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Development and Initial Validation of a Sensor-Based Motor Tracking Device for Measuring Early Childhood Motor Skills



Anton. Komaini¹, Agus. Rusdiana¹, Surya Adi. Saputra², Jaffry Bin. Zakaria³, Novadri. Ayubi⁴

¹ Faculty of Sport Science, Universitas Negeri Padang, Padang, West Sumatra, Indonesia

² Faculty of Sport Science, Universitas Negeri Malang, Malang, East Java, Indonesia

³ Faculty of Sports Science and Coaching, Sultan Idris Education University, Tanjong Malim 35900, Malaysia

⁴ Department of Sport Management, Faculty of Sport and Health Sciences, Universitas Negeri Surabaya, Surabaya, East Java, Indonesia

* Corresponding author email address: antonkomaini@fik.unp.ac.id

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ABSTRACT

Objective: This study aimed to develop a prototype sensor-based motor tracking device and to conduct an initial expert-based validation for assessing early childhood motor skills.

Methods and Materials: This study employed a Research and Development (R&D) design. Three experts in motor skills, media, and testing and measurement evaluated the prototype. The validation process was intended to identify the strengths and weaknesses of the product. After expert validation, a limited preliminary field trial was conducted with two children (one boy and one girl), aged 5-6 years, accompanied by their parents.

Findings: Expert appraisal produced feasibility ratings of 80%, 86%, and 83% for the media, motor skills, and testing and measurement domains, respectively. The overall expert-based feasibility score was $83.0 \pm 3.0\%$ (median = 83.0%; range = 80-86%), and all ratings were classified within the predefined valid category. A limited field trial involving two children aged 5-6 years confirmed basic implementation feasibility. These findings support preliminary expert-based feasibility but do not establish full psychometric validity, reliability, measurement accuracy, or criterion validity.

Conclusion: The prototype showed preliminary feasibility for early childhood motor skill assessment based on expert appraisal and limited field implementation. The evidence remains early-stage, and larger validation studies are required to determine reliability, criterion validity, measurement error, sensitivity, specificity, calibration accuracy, and agreement with standardized instruments such as TGMD-3 and MABC-2 before routine use can be recommended.

Keywords: Motor Skills, Sensor Technology, Motor Tracking

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1. Introduction

Motor skills are an essential part of preschool physical education programs (1). These skills are essential for children aged 3-8 years as specific and complex foundational skills for play, sports, and recreational activities (2). By the age of 5-6, children will have mastered several motor skills, supported by increased sensory-perceptual abilities (2). Children can walk, run, pick up, and manipulate objects to some extent. Children's motor skills developed at an early age have a significant impact on their physical activity later in life (3). Early life is a crucial period in a person's life span. Motor impairments in childhood may be associated with delays in other developmental domains. Movement is the main element in the development of children's basic motor skills, therefore children's motor development will be seen through the various movements they can do, such as crawling, creeping, walking and jumping (4). A good movement activity program can shape and develop children's basic movement skills (5). Humans need movement to work and survive from threats from their environment. Without movement skills, it is difficult for humans to survive (6).

The results of a previous study indicated that 36.07% of children's basic motor skills were in the low category and 18.98% were in the very low category (7). This finding is supported by a study reporting delayed locomotor and object-control skills among boys and girls in rural and urban areas of West Sumatra (8). If left untreated, motor delays may be associated with movement asymmetry, persistence of primitive reflexes, hypertonia or hypotonia, impaired reflexes, and uncontrolled movements (9). Furthermore, poor motor coordination may be associated with difficulties in balance, coordination, and daily motor performance (10).

Alternative approaches are needed to support early childhood motor skill assessment. One possible approach is the development of a motor tracking device that uses sensor-based technology to capture selected movement-related information. Sensors are important components in the design of movement assessment tools (11). Sensor-based systems may also support more engaging and practical assessment environments (12). Motor skill development is associated with later physical activity, health, and obesity-related outcomes (13, 14). Arduino- and ultrasonic sensor-based devices have also been developed for related movement-

measurement applications (15). Although previous studies have discussed the importance of early motor skill development and the prevalence of motor delays, fewer studies have focused on objective technology-based assessment tools for preschool settings. This gap supports the need for preliminary development and validation of a sensor-based motor tracking prototype for early childhood motor skill assessment.

