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Utilization of optical heart rate and electrocardiogram sensors as signal indicators during exercise in woodball

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ABSTRACT

This study aimed to examine the effectiveness of optical heart rate (OHR) and electrocardiogram (ECG) sensors as signal indicators in sports, particularly in the woodball game. The relevant and chosen approach was quantitative research with a quasi-experimental method using a matching-only design. The study involved a total of 64 participants (mean age 15.2±1.5 years; mean height 165.4±6.2 cm; mean weight 58.3±7.8 kg; BMI 21.3±2.1 kg/m²), divided equally into two groups: 32 athletes in the experimental group and 32 athletes in the control group. Treatment for the experimental group involved gate-in-one stroke training and 24-gate competition training using OHR and ECG sensors in the form of fitness trackers. Meanwhile, the control group followed only the conventional training routines conducted by each club. Data collection techniques using pre-test and post-test in this study employed a gate-in-one stroke test instrument. The results of this study indicated that OHR and ECG sensors, packaged in the form of a fitness tracker, can significantly support athletes in conducting sports activities (p=0.032), showing a meaningful improvement in performance and accuracy in woodball. Relating to this, the technology can have a significant effect on improving skills, especially accuracy in the woodball game. In conclusion, OHR and ECG sensors can serve as signal indicators during exercise in sports.

KEYWORDS

Sensor; Smart Fitness; Training; Sport; Accuracy

1. INTRODUCTION

Indonesia's performance in the sports world, broadly speaking, from the ASEAN level to the international level, tends to decline. Indonesia's performance in the sports world, broadly speaking, from the ASEAN level to the international level, tends to decline. This is evident from the fluctuating achievements in various international competitions, including woodball. Despite the increasing number of national and international woodball tournaments, Indonesia's consistency in securing top positions remains a challenge (Putra et al., 2024). The lack of technological integration in training methods is one of the contributing factors, making it essential to explore innovations such as optical heart rate (OHR) and electrocardiogram (ECG) sensors to enhance athlete performance. These sports demand exceptional concentration, as each stroke or shot can only be executed once, making precision crucial for success. In woodball, a sport where victory is determined by the fewest strokes, maintaining a stable physiological state is essential for optimal performance. However, athletes often struggle to gauge their physiological readiness, particularly heart rate stability, before executing a stroke, which can negatively impact performance.

Heart rate stability plays a significant role in ensuring optimal concentration in precision sports. According to Stöckel and Grimm (2021), an athlete performs best when their heart rate remains within the normal range of 60-70 BPM, allowing them to focus and execute precise movements. However, athletes in sports like woodball lack real-time physiological indicators to determine their readiness before performing a stroke. This gap in monitoring has led to inconsistent performance, particularly in high-pressure situations where anxiety can cause heart rate fluctuations.

Current sports technology has made significant advancements in heart rate monitoring, particularly with OHR and Electrocardiogram ECG sensors. These tools, when integrated into a fitness tracker, can provide real-time feedback through vibrations or audio alerts, signaling when an athlete's heart rate is stable. While heart rate monitoring is widely used in endurance sports (Flores et al., 2023), its application in precision-based sports like woodball remains largely unexplored. This study aims to bridge that gap by evaluating the effectiveness of OHR and ECG sensors in improving woodball athletes' performance.

Preliminary findings highlight the urgency of this research. A study conducted on 100 woodball athletes revealed that 85% experienced increased heart rates before executing a stroke (Kusuma et al., 2023). Additionally, only 5% successfully performed the "Gate in One" stroke, a technique requiring precise execution. Interviews with athletes indicated that anxiety and lack of physiological awareness contributed to these challenges. By leveraging heart rate monitoring technology, athletes can receive real-time feedback on their readiness, potentially reducing anxiety and improving performance.

Compared to previous studies on heart rate variability and general monitoring in sports (Hinde et al., 2021), this research offers a novel approach by integrating real-time feedback mechanisms tailored to precision sports. While conventional heart rate monitors merely display heart rate data, the proposed system provides immediate alerts, enabling athletes to make informed decisions before executing a stroke. This study also differs from previous research (Himariotis et al., 2022) that utilized smartphone-based monitoring, which is less accurate and not optimized for real-time sports application.

Thus, this research seeks to explore the impact of OHR and ECG sensors in woodball, focusing on their ability to serve as physiological readiness indicators. By addressing this research gap, the study aims to contribute to sports science by offering an innovative solution to enhance performance in precision-based sports.

