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Original Research

The Application of Artificial Neural Network and Wearable Inertial Sensor in Kicking Skill Assessment

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ABSTRACT

The trade-off between speed and accuracy in process-oriented tests of fundamental motor skills development has always been a challenge in motor development screening plans. Thus, this study was designed to evaluate the feasibility of using wearable inertial sensors (IMUs) based on artificial intelligence algorithms to assess kicking skill. Thirteen children aged 4 to 10 years (age = 8±1.37) (boys = 58%) participated in this study. The subjects were asked to do at least ten repetitions of the kicking skill according to the TGMD-3. Trials were captured with video recording and three wearable inertial sensors installed on the ankles and lower back. K-Nearest Neighbor artificial intelligence algorithms automatically classified the linear acceleration and angular velocity signals. The intraclass correlation coefficient (ICC) was calculated between expert scores and the artificial intelligence algorithm. All tests were done at a 95% confidence interval. The classification accuracy of the KNN algorithm (k=7) for kicking was 95%, ICC =0.90 (CI=0.86-0.95). The scoring time was reduced from 5 minutes per trial (in an expert-oriented way) to less than 30 seconds (using artificial intelligence). As a result, this method was a reliable and practical way to assess the fundamental motor skills. Also, by maintaining relative accuracy, it was possible to reduce test time for research, clinical, sports, and educational purposes.

Keywords: TGMD3, Wearable Inertial Measurement Unit, Artificial Intelligence, Motor Development, Automatic Assessment.

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INTRODUCTION

Motor competence is defined as perfection in individuals' skill and ability to successfully and safely perform various physical activities. In the last decade, children's and adolescents' motor skills have been confirmed as the most important factor in public health infrastructure of the society, such as the amount of physical activity, fitness, etc [1-3]. In fact, longitudinal studies prove that acquiring motor competence in childhood somehow guarantees an active adulthood and greater health of society [4, 5]. Barnett et al. (2009) investigated the effect of motor skill in childhood on performing physical activity in adulthood. In 2000, children's motor skills in object control (kicking, catching, and throwing) and displacement (sideways sliding and vertical jumping) were examined in a school-wide intervention. Seven years later, the subjects underwent a re-examination. It was found that the amount of time spent engaging in organized sports or moderate to intense physical activities during adolescence was strongly correlated with motor competence in object control during childhood. Children who demonstrated proficiency in object control were found to have a 10 to 20% higher likelihood of participating in vigorous physical activity during adolescence [4].

Result of these studies has made the advanced societies to include fundamental movement skills training in schools' educational program in order to raise developed and healthy children, hence, an active and healthier adult society. It should be noted that the early school years are a critical stage for the development of fundamental movement skills. Failure to develop these skills during childhood can lead to significant deficits in movement abilities throughout life. This deficiency may prevent the acquisition of motor skills necessary for sports performance [6]. This has led to an increase in global interest in examining and monitoring the motor skills level of children and adolescents [7].

Nevertheless, reliable and accurate assessment of motor skills has become challenging [8]. One of the challenges of process-based motor skill assessment is the reliability of the score given by different evaluators [9]. Many skills and performance can be scored simultaneously, but past research evidence has proven that although there is agreement among different evaluators in the overall motor skill score, there is still disagreement in scoring subscales (such as throwing, etc.) [9, 10]. For this reason, the performance is often filmed and scored later.

Several methods have been proposed for evaluating children's motor development. One prominent assessment tool is the Test of Gross Motor Development (TGMD), specifically designed to qualitatively assess the gross motor skills development of children aged 3 to 10 years. The TGMD adopts a criterion-norm approach, focusing on the process rather than the outcome of motor skill performance. This approach enables evaluators to identify strengths and weaknesses in motor skill performance without solely relying on achievement criteria. This test has been extensively administered in different countries in recent years to identify and screen children with developmental delay. Also, the fundamental motor skills of a wide range of individuals with disorders have been measured by this test: Klavina et al. [11] and Hartman et al. [12] children with disabilities; Ketcheson et al. [13], Dadgar et al. [14], Mache and Todd [15] and Breslin et al. [16] children of autism spectrum; Wagner et al. [17] and Haibach et al. [18] children with vision disorders; Westendorp et al. [19, 20] children with learning disabilities; Yu et al. [21] children suffering from developmental coordination disorder.