This research aims to develop a prototype sensor-based motor tracking device and to conduct an initial expert-based validation for assessing motor skills in early childhood.

2. Methods and Materials

2.1 Study Design

This research employed a Research and Development (R&D) methodology. Three experts in motor skills, media, and testing and measurement participated in the initial validation stage. The validation test aimed to identify the strengths and weaknesses of the designed product. Following expert validation, the prototype was tested in a limited preliminary field trial.

2.2 Prototype Design

The overall structure of the motor tracking device is shown in Figure 1.

The prototype was named the Motor Tracking Device: Sensor-Based Technology for Assessing Early Childhood Motor Skills. It was developed as an environment-based assessment prototype to support the measurement of early childhood motor skills through contact and timing detection. The device consisted of an aluminum frame, control cables, speakers, a scoreboard, touch sensors, pressure sensors, a switch button, and an ultrasonic sensor. These sensors were integrated into the testing environment to detect movement-related contact events and task completion, while a digital timer recorded task duration. However, detailed information on sensor specifications, sampling frequency, calibration procedures, and data-processing algorithms was not available in the present study. Therefore, these technical parameters should be clearly standardized and empirically evaluated in future validation studies. The physical device components are shown in Figure 2.

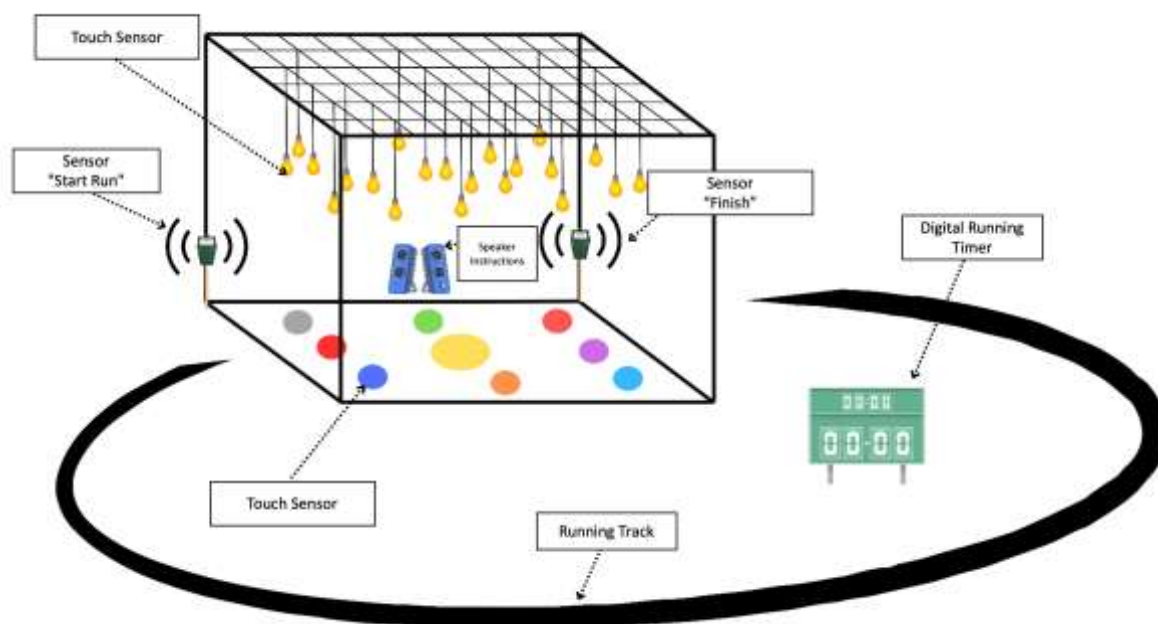


Figure 1. Design of the Motor Tracking Device



Figure 2. Device Components

2.3 Research Procedures

The research procedure consisted of four sequential stages. First, the researchers designed a sensor-based motor tracking device for assessing early childhood motor skills. Second, a working prototype of the device was produced. Third, preliminary laboratory testing was conducted to examine whether the system could detect basic locomotor activities, including stepping and running. Fourth, expert-based validation was conducted with one motor skills expert, one media expert, and one test and measurement expert.

