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Validation and Usability Evaluation of Mobile Application to Monitor Real-Time Exercise Heart Rate Zone

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ABSTRACT

A mobile application to monitor heart rate (HR) during an exercise called Chromozone was developed to enable a user to regulate exercise intensity using a color-coded system rather than numerical display in the most conventional device. In this study, the agreement of HR from Chromozone was compared against the HR dataset from a clinically accepted electrocardiogram (ECG) on different exercise intensity and to assess its reliability by intra-day repeated assessments. Additionally, the usability aspect of the Chromozone smartphone application was also assessed. Forty-two participants underwent self-selected exercise intensities (based on individual HR reserve) included for 5-min followed by a cool-down period (3-min). A 20-min rest period was given to the participant before repeating the same exercise protocol two more times. Chromozone was found to generate excellent criterion-concurrent validity (r = 0.998, $p < 0.001$) and acceptable bias of 1.96 bpm (Limits of Agreement; LoA: 3.07 to -3.51) for relative and absolute agreement, respectively. Similarly, relative (intraclass correlation coefficient test: 0.998, $p < 0.001$) and absolute (within-subject coefficient of variation: 1.95 ± 1.4%) reliability using Chromozone application shows an excellent consistency. Additionally, this study also

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showed that the usability level of the Chromozone application is beyond the satisfactory level. The outcome of this work provides strong support for Chromozone application as a valid and reliable exercise HR monitoring tool that could potentially help athletes, active individuals as well as the clinical population to monitor and regulate their exercise training regime more effectively.

Keywords: Exercise, heart rate, mobile application, usability, validation

INTRODUCTION

The heart is the hub of most circulatory functions at rest and during exercise. The heart rate (HR) is measured by the number of contractions of the ventricles located in the heart's lower chambers and regulated by both the sympathetic and parasympathetic nervous system's synchronization. HR is adjusted based on physical activity to supply the need for oxygen and the removal of metabolic by-products from the body (Schneider et al., 2018). Training adaptations and expected performance improvements can be achieved by assigning adequate physiological stressors to the body. However, the degree of physical training is challenging to monitor and control. Engaging exercise at significantly low intensities may result in an individual not achieving the desired training effect. Conversely, overtraining may occur due to continuous excessive volume of high-intensity training (Andrade et al., 2019). The HR monitor is commonly used to continuously monitor HR and enable individuals to be in their desired 'training zone.' The HR monitor enables a user to gauge the exercise intensity level and control the degree of physical effort measured by the HR signal. The invention of the HR monitor sparked much interest among coaches and athletes. They utilize this system to eliminate the guesswork during their training intensity and load quantification.

Conventionally, the HR monitor is marketed with a small digital display that provides a continuous HR reading. However, the major limitation of such a numerical digital display is that it does not offer simplicity to read the numerical digits under most conditions of physical activities (Linoby et al., 2014). It is mainly the case when a user is vigorously exercising in which body movements may prohibit the user from precisely determining the state of their exercise intensity. As a result, there is a need for a real-time HR monitoring system that enables users to quickly determine their level of physical exertion under the most strenuous exercise conditions. Smartphone applications to support health intervention and sports training are becoming an increasingly popular tool. The ubiquity of smartphone technology combined with its increasing computational capability presents an obvious opportunity to perform sophisticated physiological assessments. Color-coding technology has been used in a wide array of health-based monitoring devices, including blood pressure monitors, blood glucose monitors, and patient-monitoring systems. However, the study's previous extensive search found no HR monitor in the form of mobile application, registered or currently developed (Harun et al., 2011; Mahmood et al., 2011) for monitoring exercise intensity using color-coding technology. Hence, a mobile application called Chromozone, which incorporates a color-coded system, was developed with the aim to facilitate users to monitor their HR, and thus exercise intensity, in real-time (Linoby et al., 2019).

In order to provide evidence to support the accuracy and reliability of any form of HR monitoring tool, a thorough validation study is required prior to clinical and field-based use. The current study reported the agreement level between Chromozone smartphone application and a clinically accepted ECG system and assessed its reliability by intra-day repeated assessments. In addition, the usability aspect of the Chromozone smartphone application was also further assessed.

METHODOLOGY

Participants

Participants of both sexes (males: n = 24, females: n = 18) were recruited from the student community of a local university via email, an instant messaging application, and printed poster advertisements. Participants were required to abstain from vigorous exercise and advised to have sufficient sleep prior to each visit to the testing center. In addition, the participants were screened for the following inclusion criteria: (1) physically healthy (i.e., no contraindication to Physical Activity Readiness Questionnaire, PAR-Q); (2) subjects of both sexes; (3) aged between 18 to 25 years; (4) have experience using commercial HR monitor for an extended period (>3 months); (5) have experience using iPhone with operating system version 12; and (6) reported no history or present metabolic, cardiovascular or pulmonary diseases. In contrast, those excluded from the study were individuals identified as (1) smokers, (2) pregnant women, and (3) taking dietary supplements (excluding macronutrients) or medications (Lee et al., 2018). The statistical power of the analysis was calculated using the G*Power (v. 3.1.9), with power set at 90% and CI at 95%, revealing an effect size of 0.4 and a target recruitment number of 42 participants (Goulet & Cousineau, 2019). Ethical approval was granted from the Research Ethical Committee of UiTM [REC/01/2020 (FB/2)], and this study was conducted in accordance with the Declaration of Helsinki.