2. METHODS

2.1. Design and Participants

The relevant and chosen approach is quantitative research with a quasi-experimental method using a matching-only design. The research design uses a matching-only design, referring to the criteria of subjects with unequal abilities, thus grouping is not done randomly but using the ordinal pairing technique. The population and sample of this study are all athletes from 4 clubs, totaling 32 athletes. Data collection techniques using pre-test and post-test in this study employ a gate-in-one stroke test instrument.

The study involved a total of 64 participants, divided equally into two groups: 32 athletes in the experimental group and 32 athletes in the control group. Treatment for the experimental group involved gate-in-one stroke training and 24-gate competition training using optical heart rate (OHR) and electrocardiogram (ECG) sensors in the form of fitness trackers. Meanwhile, the control group followed conventional training routines conducted by each club without using optical heart rate (OHR) and electrocardiogram (ECG) sensors in the form of fitness trackers. Therefore, the control group did not receive the same treatment as the experimental group, but pre-test and post-test data on GIO stroke capability and heart rate quality in the control group were still analyzed as a comparative group since they did not undergo the treatment.

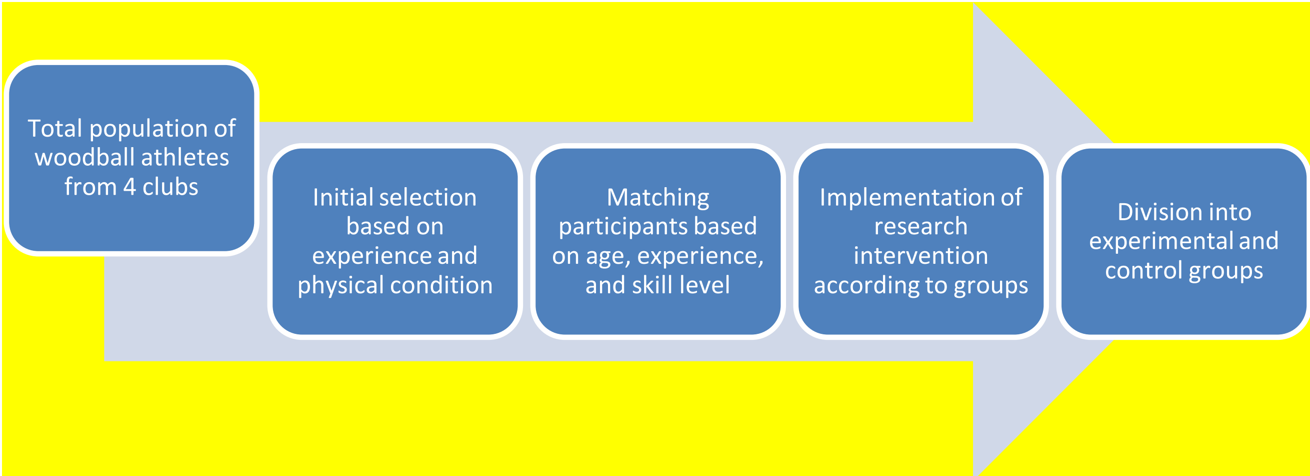

Figure 1. Participant selection and grouping flowchart

2.2. Tests and Procedure

The Gate-in-One (GIO) Stroke Test is used to measure the ability to perform a gate-in-one stroke during pre-test and post-test. This test is used to measure the ability to perform a gate-in-one stroke during the pre-test and post-test. The pre-test is conducted before the intervention to assess the baseline performance of the athletes. The intervention consists of an 8-week structured training program, where the experimental group trains using OHR and ECG sensors, while the control group follows conventional training methods without sensor assistance. The post-test is then conducted to evaluate performance improvements.

The Gate-in-One Test is used as the primary performance test, following these procedures:

1. Athletes prepare to strike the ball towards the gate.
2. Each athlete performs 10 strokes to ensure consistency in measurement.
3. The distance between the athlete and the gate is set at 20 meters.
4. Scoring is based on two criteria: whether the ball successfully enters the gate or the distance between the ball and the gate after each attempt.