2.4 Participants

A total of two children, one boy and one girl aged 5-6 years, accompanied by their parents, participated in the limited preliminary field trial. Because of the very small sample size, the field trial should be interpreted only as a feasibility check and not as evidence of generalizable validity.

2.5 Expert Validation Instrument

The expert validation instrument is presented in Table 1. This expert-review procedure was used to support content and face validity during early instrument development (16).

Table 1. Expert Validation Instrument

Validity Test	Assessment
Media expert	The device's sensor performance is optimal. The device's size meets the user's needs and characteristics. The device's design and appearance are of good quality. The device's ease of use is high. The device provides effective motor skill measurement. The device has the potential to produce measurement data; however, accuracy and reliability require further empirical testing.
Motor skills expert	The material presented in the "Motor Tracking: Sensor-Based Technology for Measuring Early Childhood Motor Skills" tool is easy to understand and aligns with the measurement objectives. The tool has the potential to support objective motor skill assessment based on the aspects being measured; further reliability and criterion-validity testing is required. The tool's design and procedures have been developed to efficiently implement motor skill measurement. The tool is easy to operate and implement in the process of measuring early childhood motor skills.
Test and measurement expert	The suitability of the instrument to the construct of early childhood motor skills being measured. The clarity of the instrument's procedures and measurement mechanisms. The instrument's ability to objectively measure motor skills. The instrument's suitability to testing and measurement principles. The perceived potential accuracy of the instrument's measurement results. The instrument's potential to produce consistent data; this should be verified in future reliability testing.

The evaluation categories were defined as follows: invalid (0-25%), less valid (26-49%), fairly valid (50-74%), and valid (75-100%).

2.6 Statistical Analysis

Because the study involved three expert ratings and a limited field trial with two children, the analysis was restricted to descriptive statistics and evidence-mapping summaries. Expert ratings were summarized using frequency, percentage, mean, standard deviation, median, minimum, and maximum values. Inferential statistical testing was not appropriate because the sample size and study design did not support hypothesis testing or group comparison.

3. Results

The results are organized according to the development pathway of the prototype, the preliminary functionality check, expert-based feasibility ratings, and the limited field trial. Because the study was designed as an early-stage development and validation study, the findings are interpreted as preliminary feasibility evidence rather than as definitive psychometric validation.

3.1 Prototype Development and Functional Verification

The prototype development and functional verification process is shown in Figure 3.



Figure 3. Prototype Fabrication Process

3.2 Prototype Assembly and Preliminary Testing

The prototype assembly and preliminary testing process is shown in Figure 4.

