Design of a sensor technology-based hand-eye coordination measuring tool: Validity and reliability

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Abstract. This research aims to design a sensor-based hand-eye coordination measuring tool and test its validity and reliability. A total of 9 experts were involved in assessing its feasibility, each of them 3 sports measurement experts, 3 motor experts, and 3 technology experts. Meanwhile, 50 students at one of the Faculty of Sports Sciences, Indonesia participated in field trials. Participants were students taking physical condition courses (aged 18-20 years), consisting of male (n=30) and female (n=20). A validation questionnaire was prepared and discussed with experts as a guide in providing an assessment of the relevance of the instrument (suitability, accuracy, ease, and practicality of the tool), and test-retest reliability for field trials carried out twice with the difference between the first and second tests being one week. Data were analyzed using Aiken’s F Index, Intraclass Correlation Coefficient (ICC), and Pearson correlation. The research results showed that the assessment of all aspects of the measuring instrument was in the high category, and the ICC value also showed no differences between assessments (P>0.05). Then, the test-retest reliability testing results obtained a significant regression analysis with a high correlation coefficient (r=0.801; P<0.05). In conclusion, this measuring tool can collect data to improve performance in sports involving hand-eye coordination (such as volleyball, badminton, tennis, basketball, hockey, martial arts and other sports that predominantly use the hands), both for coaches, athletes and sports practitioners.

Keywords: validity, reliability, coordination, sensors

Introduction

Hand-eye coordination is an essential skill in specific sports activities (Antara et al., 2023), and is directly related to visual reactions, timing speed, and motor responses (Schwab & Memmert, 2012). This approach has been demonstrated to benefit athletes during competition (Ceylan & Saygin, 2015; Chang, Tsai, Chen, & Hung, 2013), as it enhances the ability to produce complex movements (Paul, Biswas, & Singh, 2011).

Decisions are often made quickly based on the presentation of various visual stimuli (Schwab & Memmert, 2012). The more complex the movement, the higher the level of coordination required. The importance of hand-eye coordination in various sporting contexts has also been investigated, such as goalkeeping in football (Nagano, Kato, & Fukuda, 2004), dribbling in hockey (Antara et al., 2023), defence in basketball (Laurent, Ward, Williams, & Ripoll, 2006), and general movements that involve hand-eye coordination in other sports, such as passing, throwing and hitting (Zupan & Wile, 2011). Thus, measuring hand-eye coordination becomes essential in collecting data to improve performance in sports involving these basic physical abilities.

Currently, the use of technology in sports is increasing (Kim & Ko, 2019; Szynanski, Wolfe, Danis, Lee, & Uy, 2020), and its innovation have become an essential part (Ahedral, Ilhan, Mario, Aldani, & Sari, 2023; Handayani, Myori, YuliFri, Komaini, & Mario, 2023; Ratten, 2020). This aims to reduce errors in data collection (Firdaus & Mario, 2022), and facilitate performance improvements (Ferreira, Fernandes, Ratten, & Miragaia, 2020; Wang, Chen, & Lin, 2015). Additionally, wearable device sensor technology in sports has been reported to address injury prevention, motion analysis, technique classification, and performance assessment (Adesida, Papi, & Megregor, 2019; Firdausi, Andriadi, Dwisaputra, & Simbolon, 2023).
From youth sports and recreational activities to elite athletes (Adesida et al., 2019; Rana & Mittal, 2020; Stetter, Ringhof, Kraftt, Sell, & Stein, 2019) apply these devices to monitor total exposure over time during a training session, a training period or entire season, and most often in team sports (Benson et al., 2020; Heishman et al., 2020; Mcfadden, Walker, Bozzini, Sanders, & Arent, 2020; Rico-González, Arcos, Rojas-Valverde, Clemente, & Pino-Ortega, 2020), and run (Davis & Gruber, 2019; Napier, Ryan, Menon, & Paquette, 2020; Ryan, Napier, Greenwood, & Paquette, 2020).

