

Comparing sensor-assisted and traditional hand–eye coordination tests: A concurrent validity study

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Abstract

Problem Statement and Purpose. Sensor technology plays a crucial role in enhancing sports performance assessment by providing more accurate, automated data and minimizing measurement bias for both elite and amateur athletes. However, there has been little research investigating the effectiveness of sensor-assisted hand–eye coordination tests compared with traditional methods such as the hand wall toss test. This study aims to evaluate the differences between the sensor-assisted hand–eye coordination test and the hand wall toss test, with a particular focus on variations in results by gender. **Materials and Methods.** The study included 113 participants aged 18–21 years enrolled in athletics courses, comprising 66 males (aged 19.45 ± 1.00 years; BMI 20.81 ± 2.44 ; weight 61.89 ± 8.12 kg; height 168.36 ± 6.33 cm) and 47 females (aged 19.53 ± 0.97 years; BMI 21.05 ± 2.54 ; weight 52.94 ± 6.80 kg; height 156.83 ± 2.60 cm). Participants first completed a sensor-assisted hand–eye coordination test, followed by a hand wall toss test three days later. These data were analyzed using multiple statistical techniques, such as descriptive statistics, correlation, regression, and independent samples t-test to examine the differences between male and female participants on both tests. **Results.** The findings showed that the sensor-assisted hand–eye coordination test had high coefficients ($n=113$; $r=0.876$; $R^2=0.767$; $F=365.612$; $t=19.121$; $p=0.000$). High coefficients were also observed in both male participants ($n=66$; $r=0.911$; $R^2=0.831$; $F=313.685$; $t=17.711$; $p=0.000$), and female participants ($n=47$; $r=0.928$; $R^2=0.861$; $F=279.225$; $t=16.710$; $p=0.000$). However, no significant difference was found between male and female participants ($p=0.137$ and $p=0.170$, respectively). **Conclusions.** This sensor-assisted hand–eye coordination test showed consistent results and mirrored measurements from traditional assessments. The test can be recommended for collecting data on hand–eye coordination levels (such as badminton, tennis, table tennis, and other specific sports), and can be used by athletes, coaches, and related practitioners. We also suggest applying hand–eye coordination training methods that are better tailored to the characteristics of each sport, to obtain optimal performance.

Keywords: test, concurrent validity, hand–eye coordination, sensor-assisted, traditional, hand wall toss test.

Introduction

Hand–eye coordination is a motor skill that involves rapid interaction between vision (eyes) and hand movements (Antara et al., 2023; Ellison et al., 2018; Ziagkas et al., 2017), where vision serves to track moving objects, while hand movements manipulate these objects (Kovari et al., 2020; Zupan & Wile, 2011). Hand–eye coordination is not only a basic technical skill, but also a determining factor in the success of athletes in situations that require accuracy with fast time (Chan et al., 2019; Schwab & Memmert, 2012). In sports that involve hand–eye coordination, athletes must be able to respond quickly to changes in their environment (Mann et al., 2007; Yu & Seong-No, 2023). For example, in baseball, athletes must be able to predict the trajectory of a ball thrown at high speed and respond with the appropriate hand movement to hit the ball (Vickers, 2007). This coordination involves not only sharp vision but also the ability to respond with well-trained motor movements (Chan et al., 2019).

In sports with fast-moving objects (e.g. ping pong), athletes' ability to make the right decision in a short time depends heavily on how well they can integrate visual and motor information (Kovari et al., 2020; Yu & Seong-No, 2023). In tennis, athletes must be able to identify the position and direction of the ball hit by the opponent and decide the right time to hit the shot (Vickers, 2016). Likewise, in basketball, athletes catch balls thrown at high speed while avoiding opponents and plan their next moves in seconds (Williams & Ford, 2008). These concurrent actions require complex visual ability and quick motor responses because athletes not only focus on the ball, but also on the position of their opponents and teammates (Schmidt et al., 2018). Moreover, hand–eye coordination is not only limited to the ability to hit or catch the ball (Ellison et al., 2018). In more complex sports, such as golf or archery, this coordination requires athletes to have precision in controlling a tool

(e.g. bow or golf club) while continuously observing the target (Pinder et al., 2020). In this case, the role of hand-eye coordination proves to be crucial as success often depends on the level of precision and perfect tool control (Pinder et al., 2020).