Traditionally, assessing motor skills involves recording subjects' performances via video and subsequent evaluation by trained experts. However, this method has limitations, such as the need for video recording, post-analysis, and trained evaluators, which are impractical for screening large populations. Moreover, scoring relies heavily on the evaluator's expertise, leading to potential biases in larger sample sizes. Additionally, the minimum time required for each individual to undergo the test procedure, including performance, recording, and scoring, is at least 30 minutes. This not only imposes significant costs on screening initiatives but also increases errors in various aspects, including data entry.

The emergence of microelectromechanical systems (MEMS) technology has enabled the development of gyroscope sensors, accelerometers, and magnetometers, collectively referred to as inertial sensors. These sensors are characterized by their small size, affordability, and efficient battery life. In recent years, there has been widespread adoption of such sensors in laboratories and clinics for the quantitative, accurate, and stable evaluation of human movements, particularly in assessing the elderly population [22] and individuals with developmental delays [23]. The use of this technology, in addition to providing very accurate and stable objective information, is not limited to any specific disease, gender or even a specific age group [24]. Recently, a wide wave of applied research has been carried out using this technology [25]. Bisi and Stagny (2015) assessed the development of walking in healthy toddlers. According to the quantitative data of six months of assessment, many mechanisms of changes were identified [26]. Reliability of walking for toddlers, pre-school, school age, adolescents, the young ones, adults, and elderlies was analyzed with multi-scale entropy method in 2016. By placing an accelerometer on L5 vertebra, it was determined that the complexity of changes in trunk movement is an indicator of progress, perfection, and decline of walking [22]. Some other researchers evaluated the temporal and kinetic indices of fundamental movement skills using inertial sensors. Masci et al. examined running [27], hopping [28] and Grimpampi et al. over-the-shoulder throwing [29], all of whom agreed that inertial sensors are a tool applicable in-field and independent of the user, used in health care, physical education, and professional sports training. Also, the output data of these papers have confirmed the function of this technology not only for screening purposes, but also for detecting the mechanisms of development of motor skills and the effective indices in the perfection and decline of the skills.

Wang et al. (2018) conducted a study with the aim of presenting a new algorithm for estimating the vertical jump height based on inertial sensors installed on the foot. The maximum jump height was determined by inertial sensors placed on top of the toe and below the heel and was compared with the standard maximum jump height estimate obtained from motion capture. The results suggested that the presented algorithm can be applied to the inertial sensors installed on the foot to evaluate the maximum jump height outside the laboratory conditions [30]. Also, in 2017, using the same technology, Bisi et al evaluated the locomotor skills section of the second version of the test (TGMD). They obtained an agreement of 87% in the validity of simultaneous scoring using inertial sensors and experienced assessors. They also reduced the duration of the test from 15 to 2 minutes for each person [31]. As a result, it can be expected that this technology will provide quantitative data to measure the standard of motor skills, the possibility of developing intervention solutions based on reliable and objective data, saving time, easy use, and no need for video recording.

Haji Hosseini et al. (2022 and 2023) assessed the feasibility of using wearable inertial measurement units (IMU) and artificial intelligence algorithms to automatically assessment of FMS. Results showed the use of artificial intelligence in the signal processing of only three IMU was a reliable and practical method for the assessment of FMS. This approach means the monitoring and evaluation of children's movement skills can be objective [32, 33].

In prior studies, inertial sensors have consistently demonstrated effectiveness in assessing movement patterns. However, no instrument has been identified thus far for quantitatively measuring proficiency in gross motor skills tests. Additionally, while locomotor tasks are commonly emphasized as essential for promoting an active lifestyle, other fundamental movement skills, such as object control tasks like kicking, have received less attention. Consequently, this research seeks to explore the capability of inertial sensors coupled with artificial intelligence algorithms to quantitatively evaluate one of the parameters of the third edition of the motor skill development test, specifically focusing on kicking proficiency.