Regarding to hand-eye coordination measuring devices, various companies have marketed devices that they claim can be used to measure and improve hand-eye coordination (e.g. Sports Vision Trainer (SVT), Sports Vision Pty Ltd, Australia; Dynavision D2, Dynavision International LLC, USA; Wayne Saccadic Fixator, Wayne Engineering, USA; Batak Pro, Quotronics Limited, UK) (Ellison, Kearney, Sparks, Murphy, & Marchant, 2018). Sherman has applied the Wayne Saccadic Fixator to evaluate hand-eye visual-motor reaction times (Laby, Kirschen, Govindarajulu, & Deland, 2018). This study reported that out of 16 college sports populations (baseball players) had better hand-eye visual-motor reaction times in the college group. However, the study should have reported details regarding the levels of college and professional players.

Ellison et al (Ellison, Sparks, Murphy, Carnegie, & Marchant, 2014) utilized SVT to assess hand-eye coordination. The report found that hand-eye coordination measurements were reliable using SVT. Then, a Batak Pro device to measure reaction and hand-eye coordination (Millard, Shaw, Breukelman, & Shaw, 2021; Quotronics, 2011), where individuals can process and act on visual information (Lobier, Dubois, & Valdois, 2013). Batak Pro is an LED lighting fixture used for each stimulus on one of each target (Ellison et al., 2018). However, data is rarely reported on young athletes.

Additional studies such as Sonar et al (Sonar, Sawant, Salunkhe, & Baraskar, 2022), who developed an hand-eye coordination device using a pen (sensor), tested the reliability of an hand-eye coordination test using a camera (Rozan, Sidik, Sunar, & Omar, 2015), and investigated inertial sensor devices in assessing the development of locomotor skills in childhood (Masci et al., 2013). Meanwhile, the traditional hand-eye coordination test that is often used by researchers is the Hand Wall Toss Test (Ashok, 2008). This test is carried out by throwing the ball towards the wall using the right hand and catching it with the left hand or vice versa. Thus, sensor-based hand-eye coordination measurement tools must be designed to support relevant research developments in improving sports performance.

This research aims to design a sensor-based hand-eye coordination measuring tool and test its validity and reliability. Sensor-based hand-eye coordination measuring tools and field testing must be designed to support the development of relevant studies on improving sports performance. This tool is expected to help collect data to improve performance in sports that involve hand-eye coordination (such as volleyball, badminton, tennis, basketball, hockey, martial arts and other sports where hands are dominant), both for coaches, athletes and sports practitioners.

Methods

Design and participants

This research and development, research aims to design a sensor-based hand-eye coordination measuring tool and test its validity and reliability. A total of 9 experts participated assessing its feasibility, each of whom was 3 sports measurement experts, 3 motor experts, and 3 technology experts. The experts are lecturers at Universitas Negeri Padang, Indonesia, namely the Faculty of Sports Science and Engineering. The experts are doctors and professors with ± 5 years of experience in their respective fields. Then, 50 students at the Faculty of Sports Science, Indonesia, were also involved in field trials. Participants were students taking physical condition courses, who participated voluntarily and complied with the provisions before and during the test. Participants consisted of male (n=30; 19.07 ± 0.83 years; 63.33 ± 3.94 kg; 169.93 ± 3.45 cm; and BMI 21.93 ± 1.26) and female (n=20; 18.85 ± 0.81 years; 59.45 ± 2.67 kg; 164.50 ± 2.44 cm; and BMI 21.98 ± 1.02).