Given the importance of hand-eye coordination, it is essential to develop and apply appropriate training methods to reach athlete's maximum performance. Fortunately, hand-eye coordination can be trained and improved through planned and targeted exercises, where accurate and high-quality measurements are essential in designing effective training programs (Irawan et al., 2024; Lochhead et al., 2024). Moreover, with current technological advances, many sensor- and software-assisted tools are used to measure hand-eye coordination, such as computer-assisted training systems or tools equipped with touch screens and motion sensors (Carter & Luke, 2020). In addition, eye-tracking and movement sensors can be used to help coaches and sports practitioners analyze how vision and hand movements interact and provide feedback for training (Moran et al., 2018). With the help of these technologies, athletes can monitor and optimize their coordination patterns, which will ultimately improve their technical skills and performance in various sports activities (Carter & Luke, 2020; Moran et al., 2018).

A variety of companies have marketed devices and products that they claim can be used to measure and improve hand-eye coordination. These include the Sports Vision Trainer (SVT), the Wayne Saccadic Fixator (WSF), and the Batak Pro (Ellison et al., 2018). SVT, for instance, is a tool designed to improve athletes' vision skills and hand-eye coordination. It is used to train dynamic vision, reaction speed to moving objects, and the ability to optimize visual observation during sports activities (Appelbaum & Erickson, 2016; Lochhead et al., 2024). SVT is often used in training for sports that require excellent visual reaction speed and hand coordination (Appelbaum & Erickson, 2016). Similarly, the WSF is designed to train and measure saccadic eye movement and visual fixation skills – two key points that involve the ability of eyes to move quickly from one point to another and the ability to focus on a specific, single point (Foreman et al., 2016; Laby et al., 2018). Particularly, this tool is used to develop vision skills in sport and rehabilitation settings, where fast and accurate vision can help athletes respond more efficiently to moving objects and thus help them perform better (Laby et al., 2018). Another technological device that is commercially marketed is Batak Pro, a training tool designed to improve athletes' hand-eye coordination, dynamic vision, and reaction skills (Millard et al., 2021). This tool is commonly used in various sports to improve athletes' visual abilities and reactions to fast-moving objects (Lobier et al., 2013). It uses sensor and display technology to challenge athletes to practice their visual skills and reaction speed (Ellison et al., 2018).

Over the past few years, researchers have been exploring and examining new strategies to measure hand-eye coordination with high accuracy and in real-time using sensor-based technology (Camomilla et al., 2018; Ihsan et al., 2024; Irawan et al., 2024; Izzo et al., 2023; Peake et al., 2018). The technological devices have been widely used and reported to be effective in helping athletes, coaches, and medical personnel monitor functional movements, workload, biomechanics, and bio-vital signs. One example of the device is wearable sensors to improve performance, reduce injury risk (Li et al., 2015; Seshadri et al., 2017), and enhance effective training (Latino & Tafuri, 2024). Another technological device that has been used is machine learning algorithms, as reported in the study by He & Wu (2020). They investigated the algorithms to analyze eye and hand sensor data. With a big volume of data collected through eye sensors and movement sensors, machine learning algorithms such as deep learning can recognize hand-eye coordination patterns, predict errors, and provide feedback to improve performance or rehabilitation (Chen et al., 2021).

In a rehabilitation setting, Breedveld & Wentink (2001) investigated hand-eye coordination problems in surgical procedures using endoscopic assistive technology, specifically related to two types of errors (camera image placement and instrument movement orientation). One of the solutions is ViewSite, a device developed by Storz, which moves the screen above the surgeon's hand to reduce problems related to camera image placement errors (Breedveld & Wentink, 2001). More recently, Irawan et al. (2024) have developed a sensor-assisted hand-eye coordination test that works similarly to the Batak Pro. The device has been tested for validity based on expert judgment and reliability with a high correlation coefficient. However, concurrent validity, which compares sensor-assisted hand-eye coordination tests with traditional methods, such as the hand wall toss test, has not been investigated. Although the hand wall toss test has advantages such as low equipment and cost, the testee's ability to catch the tennis ball is often affected by how straight and hard the ball is thrown towards the wall (Wood, 2010).

Therefore, the purpose of this study is to compare the sensor-assisted hand-eye coordination test designed by Irawan et al. (Irawan et al., 2024) with the hand wall toss test (Ashok, 2008). Additionally, it sought to examine whether differences exist between genders. This examination is important to analyze further to facilitate data collection on hand-eye coordination levels that are more accurate and automated. Additionally, it can reduce measurement bias and support the development of this field of knowledge.