Study Procedures

All testing was completed in the exercise physiology laboratory at a local university using the same measurement devices. Participants were asked to report to the testing center between 9:00 to 10:00 am. Participants were required to arrive at the laboratory in a rested state and completely hydrated following overnight fasting prior to the test session. Upon arrival at the testing center, their height and body mass were measured using a validated weighing column scale and stadiometers. Next, participants were given a standardized breakfast consisting of one 30 g cereal bar (MyProtein, Malaysia), 500 ml of 100 Plus (F&N, Malaysia) sports drink, and raisin toast. Finally, all participants were given written, informed consent following detailed explanations in regard to the study procedures, the potential benefits, and the associated risks of participation.

The familiarisation session was initiated, and the HR transmitter and ECG unit with electrodes were then placed and attached to the chest region. Next, the participants were seated for five minutes to allow their HR to stabilize (for resting HR data). Participants were then required to perform their exercise on a motorized treadmill using the Chromozone application. In brief, the exercise session was divided into three parts: a warm-up period (three minutes); a self-selected intensity among the three lowest exercise intensities included in the Chromozone application (i.e., 50% to 60%, 61% to 70%, 71% to 80% of HR reserve) for 5 minutes; followed by a cool-down period (3 minutes). The reason for selecting the three lowest exercise intensities included in the application is because the current study requires a 10-min period of self-selected activity of HR data for analysis during the actual trial. Therefore, intense exercise will not allow the recording of HR for the required exercise duration. In addition, participants were asked to maintain their running intensity during the self-selected intensity session in the optimal color zone of the Chromozone application (i.e., green display) (Harun et al., 2011; Linoby et al., 2020). Hence, during the familiarisation session, each participant is instructed to run on a treadmill at their self-selected speed over level ground, which would elicit the required HR intensity for the pre-determined exercise objective in the Chromozone application.

Following the familiarisation and a 20-min rest, the exercise protocol and self-selected intensity in the familiarisation session were replicated three times (trials 1, 2, and 3) to measure the agreement of HR data in the Chromozone application against the reference device (i.e., ECG system). The reliability of the Chromozone application can be maintained by repeated HR data recording. During the rest period (i.e., 20 minutes), a relaxing animation video was played on the laboratory TV screen for participants to watch in a sitting position. It ensures that the subjects' HR returns to resting level prior to the next trial. During the exercise trial, the HR recordings were also simultaneously performed via both instruments (Chromozone application and ECG system). The recorded HRs were analyzed at all time points, excluding the resting period, in which only the final 5 minutes were considered in the final analysis.

For the usability testing, a pre-specified task completion test was given to each participant 30 minutes following the completion of all three self-selected exercise trials. Following the demonstration, participants were instructed to complete the demonstrated tasks independently. At the conclusion of the exercise trial, trained personnel recorded the participants' success in completing the task. At the end of the exercise trial, participants were asked to rate their likelihood of using the Chromozone application and complete a System Usability Scale (SUS) questionnaire (Xiong et al., 2020). The complete exercise trial procedure is illustrated in Figure 1.

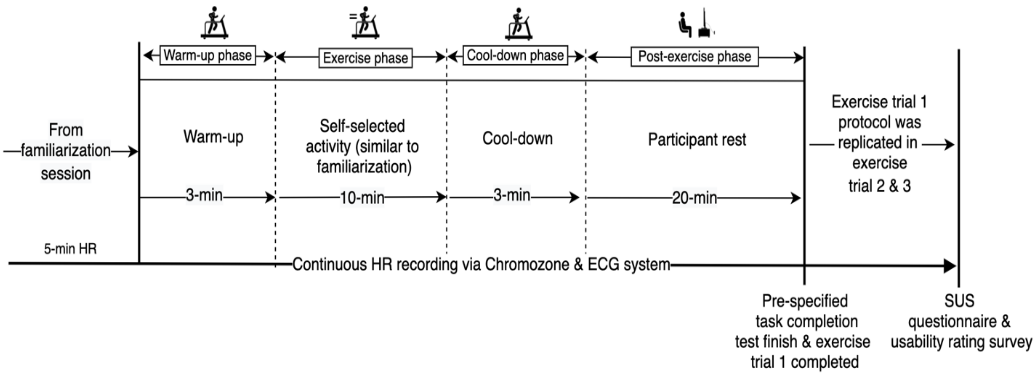

Figure 1. Exercise trial procedures

Data Analysis Procedures

Anthropometrics. Participants' height and body mass were measured using a validated digital column scale (Seca 769; Seca Corporation, Germany) and stadiometers (Seca 213; Seca Corporation, Germany) with a precision of 0.1 kg and 1 mm, respectively.

