Real-Time Heart Rate Visualization for Individuals with Autism Spectrum Disorder: An Evaluation of Technology Assisted Physical Activity Application to Increase Exercise Intensity

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Abstract: Individuals with autism spectrum disorder (ASD) often experience negative relationships with physical activity and a severe lack of motivation for exercise. While specialized exercise technologies such as internet-enabled machines and mobile applications have provided some solutions for typically developing individuals, there is a lack of research in providing exercise technology that specifically considers the needs of individuals with ASD. This paper presents a real-time heart-rate visualization application, namely the HeartRunner 2.0 App, which aims to engage individuals with ASD to exercise at higher intensity. When used to supplement exercise sessions, amongst a group of 20 participants with ASD, evaluation results showed that the App helped 83% of participants achieve higher heart rates, 66.6% to maintain heart rates at or above 90 BPM, and 27.7% to re-engage and achieve heart rates at or above 90 BPM after dropping below that threshold. Furthermore, eye tracking analyses indicate that those individuals who achieved higher heart rates have employed a more focused gaze patterns with less distributed fixations in their visual searches, as well as greater efforts in scanning various cues in the given visual scene, suggesting that visual interaction with the App may have contributed to elevated performance in the experiment.

1 INTRODUCTION

Gaining popularity during the 2000s, the intertwining developments of exercise and technology have given rise to a joint field of digital fitness – with technological advancements emerging to motivate physical activity for its users (Parrott et al., 2020). Users of fitness-oriented technical machines and applications have often found these devices to be useful tools for encouragement and prolonging of physical activity, resulting in overall improvements in personal health and quality of life. Shortcomings of these tools, however, become prevalent when applied to certain communities, such as those diagnosed with autism spectrum disorder (ASD). Studies focusing on ASD prevalence in the United States concluded that 1 in 54 children living in the U.S. were diagnosed with ASD as of 2016 (Matthew et al., 2020) – exhibiting characteristics including “deficits in social communication and interaction”, “restrictive interests”, and “repetitive behaviors” (Shaw et al., 2023). Because individuals with ASD exhibit such characteristics, alternative approaches toward encouraging physical activity, including technology-based applications and machinery, must be considered. Individuals with ASD often experience negative relationships with exercise due to a myriad of factors, which can include lacking social skills, deficits in gross motor skills, and underdeveloped coordination leading to low motivation when engaging in physical activities. ASD populations, as a result, are severely more likely to experience sedentary lifestyles, often leading to obesity and other health conditions (Dieringer et al., 2017).

This paper aims to investigate the application of technology-assisted exercise in supporting individuals with ASD during physical activity. More specifically, a tablet application is developed and evaluated to determine whether visualizing heart rates in real time during physical activity would be beneficial in encouraging higher intensity of physical

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activity for individuals with ASD. A preliminary research (Fu et al., 2020) has found that real-time visualizations of heart rates were helpful in engaging ASD individuals in physical activity. However, a multi-user mode to simulate a social environment for multiple users in one exercise session did not provide positive encouragement, as most individuals with ASD found it to be too competitive and some gave up on the exercise as a result. As such, the application presented in this paper proposes a single-user mode, in addition to utilizing music and differing visualization techniques - compared to those demonstrated in (Fu et al., 2020) - that aim to overcome the aforementioned issues discovered in (Fu et al., 2020).

2 THE HeartRunner 2.0 APP

The HeartRunner 2.0 App is built for compatibility with Apple iPadOS devices using the Swift programming language in Xcode, employing the Model-View-Controller architectural pattern to implement the user interface derived from FlappySwift (Murray, N., 2019). Additionally, the application makes use of the Scosche Rhythm24 Software Development Kit (SDK)[1] to allow heart rate data retrieval from the Scosche Rhythm24 Bluetooth heart rate monitors[2].

Prior to beginning a physical activity, a user would open the HeartRunner 2.0 App on their iPad device to take a photo of themselves (using the built-in camera on the tablet) as their profile picture in the App. Wearing a Scosche heart rate monitor, the user can then begin an exercise session after setting a targeted duration (i.e., a desired exercise duration in minutes). During the exercise, the App would show their profile picture as a main character flying forward a path, and their heart rates measured in beats per minute (BPM) would be visualised in real time as the readings from the Scosche heart rate monitor elevate or drop. The exercise session ends once the target exercise duration is completed, and the user will be shown the highest heart rate achieved during that session.