Materials & Methods

Design

This study employed a comparative design by comparing two models of hand-eye coordination tests (sensor-assisted and traditional). This design is useful for analyzing whether the sensor-assisted hand-eye

coordination test mirrored the measurements obtained from the traditional assessment. An experimental design was also used to explore whether differences in the test's results also exist between male and female genders.

Participants

This study included 113 participants aged 18–21 years, consisting of 66 males (aged 19.45 ± 1.00 years; BMI 20.81 ± 2.44 ; weight 61.89 ± 8.12 kg; height 168.36 ± 6.33 cm) and 47 females (aged 19.53 ± 0.97 years; BMI 21.05 ± 2.54 ; weight 52.94 ± 6.80 kg; height 156.83 ± 2.60 cm). The participants were sports coaching students who attended athletics courses. They were also physically fit, participated voluntarily, and were willing to comply with the rules during the research activities.

Procedures and instruments

The data in this study were obtained through two hand–eye coordination tests, namely sensor-assisted and hand wall toss tests. To begin with, participants should complete the sensor-assisted hand–eye coordination test. Three days later, they underwent the hand wall toss test. The conditions and situations of the participants during these two tests were kept the same to avoid bias in the test results. Before the participants completed both hand–eye coordination tests, they were given an explanation regarding the implementation procedure and provided an opportunity to try both tests.

Sensor-assisted hand–eye coordination test

The sensor-assisted hand–eye coordination test, a product designed by Irawan et al. (Irawan et al., 2024), is a valuable tool for measuring hand–eye coordination. The tool's design incorporates a steel frame, an LCD, a touch sensor, a carpet for the testee to stand on, an Arduino Mega, a power supply unit, a 3.5-inch TFT LCD, a voltage regulator, an LED lamp (5 watts), a vibration sensor, a relay module, and a CB connector (Irawan et al., 2024). As Irawan et al. The protocol for conducting the test is outlined as follows: (a) participants are to stand in a designated area measuring 75 centimeters in length, (b) participants are to assume a standing posture with their legs extended and their shoulders held in a neutral position, (c) the distance from the inner sensor to the center of the screen is set at 30 centimeters, while the distance from the outer sensor is 50 centimeters. The test is to be initiated upon the appearance of a "sound" indicator on the device. Participants are instructed to make movements with both hands open to turn off or press the live sensor at random. The test is to be executed for a duration of 60 seconds. The score is to be derived from the participant's best score within two repetitions (Irawan et al., 2024). As illustrated in Figure 1, the score would be displayed in the center of the screen.

Hand wall toss test

The hand wall toss test is a traditional hand–eye coordination test that is frequently utilized by researchers to collect data on the level of hand–eye coordination of participants. This test involves throwing the ball towards the wall using the right hand and catching it with the left hand or vice versa (Ashok, 2008). The equipment required for this evaluation includes a tennis ball, a flat wall, tape or a marking line, a stopwatch, and a test form. The protocol for conducting this evaluation entails the following steps: (a) the subject is positioned at the perimeter of the designated area (± 2 meters), (b) the subject propels the tennis ball against the wall with one hand and subsequently retrieves it with the other hand, (c) the tennis ball is then propelled against the wall and retrieved with the initial hand, (d) the evaluation is executed for a duration of 30 seconds, and (e) the score is derived from the participant's optimal score within two repetitions (Wood, 2010).



Figure 1. Sensor-assisted hand–eye coordination test (Irawan et al., 2024)

Statistical analysis

To reach the objectives, this study employed multiple statistical analyses, including descriptive statistics, correlation, regression, and independent samples t-test. Descriptive statistics aimed to describe the characteristics of the results of both hand–eye coordination tests (minimum, maximum, average, SD, and variance scores). Meanwhile, correlation and regression tests were used to compare the two hand–eye coordination tests. The correlation coefficients were presented by r values with the following categories: very high ($r=0.90<1.00$), high ($r=0.80<0.89$), medium ($r=0.60<0.79$), and unacceptable ($r=0.00<0.59$). Finally, the independent samples t-test was analyzed to see the differences in the test results between male and female participants. All steps in this statistical analysis were administered using the IBM SPSS Statistics 28 software.

Results

Descriptive analysis

The following section presents the results of the descriptive analysis conducted on the sensor-assisted hand-eye coordination test and hand wall toss test. The overview of the participants' performance is presented in Table 1, while the average scores for each are illustrated in Figure 2.