Heart Rate. HR was measured continuously from 5-min prior to the exercise intervention (in sitting position) until 3-min following the termination of the exercise trial. HR data was simultaneously captured using short-range HR telemetry (HRM Dual, Garmin International Inc., Garmin Ltd.) to be transferred via BLE 4.0 to Chromozone application (Harun et al. 2011; Linoby et al. 2019; Mahmood et al. 2011), and a 12-lead ECG system (Q-Stress ECG monitor, Quinton Instruments, Seattle, USA) (Thomson et al., 2019). First, the ECG electrode placement was applied with the participants standing upright while the electrical impedance-lowering gel was applied over the electrode placement area of the skin (NuPrep, Weaver and Company, USA). Next, the 3M^{TM} Red DotTM 2560 gel electrodes were applied to the subject has already prepped skin in a 12-lead with Mason-Likar placement configuration (i.e., both infraclavicular fossae, as well as the anterior axillary line midway between the iliac crest and costal margin) (Rjoob et al., 2020). After completing the test, raw HR data was exported for later analysis. The HR data from the Chromozone application and the ECG systems were time-aligned, ensemble-averaged for each minute.

Pre-Specified Task Completion Test. Pre-specified task completion tests can provide objective performance data, such as time on task and task success rate (Hu et al., 2017). The Pre-specified task completion test was performed during the first exercise trial. The trained personnel (who are experienced in using the Chromozone application) demonstrated the Chromozone app in-person to participants and instructed them to complete predefined tasks using the mobile app. The assessment was made on the completion of 7 pre-defined tasks, including (Task 1) HR chest transmitter connection set up, (Task 2) making users' information details entry, (Task 3) making exercise objective selection, (Task 4) viewing the exercise objective and exercise tips information, (Task 5) to maintain running intensity by monitoring self-selected intensity session in the optimal color zone of the Chromozone application (i.e., green display), (Task 6) viewing post-exercise information and graph, and (Task 7) making a log (save information) of exercise data. A task was considered completed if the result was consistent with a predefined activity demonstrated by the trainer. If the test appraiser observed that the user was completely frustrated, or that the participant commented indicating that he/she is giving up (e.g., "I don't know what to do," "I have no idea about this"), the appraiser proceeded to the next task to completion, and the current task was considered a failure. The task success rate (task effectiveness) and time-on-task (task efficiency) were recorded throughout the trial. Time-on-task was measured from the time users started the task to when users completed the task. Those tasks that were not completed were not included.

Usability Testing Survey. Following the exercise trial and completion of the pre-specified task completion test, participants were requested to complete the System Usability Scale (SUS) survey by comparing their usage experience of Chromozone application with participants' usage of conventional HR monitor. The tool is comprised of ten questions with five possible responses. The questions assess the product's overall performance as well as user satisfaction. The responses are ranked on a scale of 1 to 5, with one indicating "Strongly disagree" and five indicating "Strongly agree." The odd-numbered questions are phrased positively, while the even-numbered questions are phrased negatively. This structure is intended to reduce bias by encouraging users to approach questions with caution (Maramba et al., 2019). The score range is 0 to 100, indicating the degree of usability. After the exercise trial is completed, the results are interpreted as a single score. Specifically, the SUS score was analyzed the following: (1) for odd items: participant user response was subtracted by one, (2) for even-numbered items: participant user response was subtracted from 5. Subsequently, converted user responses were added up and multiplied by 2.5. It changes the possible values range from 0 to 100 to 100 instead of 0 to 40. A SUS score of less than 68 is typically below average (Weichbroth, 2020).

Statistical Analysis

Descriptive statistics were used to describe the participants' baseline characteristics and the usability testing data. The Shapiro-Wilk test was used to determine the normality of the human resource data to ensure that the assumption was not violated, followed by a natural log transformation if the data were not normally distributed. The Bland-Altman analysis was performed using the GraphPad Prism software (version 8.1.2, GraphPad Software Inc., La Jolla, California, USA) (Bland & Altman, 1987). The limits of agreement (LoA) were evaluated by comparing with the tolerable clinical difference value of the previous HR agreement study (Gaynor et al., 2019). Additionally, to determine the validity of the criterion-concurrent agreement, a Pearson correlation test was performed on both HR data sources (Chromozone application and ECG system). For relative reliability analysis, Under the reliability criterion, the Intra-class Correlation Coefficient for Consistency (ICC_C) analysis was conducted, and two-way mixed model analysis with a consistency option. In this study, an ICC_C value of 0 to 0.30 was considered small, 0.31 to 0.49 moderate, 0.50 to 0.69 large, 0.70 to 0.89 very large, and 0.90 to 1.00 nearly perfect (Hoffmann et al., 2020). Additionally, the absolute reliability was analyzed using a typical measurement error of within-subject coefficient of variation (WSCV). The WSCV value of less than 10% was considered highly reliable (Hoffmann et al., 2020). Both statistical analyses were performed using IBM SPSS® Statistics software (version 26) (IBM Corp., Armonk, NY, USA). All data were expressed as mean ± standard deviation unless otherwise stated.