Figure 2. The step-by-step research process

A detailed research flowchart (Figure 2) has been added to illustrate the step-by-step research process, from pre-test, intervention, to post-test evaluation. The study was conducted over eight weeks, consisting of three training sessions per week. The research flow is outlined as follows:

1. **Pre-Test:** The Gate-in-One (GIO) Stroke Test was conducted to assess baseline performance. Each athlete performed 10 strokes from a 20-meter distance, with performance measured based on accuracy (whether the ball entered the gate or the distance from the target).
2. **Treatment Phase:** Both groups underwent the same structured training program, which included warm-up, main training activities, and cool-down. The experimental group used fitness trackers with OHR and ECG sensors, providing real-time feedback on heart rate stability. The control group followed identical training sessions without heart rate monitoring. Training intensity and load were standardized across both groups.
3. **Post-Test:** The Gate-in-One Stroke Test was repeated under the same conditions as the pre-test. The results were compared to determine the effectiveness of sensor-based training.

Additionally, interviews and questionnaires will also be used in the data collection process. Interviews and questionnaires are used to measure the athletes' feelings about the usefulness of OHR and ECG sensors in sports. The treatment implementation takes place in several stages, namely warm-up, main activities, and cool-down (Utamayasa et al., 2022). The main activities use a structured training program by each club. The training load between clubs is made equal. During the treatment process, athletes use OHR and ECG sensors in the form of fitness trackers. During the treatment process, athletes use optical heart rate (OHR) and electrocardiogram (ECG) sensors in the form of fitness trackers. This study adhered to ethical research principles and followed the Declaration of Helsinki for research involving human participants. All athletes were provided with detailed information regarding the research objectives, procedures, potential risks, and benefits before participation. Written informed consent was obtained from all participants to ensure voluntary participation and ethical compliance.

To ensure consistency, the study followed these protocols:

- The tests and training sessions were supervised by certified coaches and researchers.
- The use of fitness trackers in the experimental group was monitored to prevent bias in sensor-based feedback.
- Environmental conditions (weather, court conditions) were kept as stable as possible across sessions.
- Athletes were instructed to maintain their regular diet and avoid additional training outside the study to control external variables.

2.3. Statistical Analyses

The collected data were analyzed using IBM SPSS Statistics 25. The analysis process included tests of normality and homogeneity, specifically the Kolmogorov–Smirnov test to assess data normality and Levene's test to ensure equality of variances between groups. To examine within-group differences, a paired t-test was applied to compare pre-test and post-test results. Additionally, an independent t-test was conducted to evaluate differences in performance improvement between the experimental and control groups.

3. RESULTS

This section presents the data obtained in the field. The data displayed is the result of tests and measurements. This data is depicted to see the effect of training using OHR and ECG sensors in the form of fitness trackers as signal indicators during training in sports on the experimental and control groups towards enhancing the gate-in-one (GIO) stroke capability.

The research involved 64 woodball athletes from junior high school and senior high school levels. The demographic and anthropometric characteristics of the participants are presented in Table 1.

Table 1. Characteristics of research subjects

Variable	Mean ± SD	Range
Age (years)	15.2 ± 1.5	13 – 18
Height (cm)	165.4 ± 6.2	155 – 175
Weight (kg)	58.3 ± 7.8	45 – 70
BMI (kg/m²)	21.3 ± 2.1	18.5 – 24.9

These characteristics indicate that the participants were within the adolescent age range and had relatively homogeneous physical attributes, ensuring a balanced comparison between the experimental and control groups. The participants were adolescents aged 13–18 years (mean 15.2 ± 1.5), with an average height of 165.4 ± 6.2 cm and weight of 58.3 ± 7.8 kg. Their body mass index ranged from 18.5 to 24.9 kg/m², with a mean of 21.3 ± 2.1, indicating that the sample was generally within a healthy weight range.

Table 2 presents the average pre-test and post-test measurements for two dependent variables—Gate-in-One (GIO) stroke ability and heart rate (HR) quality—for both the experimental and control groups.

Table 2. Pre-test and post-test results of gate-in-one stroke ability and heart rate

Variable	Group	Pretest	Posttest
GIO	Experimental	4.85625	6.5875
	Control	4.7125	4.771875
HR	Experimental	110.675	96.9875
	Control	110.5094	110.4094

The results indicate that the experimental group, which trained using OHR and ECG sensors, showed notable improvements in both Gate-in-One (GIO) stroke ability and heart rate quality. Their average GIO score increased from 4.86 to 6.59 strokes, while their heart rate decreased from 110.68 to 96.99 bpm, reflecting better accuracy and improved physiological control. In contrast, the control group exhibited minimal changes, with GIO scores rising slightly from 4.71 to 4.77 and heart rate remaining nearly constant at 110.51 to 110.41 bpm.