Procedures and instruments

The procedures in this research include designing and developing the tool's shape, testing and refining the tool, and field trials. The sensor-based hand-eye coordination test measuring tool is designed by technology experts or non-experts who are involved in assessing the tool's suitability. This is to avoid conflicts of interest. The components of the tool design consist of a steel frame, a series of touch sensors, an LCD, and a carpet for the testee to stand on. Other components are Arduino Mega, TFT LCD (3.5 inches), power supply unit, voltage regulator, vibration sensor, LED lamp (5 watts), CB connector, and relay module. Indicators for assessing measuring instruments that have been designed are presented in the form of a questionnaire that was prepared and discussed with experts as a guide in assessing the instrument's relevance (suitability, accuracy, ease and practicality) (Table 1). This validation aims to determine the designed tool's accuracy and suitability so that it can measure what it should measure. The validation results and comments from experts were discussed for improvement until there was an agreement for field trials. This field trial was conducted to determine the measuring instrument's reliability in collecting sensor-based hand-eye coordination test data. This reliability test uses the test-retest method, with two repetitions of the test. The first and second tests were carried out one week apart under the same conditions and participant situations during both tests.

The instructions for carrying out this sensor-based hand-eye coordination test are: (a) the testee stands in a prepared
area measuring 75 cm, (b) the testee stands in a ready position, legs straight and shoulder-width apart when turning off the sensor, (c) the distance between each sensor was 30-50 cm (the distance of the inner sensor from the centre of the screen was 30 cm, and the outer one was 50 cm), (d) the test begins when there is a "sound" signal on the tool, (e) the testee makes a movement with both hands open to turn off or press the sensor that is on randomly, (f) the test execution time was 60 seconds, and (g) the score taken is the best score from two repetitions (the score will appear in the middle of the screen) (Figure 1).

Table 1. Expert assessment instruments

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Tool assessment items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedures in tool design are based on appropriate norms.</td>
<td>The measurement aims to determine the level of hand-eye coordination.</td>
</tr>
<tr>
<td>The measurement results are in the form of a number (score) over a specified time.</td>
<td>The equipment designed is an innovation from sports technology.</td>
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<tr>
<td>The tool is designed based on evaluation needs for measuring hand-eye coordination.</td>
<td>The tool's working system is designed per the concept of coordination theory.</td>
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<tr>
<td>The tool is designed for sports that involve hand-eye coordination.</td>
<td>The tool design has effective size.</td>
</tr>
</tbody>
</table>

Table 2. Categories for F index, ICC, and correlation

<table>
<thead>
<tr>
<th>F Category</th>
<th>ICC Category</th>
<th>r</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>V &gt; 0.8</td>
<td>High</td>
<td>&gt; 0.90</td>
<td>Very high</td>
</tr>
<tr>
<td>0.4 ≤ V ≤ 0.8</td>
<td>Enough</td>
<td>0.76-0.90</td>
<td>High</td>
</tr>
<tr>
<td>V &lt; 0.4</td>
<td>Low</td>
<td>≤ 0.50</td>
<td>Currently</td>
</tr>
<tr>
<td>&lt; 0.50</td>
<td>Low</td>
<td>0.00 &lt; 0.50</td>
<td>Not acceptable</td>
</tr>
</tbody>
</table>

Statistical analysis

Validation from experts was analyzed using Aiken’s F index (Aiken, 1985) and ICC to analyze whether or not there are differences in assessments between experts (Koo & Li, 2016) (Table 2). Then, test-retest reliability was analyzed using the Pearson correlation coefficient. This stage uses IBM SPSS version 24 software.

Table 3. F Index

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Items</th>
<th>F</th>
<th>Raters</th>
<th>∑</th>
<th>n(-1)</th>
<th>F Index</th>
<th>M ± SD</th>
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<td>Suitability</td>
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<td>Accuracy</td>
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</tbody>
</table>