RESULTS

Twenty-four male (mean ± SD: age 21.8 ± two years, weight 73.2 ± 5 kg, height 168 ± 6 cm, BMI 25.9 ± 2 kg·m^{-2}, predicted maximum HR 199 ± two beats per minute; bpm) and 18 female (mean ± SD: age 21.6 ± two years, weight 63.4 ± 8 kg, height 164 ± 5 cm, BMI 23.6 ± 3 kg·m^{-2}, predicted maximum HR 198 ± two beats·min^{-1}) university students voluntarily participated in this study.

Agreement of Heart Rate Data

The mean HR of the Chromozone at rest, warm-up, during self-selected exercise intensity phase, and cool down were 65.6 ± 0.96 bpm, 84.7 ± 6.5 bpm, 133.3 ± 13.3 bpm, and 113.3 ± 13.3 bpm, respectively. For ECG HR data, the mean HR at rest, warm-up, during the self-selected exercise intensity phase, and cool down were 66.3 ± 1.3 bpm, 85.3 ± 9.7 bpm, 133.8 ± 13.9 bpm, and 112.8 ± 13.3 bpm, respectively. All participants achieved their target HR zone >85% of duration during the self-selected exercise intensity phase. The LoA is defined as the mean difference ± 1.96 SD of differences, and the current study found the mean Bland Altman outcome of -0.2. The 95% confidence intervals for upper and lower LoA were 3.07 and -3.51, respectively (Figure 2). This outcome provides strong support for HR data from Chromozone, which has exceeded the defined maximum acceptable difference).

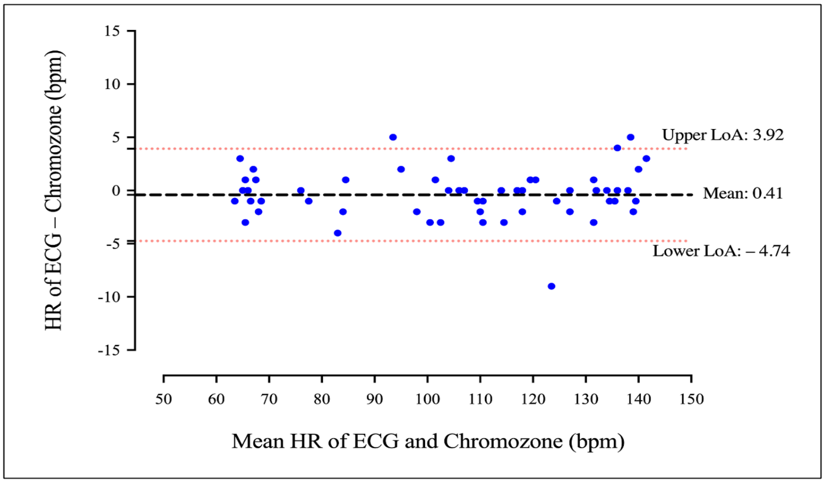

Figure 2. Bland-Altman plots depict the mean difference value between the HR dataset from Chromozone application compared to the ECG system during the exercise trials

A Pearson correlation test of both HR data sources (Chromozone application and ECG system) was performed to establish the criterion-concurrent validity between the two systems. The correlation in HR data between ECG and Chromozone application during the exercise trial is shown in Figure 3. A very strong positive correlation was found in HR data between ECG and Chromozone application ($r = 0.998$, $p < 0.001$).

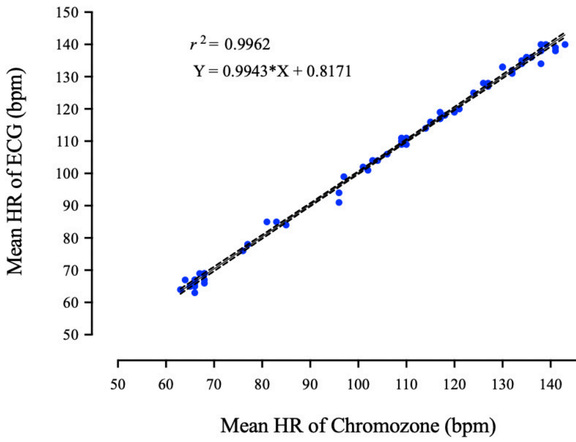

Figure 3. The relationship between the mean of Chromozone and ECG HR data during the exercise trials