Figure 1 shows a screenshot of the HeartRunner 2.0 App interface during exercise sessions that consists multiple elements that respond to real-time heart rate readings, including:

1. Heart Rate Label: Displays the user's heart rate reading in BPM in real time;
2. Profile Picture: At different ranges of heart rates (as depicted in Table 1), the profile picture taken by the user at the beginning of the user flow is placed at different horizontal locations on the screen – toward the left side ("beginning") of the screen for lower heart rate readings, and toward the right side ("end") for higher heart rate readings;
3. Sky Color and Platform Speed: At different ranges of heart rates (shown in Table 1), the color of the sky in the background of the platform would be modified to provide further indication of the changes in heart rates for that user. Additionally, the speed at which the platform moves in the horizontal direction is adjusted with heart rate readings at lower ranges moving at a slower pace than readings at higher ranges;
4. Background Music (not pictured in Figure 1): Upon reaching a heart rate of 90 BPM, the App would play music using the audio player on the tablet device. The song "Happy Rock" (Bensound, 2022) would be played as the exercise continues, which has the distributor labels of having very high/high energy levels and happy/energizing mood. 90 BPM was chosen as the threshold to initiate music play based on the recommended maximum heart rate determined by age, whereby for those 16 years old and over: *Maximum Heart Rate* = 220 – *Current Age* (Centers for Disease Control and Prevention, 2022; Riebe et al., 2018; Physical Activity Guidelines Advisory Committee, 2008), and all participants who took part in the evaluation of the App being in the 18-21 year old age group;
5. Countdown Timer: Displays the remaining time in the exercise session (in minutes). The timer incorporates a circular display with a yellow circle that progressively empties, resembling a pie chart, as each second elapses. At the completion of each minute, the circle returns to its original yellow state and continues the countdown cycle.

[1] https://www.scosche.com/rhythm-sdk, last accessed Oct 2023.

[2] https://www.scosche.com/rhythm24-waterproof-armband-heart-rate-monitor, last accessed Oct 2023.

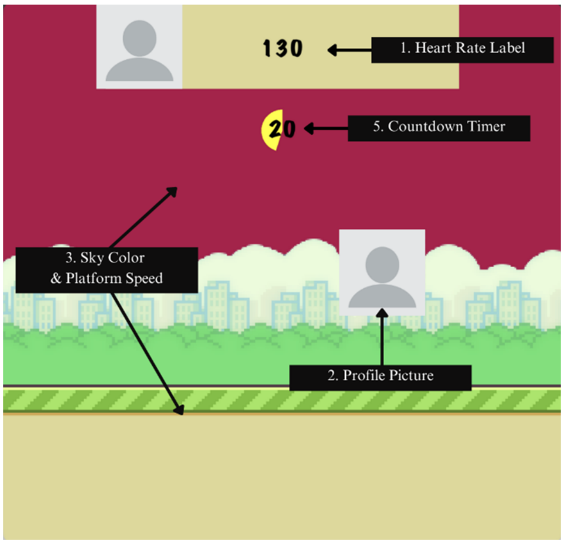

Figure 1: The HeartRunner 2.0 App user interface with elements that respond to real-time heart rate readings.

Table 1: The HeartRunner 2.0 App Visualization Features.

Heart Rate (BPM)	**Profile Picture Position**	**Sky Color**	**Platform Speed**	**Background Music**
Less than 80	Left-most fifth of screen	Grey	1	Off
Between 80 & 90	Left-most fifth of screen	Grey	1.25	Off
Between 90 & 100	Second left-most fifth of screen	Blue	1.5	On
Between 100 & 110	Center fifth of screen	Green	2	On
Between 110 & 120	Second right-most fifth of screen	Orange	3	On
More than 120	Right-most fifth of screen	Red	4	On

3 EVALUATION

A series of experiments were conducted over a 3-month period involving 20 individuals with ASD. All participants were verbal, able to read and understood the instructions given in the experiments. Participants were asked to complete a stationary bicycle exercise session. Each participant took part in the study on two separate days, completing a *control exercise session* (i.e., without the support of the HeartRunner 2.0 App) on one day and an *experimental exercise session* (i.e., with the support of the HeartRunner 2.0 App) on the other. The order in which individual participants experienced each session type was chosen randomly and counterbalanced overall to minimize order effect.