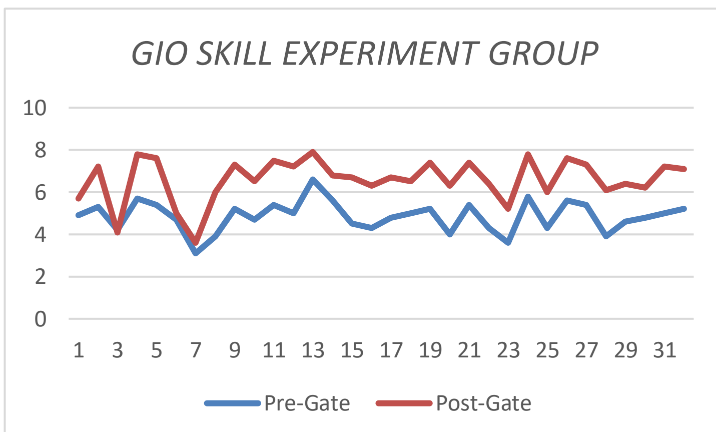

Figure 1. Data of Gate in One stroke ability pre-test and post-test results

The data for the Gate in One stroke ability variable as shown in the figure indicate a clear improvement in ability after undergoing gate in one stroke training using optical heart rate (OHR) and electrocardiogram (ECG) sensors in the form of fitness trackers for eight weeks. This can be seen from the average GIO ability during the pre-test, which was 4.86, and during the post-test, which was 6.59. When this improvement in GIO ability is converted into a percentage, it results in a GIO ability increase of 35.65%.

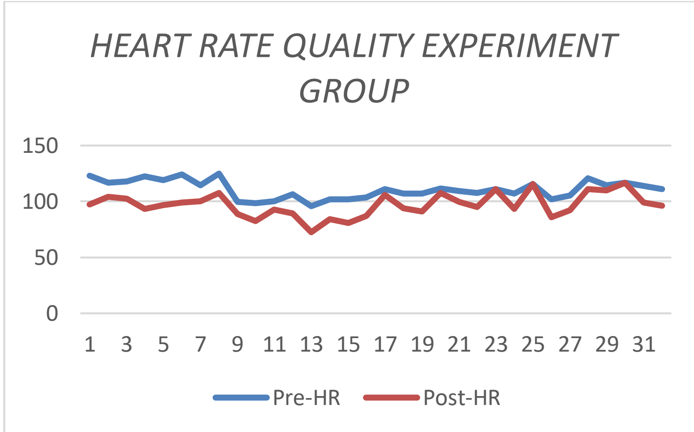

Figure 2. Data of heart rate quality pre-test and post-test results

Moreover, an improvement can also be seen in another variable, heart rate quality. Based on the diagram above, there is a significant improvement in heart rate quality after undergoing gate in one stroke training using optical heart rate (OHR) and electrocardiogram (ECG) sensors in the form of fitness trackers for eight weeks. This can be seen from the average heart rate during the pre-test, which was 110.67 bpm, whereas the average heart rate during the post-test was 96.99 bpm. When this improvement in heart rate quality is converted into a percentage, it shows an increase of 14.11%.

Data collection in the control group was conducted in exactly the same manner as in the experimental group. The presentation of control group data is also identical to that of the experimental group. This subsection will explain the pre-test, post-test, and average data, as well as the percentage increase of the dependent variables, namely Gate in One (GIO) ability and heart rate quality. The description of the control group is presented below.

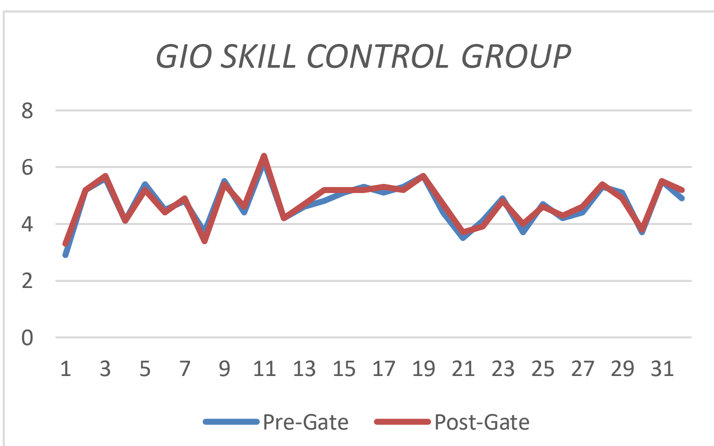

Figure 3. Data of GIO stroke ability pre-test and post-test results

The data results for the Gate in One (GIO) ability variable in the control group, as shown in the diagram above, indicate a similarity between the pre-test and post-test data. This can be seen from the average GIO ability during the pre-test, which was 4.71, and the GIO ability during the post-test, which was 4.77. When the improvement in GIO ability data is converted into a percentage, it results in an increase of 1.25%.