Reliability of Chromozone Application

The mean HR were recorded from the Chromozone application at rest (65.6 ± 0.96 bpm; 67.2 ± 1.1 bpm; 66.6 ± 1.3 bpm), warm-up (84.7 ± 6.5 bpm; 84.7 ± 9.0 bpm; 87.3 ± 10.7 bpm), self-selected exercise intensity phase (133.3 ± 13.3 bpm; 134.8 ± 13.4 bpm; 134.1 ± 12.6 bpm), and cool-down (113.3 ± 13.3 bpm; 116.3 ± 10.5 bpm; 114.3 ± 12.3 bpm) during repeated exercise trial 1, 2 and 3, respectively. The relative reliability of the HR dataset from repeated exercise trials using Chromozone application was considered nearly perfect (ICC_C average measure of 0.998, 95% CI 0.995 – 0.999, $p < 0.001$). Meanwhile, the absolute reliability of HR data from the Chromozone application was calculated using the within-subject coefficient of variation (WSCV). The absolute reliability of the HR dataset from repeated exercise trials using Chromozone application was also considered highly reliable (mean WSCV: 1.95 ± 1.4 %; WSCV value of less than 10% was considered highly reliable (Hoffmann et al., 2020).

Results of Pre-Specified Task and System Usability Scales Survey

Overall, all participants experienced a high task completion rate (mean ± SD: 95.6 ± 3.7%). However, it is noteworthy that Task 1, which required users to wear the HR chest transmitter and set up Bluetooth connection with Chromozone application, had the lowest success rate (Figure 4).

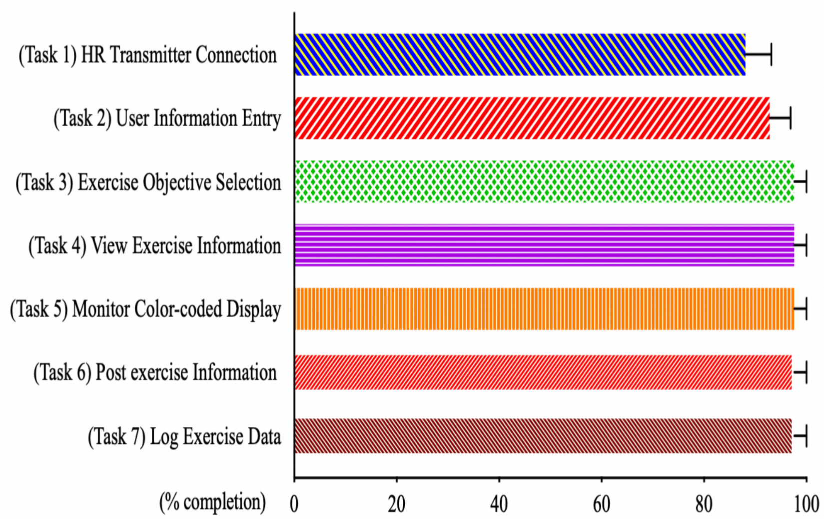

Figure 4. Pre-specified task completion rate

In System Usability Scales Survey, participants have rated an average SUS score of mean ± SD 92.2 ± 3.9. The lowest average SUS score rated by the participant was 80.8, while the highest was 97.7 (Figure 5).

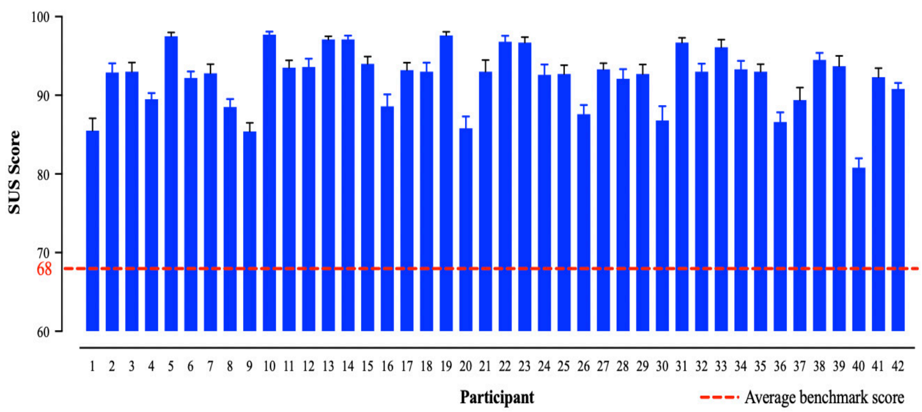

Figure 5. Individual Score of System Usability Scale (SUS) survey

DISCUSSION

It is acknowledged that exercise intensity plays a vital role in the attainment of any exercise goal. HR has been widely used as a physiologically valid signal to regulate exercise intensity in field-based and clinical settings. A mobile application to monitor heart rate (HR) during an exercise called Chromozone was developed to enable a user to regulate exercise intensity using the color-coded system, rather than numerical display in the most conventional device. Validation and usability assessment of Chromozone mobile application were comprehensively reported in the current study.

