08			0.12		
ICC	0.90*	0.89*	0.90*	0.84*	0.88*	0.92*
95% CI	0.87–0.94	0.85–0.93	0.87–0.96	0.79–0.93	0.82–0.93	0.85–0.95
IIR	0.95*	0.95*	0.96*	0.92*	0.94*	0.95*
95% CI	0.90–0.99	0.91–0.97	0.92–0.99	0.87–0.97	0.89–0.98	0.90–0.99
S1	–0.98	–0.98	–0.98	–0.96	–0.98	–0.98
S2	–0.99	–0.98	–0.99	–0.98	–0.98	–0.98
S3	–0.99	–0.98	–0.99	–0.98	–0.98	–0.98
Var	2.90	2.89	2.91	2.83	2.89	2.90
V%	96.79	96.48	96.99	94.43	96.20	96.61
KS-p	> 0.20	> 0.20	> 0.20	> 0.20	> 0.20	> 0.20
M	5.49	4.94	5.04	4.57	5.52	4.80
σ	2.66	2.51	2.46	2.42	2.43	2.54
Min	0.00	0.00	0.00	0.00	1.33	0.00
Max	12.00	11.00	12.00	12.00	12.00	11.00

* significant at $p < 0.05$
Cα – Cronbach's alpha coefficient, CV – coefficient of variation, ICC – intra-class correlation coefficient, 95% CI – 95% confidence interval, IIR – average correlation between expert judges' ratings, S1, S2, S3 – factor structure matrix coefficients, Var – variance accounted for by the factor, V% – proportion of variance accounted for by the factor, KS-p – significance of Kolmogorov-Smirnov test, M – mean, σ – standard deviation, Min – minimum result, Max – maximum result

consistency (Cα = 0.85 and Cα = 0.88 for locomotor and object control subtests, respectively). In fact, the present study has demonstrated preferential reliability and higher internal consistency (Tables 4–6). Where exploratory factor analysis resulted in an extraction of a single factor, a high percentage of explained variability was evident, with a score of more than 94% in all the tests; this indicates satisfactory construct validity of the tests for both sides of the body, at all three measuring points [32–34]. Notwithstanding, owing to the TGMD-2 popularity, construct, content, and concurrent validity have also been determined for children aged 3–10 years in the TGMD-2 [35, 36], in addition to the development of a third iteration of the test. Therefore, further work must seek to expand on the present study's promising results, and ascertain whether reliability and validity are retained across ages [37], whether actual results are concordant with the perceived skill level [38], and whether participation in sports concomitantly improves manipulative skills [39].

Observing all tests individually, reviewing the average values and other descriptive parameters of all six newly constructed tests, we can confirm very high sensitivity of these parameters; following analysis of mean values and comparison across all measurements, we found that the obtained results were stable. Abovementioned indicators clearly show the applicability of these tests, which, owing to well-established evaluation criteria and quantitative components, enable quality assessment and clear insight into the manipulative skills of 7-year-old children. Furthermore, a methodological base for further scientific research of factors that may affect the quality of motor skills performance is now established.

This study has multiple limitations to consider when interpreting our findings. Firstly, all raters assessed the performance of participants using video recordings, with only one plane of view available. Whilst this could conceivably impact the raters' perceptions, the same recordings were provided to each rater. Additionally, there were some constraints in the data collection process, such as space limitations, angle of the camera relative to the participant, and distance of the participant from the camera. However, all subjects were able to complete the assessment in accordance with the newly produced, standardized procedures, and raters had an acceptable view of all performances for scoring. A further, potential, ecological limitation is that because all scoring in this study was based on digitally recorded performances, reliability estimates should not necessarily be generalized to the professionals, educators, and other key stakeholders who would score the performances of children during live assessment. Therefore, it would be pragmatic that future research investigates the discrepancy, if any, between live and video-recorded assessment.

Conclusions

The importance of the present study is reflected in the fact that the newly constructed bilateral tests had satisfactory psychometric characteristics, which is conducive to further scientific research and practical use. Additionally, it should be emphasized that, although the newly constructed tests incorporate both qualitative and quantitative facets, they can be efficaciously operationalised to evaluate the respondents solely qualitatively (performance technique) or solely quantitatively (performance effectiveness). Furthermore, given that the newly constructed tests are bilateral, we can tentatively consider them as an instrument that can be utilised to detect manipulative skills as a whole rather than only unilateral elements. A prominent advantage of the tests is the fact that they are not financially burdensome and only require simple materials and conditions for their performance and measurement, and they take only a short amount of time to complete. Based on measures of reliability, the newly constructed bilateral tests can efficaciously be used for the assessment of manipulative skills in 7-year-old children, as a diagnostic tool, for transitional or developmental monitoring, or as an indicator of the efficacy of specific educational or training programmes that encourage children into sports activities, whilst helping to counter unilateral dominance. The authors assert that the evaluation and monitoring of manipulative skills within physical education classes, with additional teacher education, could be better and more easily realized, at no extra cost, with these newly constructed tools, facilitating the mastery or competency of sport specialised skills.

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Disclosure statement

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Conflict of interest

The authors state no conflict of interest.

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