Results

Tool validity

The experts' assessment of the sensor-based hand-eye coordination measuring tool from all aspects was obtained in the high category (V = 0.894). Meanwhile, in each aspect, the tool’s suitability, accuracy, ease, and practicality were good (V = 0.967; V = 0.870; V = 0.840; and V = 0.894) (Table 3). Then, the ICC value also shows that there is no difference in the assessments given between experts, both for all aspects and every aspect (P>0.05) (Table 4). This is also proven by the ICC values of all aspects of the assessment (ICC = 0.844) and each aspect (ICC = 0.773; ICC = 0.824; ICC = 0.897; and ICC = 0.574) (Table 5). Some comments from technology experts regarding the revision of the tool are: (a) the colour of the sensor is too bright, (b) the frame size of the measuring tool is too small, so that the tool is not sturdy when participants carry out the test, which has an impact on turning on/off the sensor, and (c) the display size on the measuring instrument needs to be enlarged. This revision was carried out and discussed with experts until an agreement was reached for field trials.
The results of the test-retest reliability test obtained a correlation coefficient in the high category ($r = 0.801$, $F = 86.038$; $t = 9.276$; $n = 50$; $P<0.05$). The correlation coefficient for male participants is in the enough category ($r = 0.711$; $F = 28.608$; $t = 5.349$; $n = 30$; $P<0.05$), and for females is in the very high category ($r = 0.943$; $F = 145.174$; $t = 12.049$; $n = 20$; $P<0.05$). The regression analysis and relationship also showed significance ($P<0.05$) (Table 6). Then, the linearity curve of each of these tests is presented in Figure 2.

Table 5.

<table>
<thead>
<tr>
<th>Source</th>
<th>ICC*</th>
<th>CI 95%</th>
<th>$F$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM</td>
<td>0.275</td>
<td>0.040, 0.801</td>
<td>4.414</td>
</tr>
<tr>
<td>AM</td>
<td>0.731</td>
<td>0.271, 0.973</td>
<td>4.414</td>
</tr>
<tr>
<td>SM</td>
<td>0.341</td>
<td>0.096, 0.791</td>
<td>5.690</td>
</tr>
<tr>
<td>AM</td>
<td>0.824</td>
<td>0.490, 0.972</td>
<td>5.690</td>
</tr>
<tr>
<td>SM</td>
<td>0.492</td>
<td>0.151, 0.938</td>
<td>9.700</td>
</tr>
<tr>
<td>AM</td>
<td>0.897</td>
<td>0.616, 0.991</td>
<td>9.700</td>
</tr>
<tr>
<td>SM</td>
<td>0.130</td>
<td>0.031, 0.677</td>
<td>2.350</td>
</tr>
<tr>
<td>AM</td>
<td>0.574</td>
<td>0.370, 0.950</td>
<td>2.350</td>
</tr>
<tr>
<td>SM</td>
<td>0.576</td>
<td>0.219, 0.922</td>
<td>6.421</td>
</tr>
<tr>
<td>AM</td>
<td>0.844</td>
<td>0.717, 0.929</td>
<td>6.421</td>
</tr>
</tbody>
</table>

*a* The estimator is the same, whether the interaction effect is present.

b. Type C intraclass correlation coefficients using a consistency definition. The between-measure variance is excluded from the denominator variance.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

**Tool reliability**

![Figure 2](https://example.com/figure2.png)

Figure 2. a) linearity curve for test-retest in male participants, b) linearity curve for test-retest in female participants, and c) linearity curve for test-retest in male and female participants

**Discussion**
The design of this sensor-based hand-eye coordination measuring instrument has high test-retest validity and reliability ($V = 0.894; r = 0.801; P<0.05$). Regression analysis and the relationship between the first and second tests also showed significant results ($P<0.05$). The first and second tests were conducted one week apart under the same conditions and participant situations. The study Sonar et al. (Sonar et al., 2022) develops and produces portable hand-eye coordination equipment with reliable readings. Rozan et al. (Rozan et al., 2015), also tested the reliability of a hand-eye coordination test using a reliable camera. It involved 33 rugby players aged 16 to 18 years, and the test was carried out twice, 6 to 7 days apart. Thus, this hand-eye coordination measuring tool is also consistent in collecting data.