Individual participants were asked to ride a Matrix IC7 Indoor Stationary Bicycle, as shown in Figure 2. Prior to the session, the seat and handlebar heights of the stationary bicycle were adjusted according to the participants' height and comfort. These settings were recorded so that participants would maintain the same seat and handlebar heights for both sessions. Each participant was also assisted to wear one Scosche Rhythm24 Heart Rate Monitor on the upper forearm (just below the elbow). Following the physical configurations, each participant was given an iPad with the HeartRunner 2.0 App installed. Participants were assisted when completing the initial steps of the application's user flow, including taking a profile picture and ensuring Bluetooth connection to the heart rate monitor.

a. A participant in a *control exercise session*	b. A participant in an *experimental exercise session*

Figure 2: Physical setup of the two experimental conditions.

Individuals participating in the *control exercise session* used a "Blank" version of the HeartRunner 2.0 App (as shown in Figure 2a), where a white screen appeared for the duration of the session instead of the actual HeartRunner 2.0 App interface. Participants in this group were instructed to complete a 20-minute exercise session on the stationary bike while using the "Blank" version of the application. Following the session, the heart rate monitor was removed from the participants' forearms, and the heart rate data was extracted from iPad storage for analysis. Individuals participating in the *experimental exercise session* were also instructed to complete a 20-minute exercise session on the stationary bike while using the HeartRunner 2.0 App (as shown in Figure 2b), where they would be able to see how various interface components reacted according to their heart rate changes. In addition to wearing the Rhythm24 Heart

Rate Monitor, participants in the *experimental exercise session* also wore the Tobii Glasses Eye Tracker (with controller model version 0.16194 and a 50Hz sample rate), which tracked and recorded participants' eye movements during an entire exercise session. Following the session, the heart rate monitor was removed from the participants' forearms, and the heart rate data was extracted from iPad storage for analysis.

4 RESULTS

Out of the 20 participants who took part in the experiment, we discarded corrupted data from 2 individuals (due to sensor failure and other technical issues resulting in null data). In total, data from 18 participants, or 36 individual exercise sessions (including 18 *control exercise* sessions and 18 *experimental exercise* sessions) were analyzed and reported in this paper.

When comparing the heart rate readings for participants between the experimental and control exercise sessions, as shown in Figure 3, 15 out of 18 participants (83.3%) experienced higher average heart rate readings when supported by HeartRunner 2.0. On average, these 15 participants exhibited an increased heart rate of approximately 12.152 BPM. Additionally, the heart rates of participants after hearing the music for the first time were analyzed as a measure of sustained physical activity. 12 out of 18 participants (66.6%) continued to exhibit heart rates above 90 BPM for the duration of their exercise sessions after music was played for the first time. Of the remaining 6 participants, none moved below 90 BPM for the entirety of the remaining session time. 5 participants (27.7% of participants) had readings which dropped below 90 BPM for short intervals before increasing past the 90 BPM mark again – with some only moving below 90 BPM once in the time after first reaching that mark. After the initial music start, these 5 individuals stayed mostly above 90 BPM – hearing music for most of their exercise session. The remaining 1 individual also experienced fluctuation around the 90 BPM mark, though staying mostly below 90 BPM and without music. The aggregated group averages are shown in Figure 4.

These findings may indicate that the heart rate visualization features of the HeartRunner 2.0 App served as motivating factors for individuals with ASD, encouraging participants to participate in their exercise sessions at higher intensities as shown through increased heart rate readings during experimental exercise sessions. It may also be suggested that, with no participants reaching heart rate readings of 90 BPM dropping below that threshold for the entire remaining session time, participants interpreted changes in the visualization elements as success signals. In response, participants may have strived to reach "success" after elements reverted to their original states, with 5 participants rising above 90 BPM after the application stopped playing music – indicating that such elements could contribute to the sustainment of physical activity.