The current study demonstrates excellent agreement between Chromozone and clinically accepted, laboratory-grade ECG system. The Bland-Altman assessment with 95% LoA was performed across all duration of the exercise trial between ECG and Chromozone application to assess absolute agreement. The current study found that the mean Bland-Altman bias of -0.2 was within the expected value compared to the result of other relevant studies that validated HR transmitter devices. In this study, the 95% confidence intervals for upper and lower LoA were narrowly between 3.07 and -3.51. It provides strong evidence that the Chromozone application shows accurate HR measurements in adults during exercise. In support of the Bland Altman assessment for absolute reliability, the current work found an excellent positive correlation in HR data between ECG and Chromozone application ($r = 0.998$, $p < 0.001$). This outcome provides strong support to Chromozone's high criterion-concurrent validity against clinically accepted laboratory-grade ECG system

(Trobec et al., 2018). These data imply that the Chromozone can detect HR changes during exercise, which correspond with the reading from ECG, in a near-perfect manner. In contrast, a study conducted by Leonard and Simpson (2017) found that continuous HR reading using an HR transmitter shows a relatively weak correlation ($r = 0.45$) with the reference device. A possible explanation for this is that they used different HR transmitters and non-clinical grades of the ECG system as a reference device. His study has predisposed HR data from detection error, particularly during the higher HR realm during intense exercise (Leonard & Simpson, 2017).

This study also demonstrates excellent reliability of the Chromozone application by repeated intra-day assessments. ICC_C analysis with two-way mixed model analysis with a consistency option was performed across repeated same-day exercise trials with HR data from Chromozone application to assess relative reliability (Mehta et al., 2018). The current study found that the relative reliability of the HR dataset from repeated exercise trials using Chromozone application was considered nearly perfect (ICC_C average measure of 0.998, 95% CI 0.995 – 0.999, $p < 0.001$). Similarly, the absolute reliability assessed using the within-subject coefficient of variation (WSCV) shows that HR data from the Chromozone application was deemed highly reliable (mean WSCV: 1.95 ± 1.4 %) (Stegmann et al., 2020). This outcome provides strong support for HR data from Chromozone, which has very high relative and absolute reliability in same-day repeated exercise trials.

Several usability assessments of the Chromozone application were performed. In the first exercise trial, a pre-specified task completion test was performed by each participant. The assessment was made on the completion of 7 relevant pre-defined tasks. The time-on-task and task success rates were recorded throughout the trial. A high task completion rate (mean ± SD: 95.6 ± 3.7 %) was recorded from this test—a mean score for the System Usability Scale score of mean ± SD 92.2 ± 3.9. The lowest average SUS score rated by the participant was 80.8, while the highest was 97.7. It shows a high degree of perceived usability of the Chromozone mobile application (Maramba et al., 2019). The margin of error of this SUS scores for a 95% confidence interval between 91.0 to 93.4. All 42 participants involved in the study scored above average benchmark scores. Generally, usability testing was chosen as a primary research method due to multiple reasons. The method is based on direct user involvement and allows to observe participants' behavior while going along the scenario tasks. Such a scenario-based approach aids the comparison and measurement of the results during the analysis stage. The method has crucial benefits over various analytical approaches (Xiong et al., 2020).

A mobile application for assessing HR in athletes has become popular amongst the general population, particularly for someone new and interested in changing their lifestyle into a healthy environment and team sports. This option is often viewed as efficient and practical when monitoring either for personal usage or athletes in a team setting as the application is capable of analyzing, collecting, and processing information and presenting in the most user-friendly style (Coppetti et al., 2017). In conjunction with the level of consistency of Chromozone as an exercise monitoring mobile application offers, its ability to remain reliable is equally as important as its validity.

The World Health Organisation provided detailed guidelines and recommendations for different age groups and specific population groups on how much physical activity is needed for good health. Adults aged 18–64 years should do at least 150–300 minutes of moderate-intensity aerobic physical activity or at least 75–150 minutes of vigorous-intensity aerobic physical activity; or an equivalent combination of moderate- and vigorous-intensity activity throughout the week (Bull et al., 2020). Chromozone is a suitable application to consider. It is easy to use, individualized, and most importantly, has specific programs to help users identify personal goals during exercise. In addition, it is important to emphasize that mobile technology has become viable in offering the possibility to monitor physiological variables, both in ambulatory conditions and in exercise, thus contributing to practical usefulness.

The strengths of this study lie in the fact that, unlike several other usability studies which employed a single test, two assessments have been made (i.e., System Usability Scale and Pre-specified task completion test) for determining the application's usability in the current study. These tests have been extensively used by a wide variety of research works and industries to test various systems and applications, including hardware, software, mobile devices, websites, and applications (Xiong et al., 2020). Besides, laboratory-based ECG used in the current study is the gold standard reference method for evaluating HR.