MATERIAL AND METHODS

Subjects

In terms of the purpose, the current study is developmental [34] and carried out in cross-sectional design [35]. Based on results of Grimpampi et al.'s study in 2016, minimum of ten trials determined for the sample size in each age group of 4 to 10 years. In the study of Barnett et al. in 2010, at the level of $\alpha=0.05$ and $\beta=0.1$ and the maximum error equal to 1, according to the gender difference in the evolution of object control movements, there were a total of 20 performances (10 girls and 10 boys) and as a result, 140 performances was determined [29, 36]. Children aged 4 - 10 years from Qeshm city in Hormozgan province of Iran were selected through convenient sampling method. Inclusion Criteria were: (1) Age ranges from 4 - 10 years, (2) No mental or physical disability, (3) No developmental delay, (4) Lateral dominance on one side of the body and (5) Obtaining written consent from the child's parents or legal guardian. Exclusion Criteria were: (1) Dissatisfaction with continuing the study and (2) Injury during the implementation of the study.

Exercise protocol

A description of the research method and objectives in plain language and a written consent form were emailed to interested parents/guardians. Then, by holding an online educational workshop, the parents were informed about the research necessity and the means of obtaining their written consent was provided. Further, to investigate children's developmental disorder, the developmental coordination disorder questionnaire was completed online by parents who volunteered to participate in the study via Porsline system[1]. Only after signing consent form by the parent/guardian and declaring consent of the child, the tests were administered.

Inertial sensors were installed on designated locations based on previous studies [25]: 3 sensors were considered for kicking skills: No. 1: above the external ankle of the dominant leg, No. 2: above the external ankle of the non-dominant leg, No. 3: in the lower back area (around the 4th and 5th lumbar vertebrae). The accurate performance of the skill was demonstrated to the children several times. They had to perform each skill according to the following criteria:

1. The child approaches the ball continuously and quickly.
2. The child takes a long step or stride before the ball contact.
3. The supporting leg is placed near the ball.
4. The child kicks the ball with instep his/her foot (not the toes).

Meanwhile, the evaluator's assistant was filming this process from the side view with a high-quality p1080 mobile camera and at a speed of 30 frames per second. Data from IMU sensors were received and stored using MATLAB/R2016a software. By re-viewing the collected videos, a score of one was recorded for each successful criterion and zero was recorded otherwise. The scores of each performance were recorded in the data bank, and each matrix received by MATLAB was coded and entered the database.

Equipment's and measurements

- IMU kit made by Shokoofa Tavan Vira Core (Tehran - Science and Technology Park of Tehran University - ID FR209.1 - Shokoofa Tavan Vira Core).

The used motion sensors were made from devices based on microelectromechanical system (MEMS). The sensors have a three-axis gyroscope with a dynamic range of +/-250°/s and a resolution of +/-1.9°/s, a three-axis accelerometer with a dynamic range of +/-2g and a resolution of +/-1.5 Mg, and a three-axis magnetometer with a range of +/- 48 gauss and a resolution of +/- 6 mGauss (mpu9250). Data were displayed with an acquisition frequency of 25 Hz through a receiver connected to a USB port using MATLAB programming environment (MathWorks, USA), and by using built-in or written functions. Response time for all three sections of each IMU sensor is 15 ms, the sensitivity of the accelerometer: 0.03 mg, gyroscope: 3.81 degrees per second, compass: 0.6 micro tesla, and the lifespan of this device is at least 10 years, which will increase with proper maintenance.

- The third edition of the test of gross motor skills development (TGMD 3)

The standard method introduced in the third edition of the process-oriented test of gross motor skills development (Webster and Ulrich, 2017) was employed for assessment. This test consists of 13 sub-skills in 2 sections (locomotor and object control), graded based on 3 to 5 criteria in two trials by an experienced expert [37, 38]. In the study of Mohammadi et al. (2017) among children aged 3 - 10 years in Ahvaz, the following results were obtained: content validity index indicated a range of 0.80 to 1, reliability of the internal homogeneity of the subtests of locomotor, object control, and the overall test were obtained 0.85, 0.85, and 0.91, and the test-retest reliability was achieved 0.92, 0.94, and 0.95, respectively, [39].