This tool is an innovation in sports technology for collecting data in sports involving hand-eye coordination (such as volleyball, badminton, tennis, basketball, hockey, martial arts and other sports where hands are dominant). This includes games in physical education as well (Firdaus et al., 2023; Umar, Alnedral, Ihsan, Mario, & Mardesia, 2023; Welis, Yendrizal, Darni, & Mario, 2023). Previous studies reported that technology in the sports sector is a complex system for collecting and processing large amounts of data (Camomilla, Bergamini, Fantozzi, & Vannozzi, 2018; Ratten, 2020). It aims to improve sports performance, where its use has been proven effective in sports training (Firdaus & Mario, 2022; Handayani et al., 2023; Kokarev, Kokareva, Atamanuk, Terehina, & Putrov, 2023; Lisenchuk et al., 2023; Oh, Johnson, & Syrop, 2019). Another study reported that sensor technology benefits transparent and objective measurement results (Eitzen, Renberg, & Færevik, 2021).

The absolute assessment that must be fulfilled in developing an instrument or measuring tool is validity and reliability (Rifki et al., 2022; Susiono et al., 2024). Validity refers to the accuracy of what the instrument is intended to measure, while reliability refers to the consistency of data obtained repeatedly in the same situation (Heale & Twycross, 2015; Lexell & Downham, 2005). According to Almansreth et al. (Almansreth, Moles, & Chen, 2019), content validity is the minimum requirement for all instruments developed. Content validity is different from other types of validity. It describes what is required of the instrument’s content and is not related to the scores obtained on the constructs (Sireci & Faulkner-Bond, 2014; Yaakop, Koh, & Yasin, 2023). In this regard, the construct underlying a test or instrument must be conceptualized and have clear evidence regarding its operational components (Polit, Beck, & Owen, 2007).

This measuring instrument was validated by 9 experts, each of whom provided an assessment regarding the relevance of the instrument independently (Heale & Twycross, 2015; Larsson et al., 2015). Previous studies reported that involvement and a more significant number of experts will reduce the possibility of coincidental agreement so that the information provided from instrument development will be better (Rubio, Berg-weger, Tebb, Lee, & Rauch, 2003). Inter-expert assessment of the designed measuring instruments also showed no differences, where ICC was used to analyze this. According to Almansreth et al. (Almansreth et al., 2019), the content validity index and other types of construct validation are equally important in developing an instrument, so this must be done. Meanwhile, the participation and involvement of experts in providing assessments must be based on clear criteria (for example, relevant expertise, qualifications and experiences). This will impact the assessment results and comments on the contents of an instrument being developed (Almansreth et al., 2019).

The stages of designing this measuring instrument have been attempted as closely as possible. However, several limitations need to be reported. This measuring tool was only tested on participants aged 18 years and over, and norms/classifications for hand-eye coordination tests have yet to be prepared for this test. This research is designed for the first year funded by the institution, and in the second year, it will be planned to test measuring instruments on a large scale with different age groups. The operation involves IP address with web browser applications. Then, test norms need to be displayed on the measuring instrument to determine the level of hand-eye coordination.

**Conclusion**

The conclusion from these findings is the creation of a sensor-based hand-eye coordination measuring tool that meets the feasibility criteria, namely validity and reliability. This measuring tool was assessed by experts before being tested (sports measurement, motor and technology), with the $V$ index in the high category ($V = 0.894$) and the ICC value also showed that there were no differences in assessments between experts ($P>0.05$). Then, the results of test-retest reliability testing obtained a high correlation coefficient ($r = 0.801; P<0.05$), with regression analysis and a significant relationship ($P<0.05$). The hand-eye coordination test on this tool is carried out in a standing position at 30-50 cm from each sensor. Turning on or off the sensor on the tool is carried out randomly, and the testee does this by pressing small circles. The test execution time and the number of sensors the testee has successfully turned off will be displayed on the screen. This tool can collect data to improve performance in sports involving hand-eye coordination (such as volleyball, badminton, tennis, basketball, hockey, martial arts and other sports where hands are dominant), both for coaches, athletes and sports practitioners. Future research is needed to test sensor-based hand-eye coordination measures on a large scale with different age groups.

**Conflict of interest**

The authors report no potential conflicts of interest.

**Acknowledgment**

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