This study has some limitations. Firstly, this study employed a cross-sectional design of the student community of a local university with a relatively small sample size (n = 42). While external validity can be compromised, it is inconceivable that this will be a significant concern since this study had achieved a minimum sample size as determined by a priori sampling power calculation. Secondly, estimation of maximum HR of participants using prediction equations of previous maximum HR modeling studies was used in the current study instead of actual maximum HR from maximal testing. Using the prediction equations method, maximum HR inserted in the calculation of HR zone may not reflect the actual maximum HR of each participant. Also, it is acknowledged that each participant's circadian rhythms were likely unique, which may have interfered with the physiological response, thereby affecting the participant's HR responses. However, this effect is likely to be very minimal as participants were tested during a similar time in the trial (9:00–10:00 am). Lastly, while using a homogenous population (i.e., physically healthy university student population), it is still possible that variances still exist in the fitness and physical activity level of the subjects and thus may affect HR responses. An obvious limitation of the present study is that physical activity level prior to the exercise trial was not measured (e.g., using International Physical Activity Questionnaire). However, this study did not compare the subjects and rather compared the HR data between the two HR devices (i.e., laboratory-based ECG and Chromozone). Thus, any inter-subject variability in the HR responses to the exercise test would not affect the main objective of this study.

Future research should be conducted to measure the HR reading during different conditions. A comparison study of HR measurement should be made at a sitting, biking, and certain running positions. Assessment of laboratory-based ECG and Chromozone should directly examine the HR reading. It would be valuable if the HR reading between both devices records valid and consistent data, be established on ergometer cycling, and is interchangeable with other regular activities (such as level walking or running). The future study is therefore aimed to examine the interchangeability of the HR recording method when estimating ergometer cycling and level treadmill walking in submaximal conditions.

CONCLUSION

The Chromozone mobile application system has been designed to help eliminate the need for users to monitor a numerical display just like any other conventional HR monitor available in the market today. Chromozone accuracy was compared to the validated laboratory-based ECG, and its consistency was measured. The results provide individuals, athletes, coaches, and clinicians with useful information on the accuracy, consistency, and acceptability of the Chromozone mobile application in this population. The results presented in this study also collectively suggest that the Chromozone mobile application can be used by individuals who wish to take advantage of using technological advancements in health monitoring systems and sports performance tools to their fullest potential.

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REFERENCES

Andrade, A., Casagrande, P., Bevilacqua, G., Pereira, F., Matte, D., & Coimbra, D. (2019). Burnout in elite junior tennis players: A multiple case study. *Revista de Psicologia Del Deporte*, *28*(4), 97-105.

Bland, J., & Altman, D. (1987). Caveat doctor: A grim tale of medical statistics textbooks. *British Medical Journal (Clinical Research Ed.)*, *295*(6604), 979. https://doi.org/10.1136/bmj.295.6604.979

Bull, F., Al-Ansari, S., Biddle, S., Borodulin, K., Buman, M., Cardon, G., Carty, C., Chaput, J., Chastin, S., Chou, R., Dempsey, P., Dipietro, L., Ekelund, U., Firth, J., Friedenreich, C., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P., … & Willumsen, J. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine*, *54*(24), 1451-1462. https://doi.org/10.1136/bjsports-2020-102955

Coppetti, T., Brauchlin, A., Müggler, S., Attinger, A., Templin, C., Schönrath, F., Hellermann, J., Lüscher, T., Biaggi, P., & Wyss, C. (2017). Accuracy of smartphone apps for heart rate measurement. *European Journal of Preventive Cardiology*, *24*(12), 1287-1293. https://doi.org/10.1177/2047487317702044

Gaynor, M., Sawyer, A., Jenkins, S., & Wood, J. (2019). Variable agreement between wearable heart rate monitors during exercise in cystic fibrosis. *ERJ Open Research*, *5*(4), 00006-02019. https://doi.org/10.1183/23120541.00006-2019

Goulet, M., & Cousineau, D. (2019). The power of replicated measures to increase statistical power. *Advances in Methods and Practices in Psychological Science*, *2*(3), 199-213. https://doi.org/10.1177/2515245919849434

Harun, C., Zulkarnain, N., Aziz, M., Mahmood, N., Kamarudin, M., & Linoby, A. (2011). Pulse oximetry color coded heart rate monitoring system using Zigbee. In *5th Kuala Lumpur International Conference on Biomedical Engineering 2011* (pp. 348-351). Springer. https://doi.org/10.1007/978-3-642-21729-6_90

Harun, F., Zulkarnain, N., Aziz, M., Mahmood, N., Kamarudin, M., & Linoby, A. (2011). Pulse oximetry color coded heart rate monitoring system using ZigBee. *IFMBE Proceedings*, *35*, 348-351. https://doi.org/10.1007/978-3-642-21729-6_90

Hoffmann, B., Flatt, A., Silva, L., Nczak, M., Baranowski, R., Dziedzic, E., Werner, B., & Gasior, J. (2020). A pilot study of the reliability and agreement of heart rate, respiratory rate and short-term heart rate variability in elite modern pentathlon athletes. *Diagnostics*, *10*(10), Article 833. https://doi.org/10.3390/diagnostics10100833

Hu, W., Miyato, T., Tokui, S., Matsumoto, E., & Sugiyama, M. (2017). Learning discrete representations via information maximizing self-augmented training. In *34th International Conference on Machine Learning, ICML 2017* (Vol. 4, pp. 2467-2481). MLResearch Press.