Data analysis

The best method to check the inter-rater reliability, in the present study, between the expert and automatic algorithm is a concept called Intraclass Correlation Coefficient (ICC). ICC reliability output is classified as

[1] https://survey.porsline.ir/

follows: ICCs less than 0.5, between 0.5 and 0.75, between 0.75 and 0.9 and more than 0.9 as weak, moderate, good, and excellent, respectively. To analyze the reliability of kicking skill for screening human movements, at least 0.6 is defined for ICC" [40].

RESULTS

Thirteen children (7 boys and 6 girls) aged 4 -10 years (mean = 7±1.84 years) were included in the study after meeting the required criteria. The mean height and weight of the subjects were 129.46±7.17 cm and 28.15±3.53 kg, respectively. Also, their mean developmental coordination disorder test score was DCDQ=63.4±6.32 (Table 1).

Table 1. Information about height, weight, and age of subjects (N = 13)

	Height (cm)	**Weight** (kg)	**Age** (year)	**DCDQ**
Mean	129.46	28.15	7	63.4
Standard Deviation	7.17	3.53	1.84	6.32
Maximum	144	47	10	74
Minimum	120	15	4	55

The implemented kicking skill was classified into three levels: proficient (scoring 1 in all criteria), semi-proficient (scoring 1 in at least 50% of criteria) and beginner. In the kicking skill, if the performance scores one in all four criteria, it is marked as "proficient" (74%), and if three criteria are met, "semi-proficient" (26%) and less than three criteria, as "Beginner" (0%).

Table 2. Percentage of success in different criteria

	Criteria	**Performance No.**	**Successful performance**	**Success percentage**
Kicking	1. The child approaches the ball continuously and quickly.	148	148	100
	2. The child takes a long step or stride before touching the ball.		135	91
	3. The supporting leg is placed near the ball.		148	100
	4. The child hits the ball with instep his/her foot (not the toes)		92	83

In the following, K-Nearest Neighbor algorithm was applied for automatic data classification and scoring. First, 20% of the data was randomly separated for testing. Another 20% were randomly separated for the K validation step, again. The remaining data was used to train the algorithm. By choosing K = 7, the algorithm was ready to classify the data set aside for the test phase. Classification results were considered in two cases: false acceptance where a "bad" performance is classified as "good" and false rejection where a "good" performance is classified as a "bad" one. In the first criterion, 100% of the data were classified appropriately. Regarding the second, third and fourth criteria, this value was equal to 87, 100 and 94 percent, respectively. In total, the classification accuracy in overall skill was 95% (Table 3).

Table 3. Algorithm measurement of kicking skills

	TGMD-3 receiving skills	No. of Attempt	Correct classification	False acceptance	False rejection	Accuracy percentage in each criterion	Accuracy percentage in each skill
1	The child approaches the ball continuously and quickly.	47	47	0	0	100	95
2	The child takes a long step or stride before touching the ball.	47	41	0	6	87	
3	The supporting leg is placed near the ball.	47	47	3	6	100	
4	The child hits the ball with instep his/her foot.	47	43	1	3	94	

Here, the differentiation coverage regarding criteria were 100%. The accuracy of the classification can be observed in Table 4.

Table 4. Precision, accuracy, and coverage output of kicking skill classification algorithm

	Precision of classification	Accuracy of classification	Recall
Criteria 1	1	1	1
Criteria 2	0.87	0.87	1
Criteria 3	1	1	1
Criteria 4	0.94	0.94	1

To calculate the agreement level in scoring kicking skill, the intra-class correlation coefficient of the data score of the test phase was calculated in KNN algorithm by two scoring methods (automatic and expert-based). With a 95% confidence interval, ICC =0.90 (CI=0.86-0.95) ($P_{value}<0.001$). Based on the intended values, this is an average agreement coefficient.

DISCUSSION

Evaluating fundamental motor skills can be a time-consuming process, often demanding a certain level of pre-training and experience to ensure accurate scoring. Hence, the primary aim of this research was to explore the viability of employing commercially available and cost-effective technologies, such as wearable inertial sensors, for assessing the proficiency of fundamental motor skills. This approach aims to mitigate the reliance on evaluators' expertise for assessment outcomes. Specifically, the study focused on assessing kicking skills using inertial measurement units (IMU) aligned with the TGMD-3 standard test criteria, achieving a classification accuracy of 95%. These results were automatically generated through signal processing techniques without the need for expert intervention, indicating a high level of promise in terms of accuracy. It is worth noting that the assessment of kicking skills exhibited moderate agreement with evaluator scores. Overall, the findings suggest that employing only three sensors enables accurate skill assessment with the minimum reliability required for evaluation [32, 33].