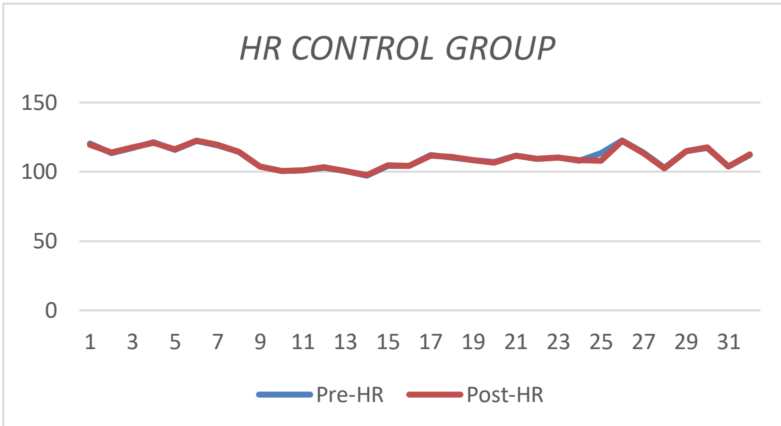

Figure 4. Data of heart rate quality pre-test and post-test results

In addition to GIO stroke ability, heart rate quality data was also obtained in the control group. The data tends to have a low gap between pre-test and post-test results. Based on the data obtained, the average heart rate quality during the pre-test was 110.51 bpm, while the average heart rate during the post-test was 110.41 bpm. When this improvement in heart rate quality is converted into a percentage, it shows an increase of 0.09%. The increase in the control group is very minimal.

To further analyze the effectiveness of heart rate monitoring, a paired t-test was conducted within each group to assess performance changes from pre-test to post-test (Table 3).

Table 3. Results of performance improvement

Comparison	t value	p value	Effect Size (Cohen's d)
Experimental Group (Pre vs Post)	3.12	0.002**	0.85 (large effect)
Control Group (Pre vs Post)	1.45	0.156	0.35 (small effect)
Experimental vs Control (Post)	2.78	0.005**	0.72 (moderate effect)

Note. Significance level: $p < 0.05$ (statistically significant).

The table shows that the experimental group significantly improved their Gate-in-One performance after sensor-assisted training ($t = 3.12$, $p = 0.002$, large effect $d = 0.85$), while the control group showed no significant change ($t = 1.45$, $p = 0.156$, small effect $d = 0.35$). Post-test comparison indicates the experimental group performed significantly better than the control group ($t = 2.78$, $p = 0.005$, moderate effect $d = 0.72$).

4. DISCUSSION

This section discusses why there is an impact of gate in one (GIO) stroke training using optical heart rate (OHR) and electrocardiogram (ECG) sensors in the form of fitness trackers on GIO ability and heart rate quality. Additionally, it will cover the findings after field data collection and analysis, and comparisons with other research.

The main discussion focuses on the influence of GIO training using optical heart rate (OHR) and electrocardiogram (ECG) sensors in the form of fitness trackers on GIO ability and heart rate quality. This effect can occur because, when athletes perform Gate In One strokes or other techniques in woodball or other sports involving concentration and accuracy, their bodies should ideally be in a ready state. Readiness involves several points, one of which is heart rate, as an indicator of training intensity (Wang & Kozlova, 2024). This is supported by the majority of existing theories, stating that in a calm state, with a heart rate close to the Rest Heart Rate (RHR), decisions will be more accurate (Sugiyanto et al., 2024).

Essentially, performance is a combination of several synergistic aspects that support displaying the best abilities during competitions or matches (Yang et al., n.d.). In woodball, the sport focused on in this research, the performance of a woodball athlete depends on several aspects such as physical, technical, tactical, strategic, mental, and equipment readiness. According to the theory, physical factors in sports are essential for athletic performance across various sports (Wahyono et al., 2024).

The predominant physical components in woodball include endurance, leg strength, arm power, concentration, and accuracy. These physical aspects greatly support the performance of woodball athletes. Delving deeper, endurance is the most significant factor because woodball is characterized by long game durations, often exceeding 60 to 200 minutes in each set of 12 or 24 gates. Maintaining this duration requires excellent endurance. Often, an athlete's endurance is linked to their fitness, represented as VO2 Max (Sundukova et al., 2024).