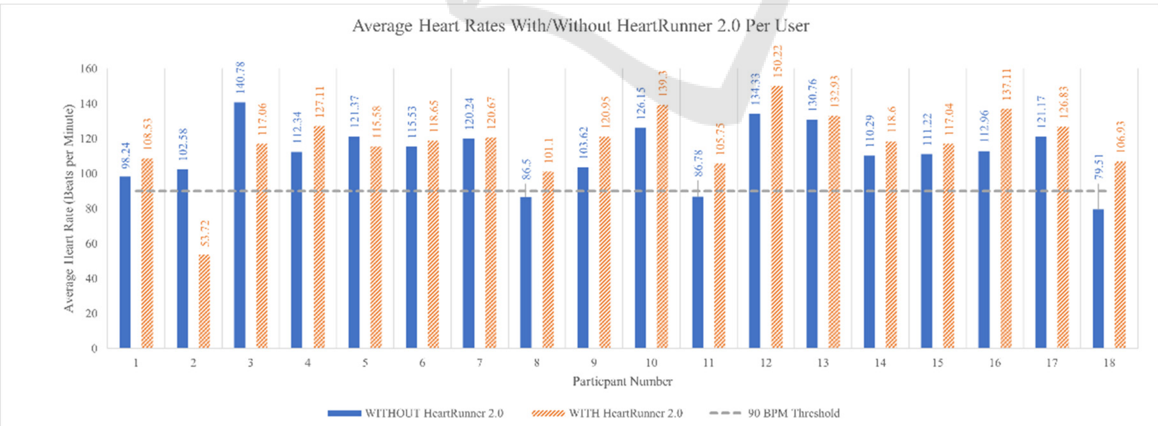

Figure 3: Average heart rate readings for individual participants with ASD during exercise sessions without the HeartRunner 2.0 App (denoted in solid blue, on the left) and with the HeartRunner 2.0 App (denoted in shaded orange, on the right).

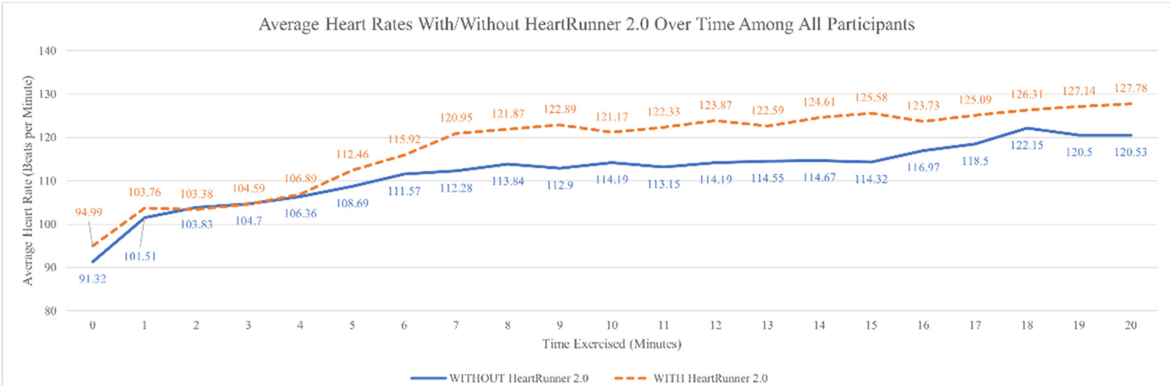

Figure 4: Average heart rate readings for participants with ASD over a 20-minute period, for both control exercise sessions (denoted as a solid blue line) and experimental exercise sessions (denoted as a dashed orange line).

To further compare the visual attention and interaction with the HeartRunner 2.0 App amongst the participants, we grouped them into two categories using a median split of the average heart rate recorded across all experimental sessions. In other words, the participants who achieved an average heart rate above the median value (at 118 BPM) are referred to as the *above median heart rate* group, and those participants who achieved a lower average heart rate are grouped into the *below median heart rate* group. Using eye tracking, we aim to compare how these two participant groups spent their visual attention during the exercise, and whether there are significant differences in gaze behaviors between the group who achieved higher heart rates than those who did not.

In this paper, we report a number of notable gaze measures such as saccade lengths and convex hull areas. As participants interact with an interface such as the HeartRunner 2.0 App showing real-time heart rate visualizations, they would direct their gaze to various points of interest on the screen. They may fixate their attention on a visual point and moves their gaze in search for the next relevant visual cue as they interact with the App. Fixations are typically understood as behaviors of information processing activities, where a person's eyes are relatively stationary. Saccades refers to those quick eye movements during successive pairs of fixations and are typically understood as behaviors of information search activities. Given fixations located on various parts of a tablet screen, the distance (measured in px) between pairwise fixations are determined by saccade lengths, which typically indicate how far or close a person searched for relevant visual information. An interactive session would entail multiple stages of information search and processing activities, where a collection of fixations would be recorded by the end of a session. The bounding fixations found in a session would therefore outline an area (measured in px^2) where all fixations generated during a session fall within, and referred to as the convex hull area, which typically indicates how large or small a person's entire gaze journey captured during an experimental session.