Lee, M., Lee, H., Kim, Y., Kim, J., Cho, M., Jang, J., & Jang, H. (2018). Mobile app-based health promotion programs: A systematic review of the literature. *International Journal of Environmental Research and Public Health*, *15*(12), Article 2838. https://doi.org/10.3390/ijerph15122838

Leonard, A., & Simpson, S. (2017). *The accuracy of heart rate-based zone training using predicted versus measured maximal heart rate* (Master thesis). University of Wisconsin-La Crosse, USA. https://minds.wisconsin.edu/handle/1793/76886

Linoby, A., Asraff, I., Rodzi, A., Mauzaulan, M., Abdul, R., & Abdul, M. (2019). iCobra: A smartphone application for monitoring real-time exercise heart rate using color-coded system. *IEEE Reviews in Biomedical Engineering*, *9*(1), 95-98.

Linoby, A., Khairi, F., & Kamaruddin, F. (2014). Development of heart rate monitor using colour-coding system to communicate exercise intensity. In *Proceedings of the International Colloquium on Sports Science, Exercise, Engineering and Technology 2014 (ICoSSEET 2014)* (pp. 421-428). Springer. https://doi.org/10.1007/978-981-287-107-7_44

Linoby, A., Kusrin, J., Asraf, M. I., Rodzi, M. A., Zaki, S., & Hasan, H. (2020). Chromozone: iOS-based exercise heart rate application using universal colour-coding system. *Jurnal Inovasi Malaysia, 4*(1), 193-208.

Mahmood, N., Uyop, N., Zulkarnain, N., Harun, F., Kamarudin, M., & Linoby, A. (2011). LED indicator for heart rate monitoring system in sport application. In *2011 IEEE 7th International Colloquium on Signal Processing and Its Applications* (pp. 64-66). IEEE Publishing. https://doi.org/10.1109/CSPA.2011.5759843

Maramba, I., Chatterjee, A., & Newman, C. (2019). Methods of usability testing in the development of eHealth applications: A scoping review. *International Journal of Medical Informatics*, *126*(February), 95-104. https://doi.org/10.1016/j.ijmedinf.2019.03.018

Mehta, S., Bastero, R., Sun, Y., Zhu, R., Murphy, D., Hardas, B., & Koch, G. (2018). Performance of intraclass correlation coefficient (ICC) as a reliability index under various distributions in scale reliability studies. *Statistics in Medicine*, *37*(18), 2734-2752. https://doi.org/10.1002/sim.7679

Rjoob, K., Bond, R., Finlay, D., McGilligan, V., Leslie, S., Rababah, A., Guldenring, D., Iftikhar, A., Knoery, C., McShane, A., & Peace, A. (2020). Machine learning techniques for detecting electrode misplacement and interchanges when recording ECGs: A systematic review and meta-analysis. *Journal of Electrocardiology*, *62*, 116-123. https://doi.org/10.1016/j.jelectrocard.2020.08.013

Schneider, C., Hanakam, F., Wiewelhove, T., Döweling, A., Kellmann, M., Meyer, T., Pfeiffer, M., & Ferrauti, A. (2018). Heart rate monitoring in team sports - A conceptual framework for contextualizing heart rate measures for training and recovery prescription. *Frontiers in Physiology*, *9*, Article 639. https://doi.org/10.3389/fphys.2018.00639

Stegmann, G., Hahn, S., Liss, J., Shefner, J., Rutkove, S., Kawabata, K., Bhandari, S., Shelton, K., Duncan, C., & Berisha, V. (2020). Repeatability of commonly used speech and language features for clinical applications. *Digital Biomarkers*, *4*(3), 109-122. https://doi.org/10.1159/000511671

Thomson, E., Nuss, K., Comstock, A., Reinwald, S., Blake, S., Pimentel, R., Tracy, B., & Li, K. (2019). Heart rate measures from the Apple Watch, Fitbit Charge HR 2, and electrocardiogram across different exercise intensities. *Journal of Sports Sciences*, *37*(12), 1411-1419. https://doi.org/10.1080/02640414.2018.1560644

Trobec, R., Tomasiv, I., Rashkovska, A., Depolli, M., & Avbelj, V. (2018). Commercial electrocardiograpm systems. In *SpringerBriefs in Applied Sciences and Technology* (pp. 101-114). Springer. https://doi.org/10.1007/978-3-319-59340-1_6

Weichbroth, P. (2020). Usability of mobile applications: A systematic literature study. *IEEE Access*, *8*, 55563-55577. https://doi.org/10.1109/ACCESS.2020.2981892

Xiong, J., Ziegler, C., & Kortum, P. (2020). SUSapp: A free mobile application that makes the system usability scale (SUS) easier to administer. *Journal of Usability Studies*, *15*(3), 135-144.