A secondary benefit of using automated scoring algorithms was time- savings. The usual way of summing up the time (playing performance videos + re-viewing the related video several times to ensure the score accuracy + entering score data into the computer) for each skill takes at least 5 minutes, while in this study, the maximum processing time for a movement was less than 30 seconds. As a result, providing immediate feedback along with the benefits of portability, cost-effectiveness and easy application ensure its effectiveness in educational environments.

The highest classification accuracy was observed in the first criterion, i.e., constantly approaching the ball. This amount of accuracy may be because the initial stage of approaching the ball for a kick, described in the motor development literature as pushing the ball in a standing posture, was not observed even in youngest participants (4 years old)[41-43]. The results of the current study suggest that highly skilled kickers approach the ball in a manner that involves a step, jump, or leap (i.e., resulting from walking or running) just prior to ball contact, as suggested by Haywood and Getchell [44]. The momentum gained from the approach contributes to the force generated before the ball is struck. When the approach to the ball is accompanied by an angular approach of the foot to the ball, the range of motion increases and the maximum possible radius of the swinging foot potentially increases, leading to increased acceleration and force production [45].

The lowest classification accuracy was obtained in second criterion. However, the level of accuracy was still acceptable. The less skilled kicker just bends the knee in a fixed position before kicking. In a linear or angular approach, skilled kickers actively bend their knee and raise their ankle to a height equal to or higher than the midline of the kicker's knee. This active preparatory rotation increases the range of motion and allows for concentric contraction of the quadriceps muscle and increased acceleration prior to ball contact [45].

Novice kickers stand directly behind the ball before turning the kicking foot. As a result, there is no option for location of the supporting leg. As players enhance their skill level by adopting a linear or angular approach, they optimize performance by placing their supporting foot closer to the ball. competent kickers place their feet parallel to the middle of the ball they are going to kick. Placing their foot before or after the middle of the ball is the result of a lack of coordination and control of their center of mass, which directly leads to changes in kinetic chain during the kicking movement that may reduce the likelihood of the foot reaching the optimal ball contact position [46]. An acceptable classification accuracy was obtained in third criterion, related to the explanation given above.

Less competent kickers lack trunk and hip rotation. This finding confirms the explanation of Haywood and Getchell (2019), who report that the trunk and arms in these subjects have minimal rotation and may even remain fixed during kicking of low-skilled players. By moving their pelvis and trunk away from the intended path, the competent kickers initiate differential rotation of the pelvis and trunk [47]. Trunk movement may be maximized with an angular approach, when the players move their hips in the direction of the target, immediately prior to trunk movement and upper thigh and lower leg (calf, ankle, and knee). This increased abnormal loading of the hip flexors and knee extensors may facilitate increased storage and recovery of elastic energy of the extension-shortening cycle, leading to increased force production during the kicking movement [45, 46, 48].

Less competent kickers lack approaching and motion generation. As a result, there is no follow-through to the motion, so they place their kicking foot in the same position as they used before starting any movement. The momentum generated by the approach, center of mass transfer and rotation of the skilled kicker's foot results in a stepping, hopping (landing on the supporting foot) or jumping (landing on the striking foot) movement. The variance of these movements is likely to depend on the intended flight path of the ball. For example, if the intended trajectory is high (i.e., kicking a field goal in American football), the result is a jump, while a lower trajectory (i.e., kicking the ball toward the goal in football) results in a bounce [44].