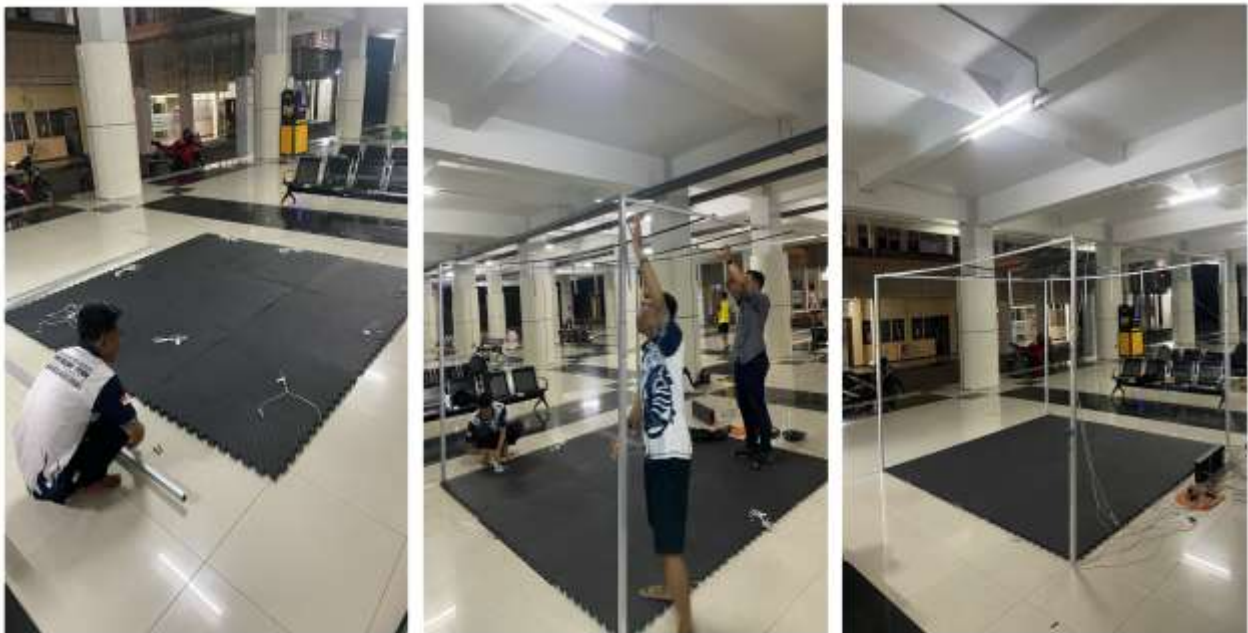


Figure 4. Prototype Assembly Process

3.3 Preliminary Field Feasibility Testing

The preliminary field feasibility testing process is shown in Figure 5.

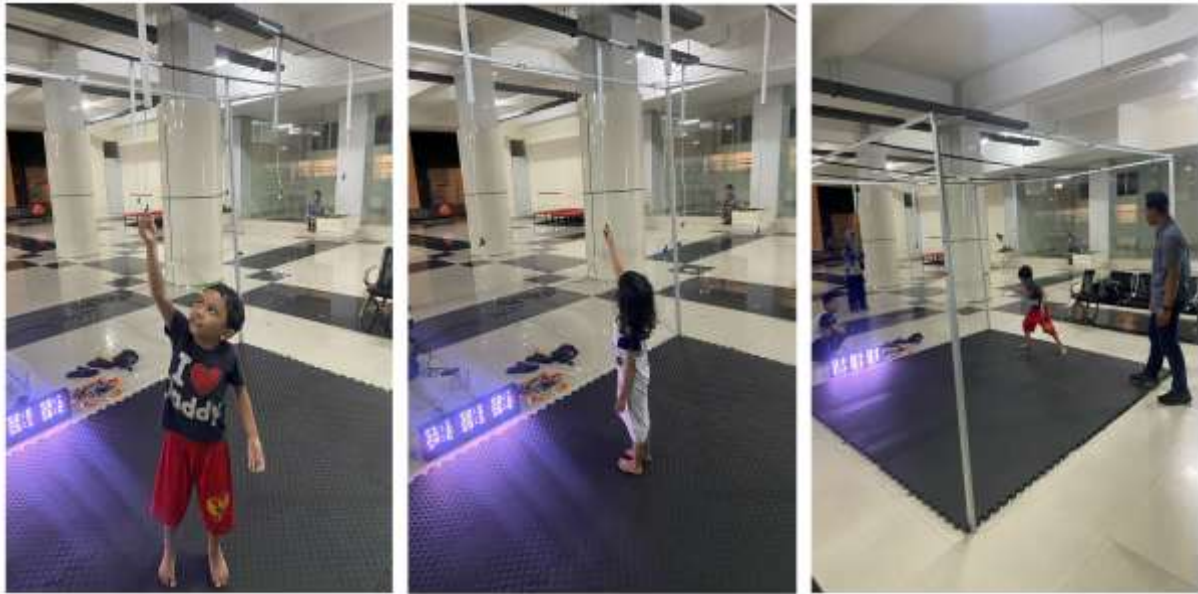


Figure 5. Preliminary Field Testing Process

3.4 Expert-Based Feasibility Validation

The expert-based feasibility ratings and preliminary field-trial characteristics are summarized in Tables 2-4.