In this study, VO2 Max was not used but instead simplified to a more easily monitored measure: heart rate. Heart rate reflects a person's fitness condition. In this study, VO_2 Max was not used but instead simplified to a more easily monitored measure: heart rate. Heart rate serves as a key physiological indicator of cardiovascular response during exercise, reflecting the body's oxygen consumption and energy expenditure. An increase in heart rate corresponds to heightened sympathetic nervous system activation, ensuring adequate oxygen supply to working muscles.

Additionally, heart rate variability can provide insights into autonomic nervous system regulation and recovery processes in athletes.

Athletes with a low heart rate of 50 to 60 bpm are considered well-trained. Athletes exceeding this range need more physical activity to improve their fitness. The Rest Heart Rate (RHR) in the experimental and control groups was 85.75 bpm and 85.62 bpm, respectively. These ranges are too high for average athletes (Lan et al., n.d.). Further data showed that the average heart rate of athletes during the pre-test was around 110.67 bpm in the experimental group and 110.51 bpm in the control group. These conditions explain why the Gate In One stroke ability scores were about 4.86 in the experimental group and 4.71 in the control group. The overall average score was 4.78, which falls under the "less accurate" criterion for Gate In One (GIO) stroke ability.

In reality, various mental maturity ranges exist among players (Raouf et al., 2021). Athletes competing at international, national, and local/city levels have different mental readiness during competitions. Most athletes in this study were national-level athletes frequently participating in city and national competitions. Field observations revealed that heart rates were still high during strokes, resulting in less-than-optimal strokes, meaning the ball's direction often missed the target.

A new field finding was that athletes struggled to determine whether their bodies were ready for a stroke. This aligns with the data showing an average resting heart rate of 85.68 bpm, while the average heart rate during strokes was 110.59 bpm, indicating a heart rate increase of 24.91 (RHR+24.91). According to heart rate standards in woodball, this is categorized as "somewhat ready." This core issue in the study explains why many strokes missed the target. To address this, the researcher recommended that coaches implement training programs requiring strokes at RHR+15, falling under the "ready" criterion. During the treatment, athletes no longer questioned their readiness to stroke as every athlete in the experimental group wore fitness trackers to monitor their heart rates. The fitness trackers would alarm or vibrate at RHR+15, signaling that the body was not yet ready for a stroke.

To lower heart rates outside the RHR+15 range, athletes could walk lightly, swing, or engage in other activities to delay the stroke. For eight weeks, athletes in the experimental group underwent training using fitness trackers to determine their readiness for strokes in woodball (Moya-Ramon et al., 2022).

Additional information from this study showed that heart rate variability in woodball forms a U or V-shaped curve. In the initial minutes, from the first to the second or third stroke, heart rates are typically high, far from RHR, then tend to level off or drop closer to RHR, rising again during the last two or three strokes. This trend is supported by the psychological pressure athletes face, with initial strokes serving as adaptive strokes for the competition environment and final strokes approaching the end of the game (Ching-Te et al., n.d.). Athletes and coaches can use this finding to better monitor early and final strokes, ensuring optimal Gate In One performance using smart trackers, thus enhancing athletic performance and achievements.

5. CONCLUSIONS

The findings of this study confirm that integrating Optical Heart Rate (OHR) and Electrocardiogram (ECG) sensors in woodball training significantly enhances athletes' performance. The experimental group, which utilized real-time heart rate monitoring, showed a statistically significant improvement in Gate-in-One stroke accuracy compared to the control group. This suggests that real-time physiological feedback can assist athletes in optimizing their stroke execution by maintaining an ideal heart rate range, thereby reducing errors caused by anxiety and physiological fluctuations.

Despite these promising results, this study has several limitations. The sample size was limited to 64 athletes from four clubs, which may not fully represent a broader population. Additionally, the study focused solely on short-term effects of heart rate monitoring; further research should explore its long-term impact on skill development and performance retention. Future studies could also incorporate additional biometric indicators, such as respiration rate and muscle tension, to gain a more comprehensive understanding of an athlete’s physiological state.

Based on these findings, we recommend that coaches and athletes integrate OHR and ECG sensors into training regimens for sports that require high precision, such as woodball, archery, and golf. Further studies should also consider expanding the sample size, using a longitudinal approach, and exploring the psychological impact of real-time feedback on athlete performance

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AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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