Table 1. Summary of descriptive analysis of the two hand-eye coordination tests

Test	Gender	N	Min	Max	Mean	SD	Variance
Sensor-assisted	Male	66	60.00	82.00	73.29	5.98	35.78
	Female	47	55.00	86.00	71.19	8.89	79.16
Hand wall toss test	Male	66	14.00	24.00	18.61	2.50	6.27
	Female	47	16.00	26.00	19.30	2.78	7.78
Sensor-assisted	Male*female	113	55.00	86.00	72.42	7.37	54.35
Hand wall toss test	Male*female	113	14.00	26.00	18.89	2.64	6.95

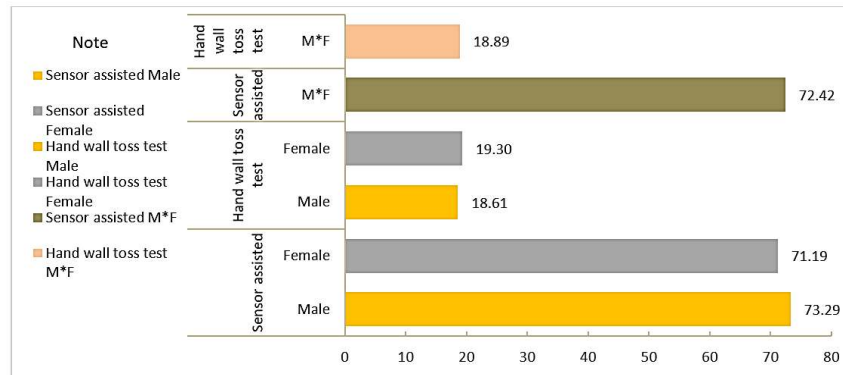


Figure 2. Mean scores of the two hand-eye coordination tests

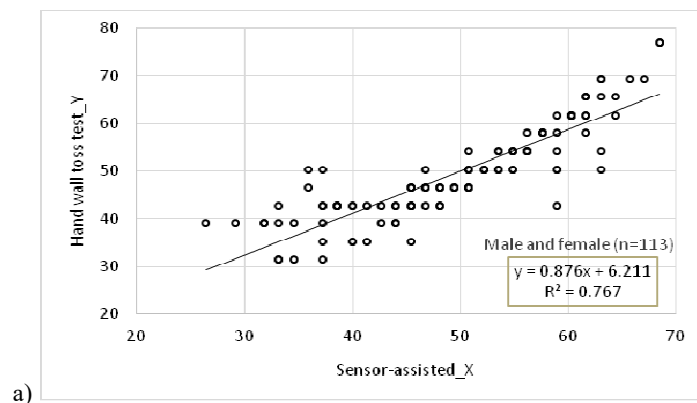
Comparative analysis of sensor-assisted hand-eye coordination test with hand wall toss test

The second analysis compared the sensor-assisted hand-eye coordination test with the traditional hand wall toss test to determine the strength of their relationship. The overall test results of both hand-eye coordination tests (sensor-assisted and traditional) showed a strong correlation, with coefficients in the high category ($n=113$; $r=0.876$; $R^2=0.767$; $F=365.612$; $t=19.121$; $p=0.000$). When analyzed by gender, the coefficients were also very high both for male participants ($n=66$; $r=0.911$; $R^2=0.831$; $F=313.685$; $t=17.711$; $p=0.000$), and female participants ($n=47$; $r=0.928$; $R^2=0.861$; $F=279.225$; $t=16.710$; $p=0.000$) (see Table 2). In addition, the regression equations were as follows: $y=0.876x + 6.211$ for all participants ($n=113$), $y=0.911x + 4.434$ for male participants ($n=66$), and $y=0.928x + 3.600$ for female participants ($n=47$), as shown in Figure 3.

Table 2. Summary of the analysis of the comparison of the two hand-eye coordination tests

Gender	N	R	R^2	p	F	t	p
Male	66	0.911	0.831	0.000	313.685	17.711	0.000
Female	47	0.928	0.861	0.000	279.225	16.710	0.000
Male*female	113	0.876	0.767	0.000	365.612	19.121	0.000

Note- Dependent variable: Hand wall toss test; Predictors: Sensor-assisted; R : Correlation coefficient; R^2 : Magnitude of effect, F : Regression significance; t : Significance of relationship; Significance: $p < 0.05$.