Table 2. Percentage and Eligibility Level of Experts

No	Expert	Percentage	Eligibility level
1	Media expert	80%	Valid
2	Motor skills expert	86%	Valid
3	Test and measurement expert	83%	Valid

Table 3. Descriptive Statistics of Expert-Based Feasibility Ratings

Statistic	Value
Number of expert ratings	3
Mean $\pm$ SD (%)	83.0 $\pm$ 3.0
Median (%)	83.0
Minimum-Maximum (%)	80-86
Overall interpretation	Valid (preliminary expert-based feasibility only)

Table 4. Characteristics of the Limited Preliminary Field Trial

Variable	Result
Total participants, n	2
Boys, n (%)	1 (50.0%)
Girls, n (%)	1 (50.0%)
Age range	5-6 years
Interpretation	Limited feasibility check; not evidence of generalizable validity

Expert-based appraisal supported the preliminary feasibility of the sensor-based motor tracking prototype. Domain-specific ratings were 80% for media and usability, 86% for motor-skill relevance, and 83% for testing and measurement. The overall feasibility estimate was $83.0 \pm$

3.0%, with a median of 83.0% and a range of 80-86%. All ratings were therefore located within the predefined valid category. The limited field trial included two children aged 5-6 years, one boy and one girl. This field component demonstrated that the prototype could be implemented in a

real testing context; however, because repeated measurements, criterion comparison, measurement-error estimation, and inter-rater or test-retest reliability analyses

were not performed, the field findings should be interpreted only as preliminary feasibility evidence.

The evidence map and future validation requirements are presented in Tables 5 and 6.

Table 5. Evidence Map of Prototype Development and Validation Status

Development or validation element	Evidence available in this study	Interpretation
Prototype construction	Completed	The device reached a working prototype stage.
Laboratory functionality check	Completed at a preliminary level	Basic detection of selected movement tasks was examined.
Expert validation	Completed by three experts	Initial expert-based feasibility was supported.
Limited field trial	Completed with two children	Feasibility only; not generalizable validation.
Reliability testing	Not performed	Requires future repeated-measurement studies.
Criterion validity	Not performed	Requires comparison with TGMD-3 or MABC-2.

Table 6. Summary of Current Evidence and Future Validation Requirements

Domain	Current evidence	Required future validation
Media and usability	Expert feasibility rating of 80%	Structured usability testing with teachers and practitioners
Motor skill relevance	Expert feasibility rating of 86%	Comparison with standardized motor skill instruments
Testing and measurement	Expert feasibility rating of 83%	Reliability, calibration, and measurement-error testing
Field application	Two-child preliminary field trial	Larger sample, repeated trials, and subgroup analysis
Technical performance	Preliminary functionality only	Sensor accuracy, sampling frequency, and algorithm validation

4. Discussion

This study aimed to develop a prototype sensor-based motor tracking device for assessing early childhood motor skills and to conduct an initial expert-based validation. In the initial stage, the researchers designed the motor tracking device and then produced a prototype. A preliminary laboratory test was conducted to examine basic device functionality. Subsequently, expert validation was conducted. The media expert, motor skills expert, and test and measurement expert rated the device at 80%, 86%, and 83%, respectively. According to the predefined assessment range, all three scores were classified as valid. These results indicate preliminary feasibility based on expert judgment, but they should not be interpreted as evidence of full psychometric validation.

Research on the use of sensors in product design in sports and movement assessment has increased in recent years. In this prototype, touch and pressure sensors were used to detect selected movement-related tasks, such as stepping, running, standing, and lateral steps. However, the present study did not directly test measurement accuracy, reliability, or agreement with established motor skill assessment

instruments. Therefore, claims regarding automatic detection, reduced observer bias, and improved efficiency should be considered preliminary until confirmed by empirical validation.