Children without disabilities (in the current study) were expected to have reached the highest level of development of kicking by age 14. However, a number of these subjects failed to perform all four criteria. These observations suggest that children may not have sufficient time to learn and practice kicking skills. Therefore, these sequences may help to identify those who do not develop appropriate kicking skill. Mali et al. (2011) showed that kicking for a certain distance is a controlling parameter for performance, therefore, with high effort, the skill of kicking can contribute to the skill development. Increasing the approaching distance and more complete action of the kicker's leg and follow-up, as well as the coordinated movement of the trunk and arms, are essential to increase speed of the kick. The ultimate hypothetical developmental sequences for powerful kicks provide a useful assessment tool for physical educators, athletic trainers, and physical activity specialists. Future development of learning activities and teaching materials is ensured to facilitate the successful dissemination of these hypothetical sequences to teachers and educators. Educational methods should emphasize training that encourages, rather than constrains, large, rapid kicking movements and avoids the use of specific targets [49, 50].

Although the use of IMUs to evaluate motor skills has major advantages, there are also disadvantages in the current method. Reducing the number of sensors to three makes for a much more feasible method, but less important data from parts of the body is lost. In fact, the number of sensors has led to ease of use, which may lead to increased attractiveness, application, and use in real environments, especially in school physical education classes. As a result, a large part of the society is evaluated and the chance of planning for targeted interventions and ultimately improving the motor skills of the society increases. However, some TGMD skill metrics were not fully evaluated using machine learning, such as ball trajectory in the kicking skill. The flaw in the evaluation reduced the quality of the output; Therefore, it may reduce its diagnostic utility. Also, the decrease in accuracy may decrease the attractiveness of its use by teachers. While artificial intelligence may increase the use of TGMD in schools, sports fields, etc., but as this study found, objective or automated implementation of wearable sensor data may not evaluate all criteria[51].

CONCLUSION

In conclusion, the use of artificial intelligence in signal processing of only three IMUs was a reliable and practical method for FMS evaluation. This approach means that monitoring and assessment of children's motor skills can be objective. Furthermore, while maintaining relative accuracy, the time involved in FMS process-oriented analysis for research, clinical, sports, and educational purposes has been reduced entirely. As a result, it can be expected that a large population will be evaluated for screening and the chances of planning for targeted interventions and ultimately, improving sports participation and a healthier society will increase.

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کاربرد شبکه عصبی مصنوعی و حسگر اینرسی پوشیدنی در ارزیابی مهارت ضربه با پا

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همواره مبادله دقت و سرعت در نمره‌دهی آزمون‌های فرایندمحور ارزیابی رشد مهارت‌های حرکتی بنیادی چالش‌برانگیز بوده است.. بنابراین، این مطالعه به منظور ارزیابی امکان‌سنجی استفاده از واحدهای اینرسی پوشیدنی (IMU) بر اساس الگوریتم‌های هوش مصنوعی برای ارزیابی عینی مهارت ضربه با پا طراحی شد. از سیزده کودک ۴ تا ۱۰ ساله (سن ۱,۸۴ ± ۷) (پسران = ۵۳ درصد) خواسته شد که حداقل ۱۰ بار مهارت ضربه با پا را طبق معیارهای آزمون رشد مهارت‌های حرکتی درشت - ویرایش سوم (TGMD-3) انجام دهند. آزمون‌ها با ضبط ویدئو و سه IMU به طور همزمان ثبت شدند. الگوریتم های هوش مصنوعی به طور خودکار سیگنال های IMU را طبقه بندی می کند. ضریب همبستگی درون طبقاتی (ICC) بین نمرات و الگوریتم هوش مصنوعی محاسبه شد. تمامی آزمون ها با فاصله اطمینان ۹۵ درصد انجام شد. دقت طبقه بندی الگوریتم برای ضربه زدن ۹۵٪ بود. زمان امتیازدهی از ۵ دقیقه در هر آزمون (به روش متخصص محور) به کمتر از ۳۰ ثانیه (با استفاده از هوش مصنوعی) کاهش یافت. در نتیجه این ارزیابی ابزار بازخورد فوری ارائه داده و قابل حمل و مقرون به صرفه است. در آینده، تحقیقات بیشتری باید در مورد کاربردهای دنیای واقعی IMU توسط معلمان، محققان، پزشکان و مربیان انجام شود.

واژه‌های کلیدی: آزمون رشد حرکتی، واحد اندازه گیری اینرسی پوشیدنی، هوش مصنوعی، رشد حرکتی، ارزیابی خودکار