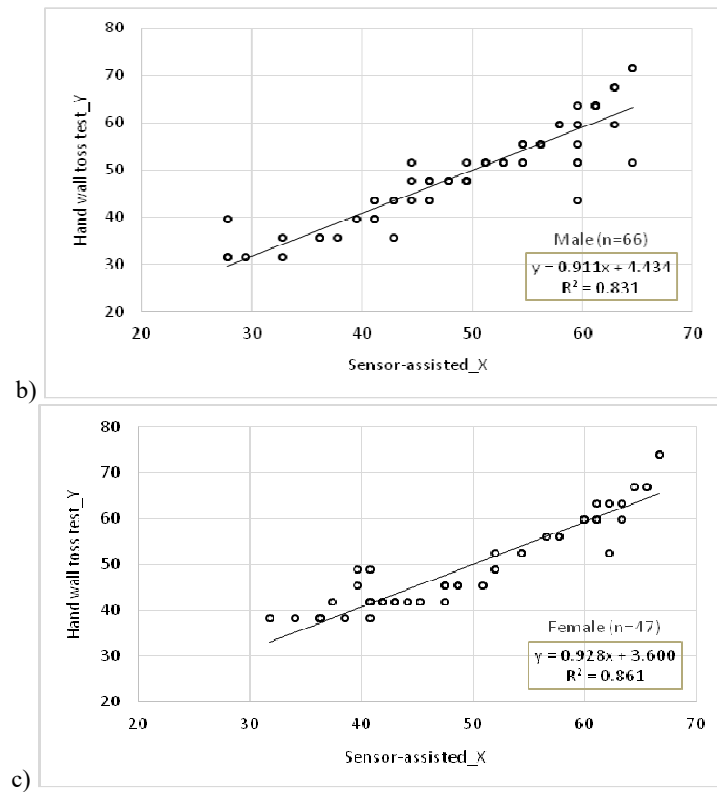


Figure 3. a) Linearity curves for male and female participants, b) male participants, and c) female participants

Analysis of differences in hand-eye coordination tests between male and female participants

The third analysis aimed to determine whether there were any differences in hand-eye coordination test results between male and female participants. A difference analysis of the two hand-eye coordination tests for male and female participants showed no significant difference in mean scores ($p=0.137$ and $p=0.170$). A detailed result of these tests is shown in Tables 3 and 4.

Table 3. Summary of analysis of differences in sensor-assisted hand-eye coordination test between male and female participants

Test	t-test for Equality of Means				Mean Difference	Std. Error Difference	95% C. I.	
	t	df	p				Lower	Upper
Sensor-assisted	EVA	1.498	111	0.137	2.096	1.399	-0.677	4.869
	Not	1.405	74.886	0.164	2.096	1.492	-0.876	5.069

Note- Significant ($p<0.05$).

Table 4. Summary of analysis of differences in the traditional hand-eye coordination test between male and female participants

Test	t-test for Equality of Means				Mean Difference	Std. Error Difference	95% C. I.	
	t	df	p				Lower	Upper
Hand wall toss test	EVA	-1.380	111	0.170	-0.692	0.501	-1.685	0.301
	Not	-1.355	92.431	0.179	-0.692	0.510	-1.706	0.322

Note- Significant ($p<0.05$).

Discussion

This study aimed to compare sensor-assisted and traditional hand-eye coordination tests. The findings showed a high coefficient between the two methods across all participants ($n=113$; $r=0.876$; $R^2=0.767$; $F=365.612$; $t=19.121$; $p=0.000$), including male ($n=66$; $r=0.911$; $R^2=0.831$; $F=313.685$; $t=17.711$; $p=0.000$) and female participants ($n=47$; $r=0.928$; $R^2=0.861$; $F=279.225$; $t=16.710$; $p=0.000$). Furthermore, there was no significant difference in the results of the two hand-eye coordination tests between male and female participants ($p=0.137$ and $p=0.170$). These results suggest that the sensor-assisted hand-eye coordination test consistently reflects the measurements obtained from traditional assessments. This is in line with DeVellis & Thorpe (2021), stating that sensor-assisted technology can be used as an effective alternative to the traditional method to measure hand-eye coordination, provided the results are very similar to more traditional manual measurement tools. These results provide strong evidence that technology offers many advantages, such as automated data collection, reduced measurement bias, and the ability to more objectively monitor athletes' progress (Kim & Ko, 2019).