Henderson et al. reported that smart glove technology equipped with sensors can provide valid range-of-motion measurements (17). Sousa et al. showed that a sensor-based system can be used to evaluate repeated sprint capability (18). Del Toro et al. found that low-cost sensor technology can be used to assess muscle fatigue (19). These findings suggest that sensor-based systems can support movement measurement in several contexts. However, most previous studies have focused on athletes, adolescents, adults, sports performance, or rehabilitation, whereas the application of sensor technology to early childhood motor skill assessment remains relatively limited.

Compared with widely used motor skill measurement instruments, such as the Test of Gross Motor Development (TGMD-3) and the Movement Assessment Battery for Children (MABC-2), the device developed in this study may have potential practical advantages. The TGMD-3 and MABC-2 have been shown to have good validity and reliability in measuring children's motor skills (20, 21).

However, these instruments require trained observers and standardized scoring. The present prototype may reduce some observational burden by integrating sensors into the testing environment. Nevertheless, this potential advantage was not directly tested in the present study, and future research should compare the prototype with TGMD-3 and MABC-2.

The device developed in this study also differs from wearable sensor systems used in previous research (22, 23). Many existing systems use inertial measurement units (IMUs), accelerometers, gyroscopes, or body-worn smart devices to monitor locomotor performance (24, 25). Such technologies can generate detailed biomechanical data but may be less practical for some early childhood settings because of cost, device placement, and child compliance. In contrast, the present prototype uses touch and pressure sensors integrated into the testing environment. However, its practical usability and measurement accuracy must be confirmed in larger studies.

A potential contribution of this research is the early-stage application of sensor technology to motor skill assessment in young children. Previous sensor-based research has mainly focused on sports performance, rehabilitation, gait analysis, physical activity monitoring, and fatigue detection (15, 22, 26). The present study extends this line of work toward early childhood motor development assessment. However, because the current evidence is limited to prototype development, expert appraisal, and a very small feasibility trial, stronger validation evidence is required before broad application.

This study has several limitations. First, the research focused on prototype development and expert-based validation; therefore, the psychometric characteristics of the tool, including reliability, test-retest reliability, construct validity, criterion validity, sensitivity, and specificity, have not been thoroughly tested. Second, the preliminary field trial included only two children, which prevents generalization. Third, the prototype was not compared with established instruments such as TGMD-3 or MABC-2. Fourth, the present study does not provide sufficient technical details about sensor specifications, calibration, data acquisition, or the scoring algorithm. Future studies should address these limitations through larger samples, repeated trials, technical validation, and comparison with standard motor skill assessment instruments.

5. Conclusions

This study developed a prototype sensor-based motor tracking device for assessing motor skills in early childhood. Initial expert validation indicated that the prototype met preliminary feasibility criteria in media, motor skills, and testing and measurement domains, with scores of 80%, 86%, and 83%, respectively. These findings suggest that the device may be promising for further development. However, the study does not yet establish full validity, reliability, sensitivity, specificity, or criterion validity. Larger field studies, repeated measurements, and comparisons with standard instruments such as TGMD-3 and MABC-2 are required before the device can be recommended for routine use by teachers, lecturers, or sports practitioners.

Authors' Contributions

All authors contributed to the conception and design of the study, prototype development, expert-validation process, interpretation of findings, drafting, critical revision, and approval of the final manuscript.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

The study was conducted in accordance with ethical principles for research involving human participants. Ethical approval was obtained from the Research Ethics Committee of the Directorate of Research and Community Service, Universitas Negeri Yogyakarta, under approval number No. 255.17/DST/UN34.9/T/PT.01.04/2026 before the commencement of data collection. The study was declared ethically appropriate according to the seven WHO 2011 ethical standards and referred to the CIOMS 2016 guidelines. All participants were informed about the objectives, procedures, potential benefits, and possible risks associated with participation. Participation was voluntary, and written informed consent was obtained before testing and intervention procedures were initiated. Participant confidentiality and privacy were maintained throughout data collection, analysis, and reporting.

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