In addition to the results shown above, our eye tracking analysis has revealed further insights into how the two participant groups' gaze behaviors differed during the experiment. Though the differences were not shown to be statistically significant (potentially due to a small sample size), these results provide useful evidence nonetheless for future research in how accelerated heart rates may be associated with certain desirable gaze behaviors. This knowledge may inspire the development of subsequent refinement of the visual features and functionalities of the HeartRunner 2.0 App and beyond.

Figure 5 shows the correlations between heart rates and the average saccade lengths. In particular, those participants who achieved higher heart rates exhibited smaller saccade lengths ($r = -0.511$, $p > 0.05$). This result is in contrary with the participant group who achieved lower heart rates, whereby longer saccade lengths were found ($r = 0.444$, $p > 0.05$). In other words, those individuals who generated higher heart rates searched for visual cues that were relatively close to one another, suggesting a more consistent and controlled interaction. This is further amplified by the standard deviations (StDev) found in each participant group. As shown in Figure 6, a positive correlation ($r = 0.345$, $p > 0.05$) was found for the *below median* participant group, whereas a negative correlation ($r = -0.273$, $p > 0.05$) was found for the *above median* participant group. This result indicates that those individuals who achieved higher heart rates during the given physical activity exhibited less dispersed fixation points, suggesting more focused search behaviors during their interaction with HeartRunner 2.0.

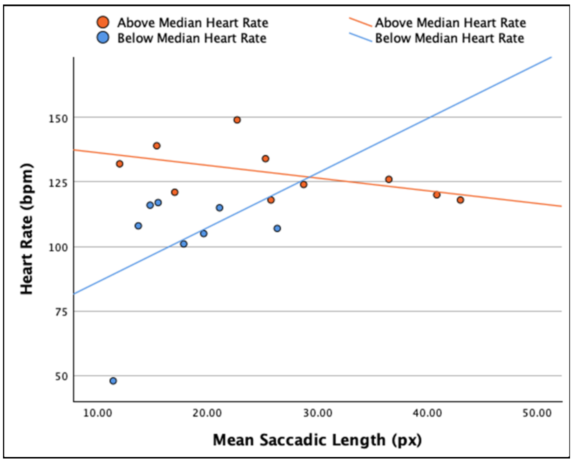

Figure 5: Positive (for the *below median heart rate* group, where r = 0.444, p > 0.05) and negative (for the *above median heart rate* group, where r = -0.511, p > 0.05) correlations between heart rate and average saccade length.

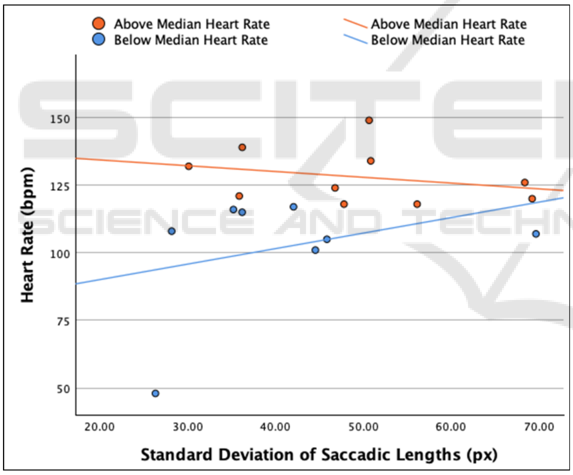

Figure 6: Positive (for the *below median heart rate* group, where r = 0.345, p > 0.05) and negative (for the *above median heart rate* group, where r = -0.273, p > 0.05) correlations between heart rate and the StDev of saccade lengths.

Overall, throughout an entire exercise session, we found that those individuals who achieved higher heart rates also generated longer scanpaths (i.e., the sum of all saccade lengths captured during an interaction), as shown in Figure 7. This correlation was evident in both participant groups with varied degrees (r = 0.261, p > 0.05 for the *above median* group, r = 0.416, p>0.05 for the *below median* group), suggesting an increased engagement with the HeartRunner 2.0 App may have contributed to elevated heart rates during the experiment. Similarly, we found positive correlations between one's heart rate and the visual area this person searched and processed information (i.e., convex hull area), as shown in Figure 8. This is evident in both participant groups and notably, the correlation found in the *above median* group is shown to be statistically significant (r = 0.633, p < 0.05 for the *above median* group, r = 0.416, p > 0.05 for the *below median* group), showing that the individuals with higher heart rates also scanned a larger area as they interacted with the HeartRunner 2.0 App.