The results of this study support previous findings that show the importance of hand–eye coordination tests in supporting a variety of tasks that require motor control and high accuracy. According to earlier scholars, a test tool must be "valid" before being used to measure a particular object (Handayani et al., 2023; Irawan et al., 2024). This is in line with a study from **Gierczuk & Bujak (2014)**, which examined wrestlers and confirmed the reliability and validity of perceptual-motor training using the Batak Pro reflexometer. Likewise, Trost et al. (2005) investigated health and fitness measurement tools (such as accelerometers) with traditional measurement methods such as questionnaires and direct observation. The results showed that accelerometers have good concurrent validity with more conventional measurements. However, it is important to note that the use of the device and the duration of measurement need to be considered to improve accuracy (Trost et al., 2005).

More recent research highlights that technology-assisted tools, such as sensors or computer-based devices, have a number of advantages over traditional tests. For example, according to Clark et al. (2021), technologies that use human movement analysis can assist in assessing motor skills, provide objective quantitative measures of what is typically assessed traditionally, and can be integrated with analytical approaches to provide new insights in a more thorough assessment. Studies conducted by Sacko et al. (2019) and Duncan et al. (2019) highlighted the use of accelerometers to measure energy expenditure associated with specific basic movement skills. Meanwhile, other studies have demonstrated the ability of technologies that automatically assess motor skills and compare the results with human judgment (Barnes et al., 2018; Bisi et al., 2017).

Interestingly, while many studies have reported sensor-assisted tools as a valid alternative to the traditional method in measuring motor skills, some were against their application in several contexts. For example, the study conducted by Ellison et al. (2018) investigated a widely marketed hand–eye coordination training device to improve athletes' performance in a variety of sports.

The study involved 87 participants who completed four tests, three laboratory tests (SVT, Batak Pro, and Graded Pegboard) and one field test (wall catch test). The findings showed mutual correlations between the tasks that ranged from weak to strong, but the percentage of shared variance explained by these correlations was typically low. This study does not support the idea that hand–eye coordination is a general ability that can be widely applied to a variety of hand–eye coordination training tools. Coaches and sports scientists are advised not to rely on generic hand–eye coordination training tools to improve overall sport performance. Instead, they are encouraged to seek hand–eye coordination training approaches that are more tailored to the characteristics of each sport (Ellison et al., 2018).

Concurrent validity is a type of validity used to measure how well the results of a new measurement tool compare to an existing measurement tool that is recognized as a standard or tool that has been tested for validity (Alvurdu et al., 2024; Colliver et al., 2012; DeVellis & Thorpe, 2021; Higgins & Straub, 2006). It involves comparing the results obtained from a new measurement tool with more established or better-known measurement tools in laboratory settings and practical situations (Jeyaraman et al., 2020). Based on previous studies, concurrent validity on both measurement tools (technology-assisted and traditional) showed that modern technology-assisted measurement tools have excellent concurrent validity compared to more established traditional measurement tools (Bisi et al., 2017). This validity suggests that these new tools are reliable in relevant measurements, although it is important to consider factors such as measurement conditions, test duration, and the type of activity being tested (Jeyaraman et al., 2020; Trost et al., 2005).

In short, these findings support the use of technology in sports training to measure hand–eye coordination skills. The findings create opportunities for the development of more sophisticated and affordable tools for use at different levels of athletes. However, we also note some limitations that need to be reported, including that the device may experience damage or technical glitches, and limitations in replicating real conditions that match the characteristics of each sport. Furthermore, there are no norms/classifications for this test, so norms need to be established and displayed on the device to determine the level of hand–eye coordination of individuals.

Conclusions

Sensor-assisted measurement is important for improving sports performance that rely on hand–eye coordination by providing more accurate and automated data and reducing measurement bias for both elite and amateur athletes. Hand–eye coordination is a fundamental skill that is essential in many sports because it integrates visual information with hand motor movements to support athlete performance and fast and accurate decision-making. In this research, the sensor-assisted hand–eye coordination test had high coefficients, including for male and female participants.

Furthermore, there was no significant difference in the results of the two hand–eye coordination tests between male and female participants, indicating that gender does not influence hand–eye coordination training. By using this sensor-assisted hand–eye coordination test, coaches and sports practitioners can analyze how vision and hand motor movements interact in various sports contexts.

This test can be recommended for collecting data on hand–eye coordination levels (such as badminton, tennis, table tennis, and other specific sports), whether used by athletes, coaches, and related practitioners. We also suggest that they apply hand–eye coordination training approaches that are more tailored to the characteristics of each sport to obtain optimal performance.

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Conflict of interest- The authors report no potential conflicts of interest related to this article.

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