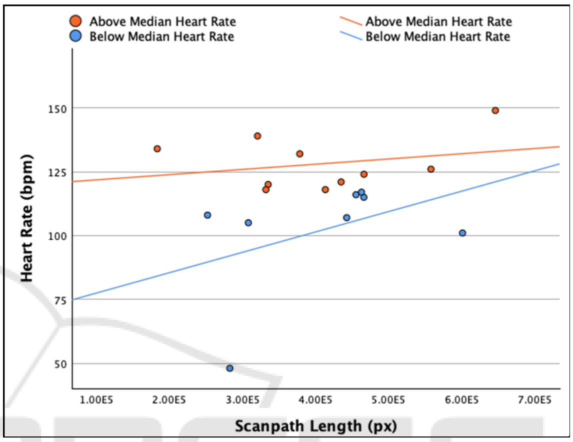

Figure 7: Positive correlations found in both participant groups between heart rate and scanpath length, where r = 0.261 (p > 0.05) in the *above median heart rate* group and r = 0.416 (p > 0.05) in the *below median heart rate* group.

In summary, the experimental results showed that 83.3% of participants with ASD exhibited increased heart rates during their exercise session supported by the HeartRunner 2.0 App, with these participants having an average increase of 12.152 BPM. After the application's music functionality was triggered for the first time per user, 66.6% of these participants were able to maintain heart rates at or above 90 BPM for the entire remaining period of their exercise sessions while another 27.7% of participants stayed mostly at or above 90 BPM with few fluctuations below this benchmark. These results suggest that real-time heart rate visualizations such as those included in the HeartRunner 2.0 App can serve as effective motivating factors for individuals with ASD, providing encouragement for them to exercise for longer durations and in higher intensities. Furthermore, the findings from analyzing participants' eye movements indicate that those individuals who achieved higher heart rates have exhibited gaze behaviors resembling a pattern of more focused visual search (smaller saccade lengths), less distributed points of interest (lower StDev of saccade lengths), and greater efforts in scanning various cues in the given visual scene (longer scanpaths and larger convex hull areas). This result provides further evidence for the effectiveness of real-time heart rate visualization in the context of technology-assisted exercise and the potential of its future application in other scenarios beyond the experimental conditions shown in this paper.

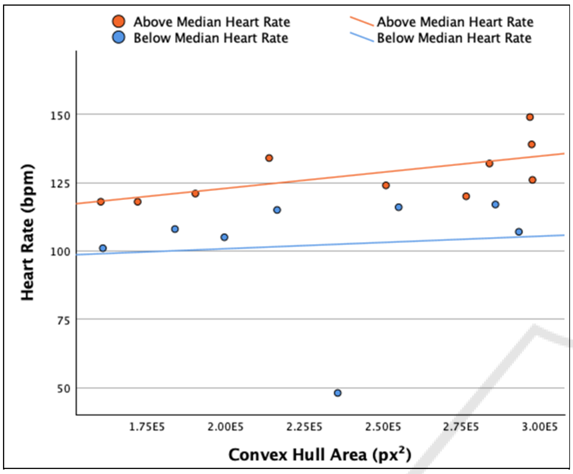

Figure 8: Positive correlations found in both participant groups between heart rate and convex hull area, where r = 0.633 ($p < 0.05$) in the *above median heart rate* group and r = 0.096 ($p > 0.05$) in the *below median heart rate* group.

5 RELATED WORK

A brief overview of related work is presented in this section, more extensive reviews of empirical evidence for the use of exercise as an evidence-based practice for individuals with ASD can be found in (Dillon et al., 2017; Bittner et al., 2018).

In recent years, technology assisted exercise has been shown to have a positive effect on individuals with ASD (Wong et al., 2015), suggesting visual stimulation from the use of technology may increase participation. Technology has been shown to be an effective mean to promote motivation (Takeo et al., 2007), with prior studies demonstrating individuals with ASD are able to engage in more on-task behaviors and may learn physical activity skills at a faster rate than those without technology-aided instruction (Case & Yun, 2015). In another study, the notion of coupling gaming and technology is applied to engage individuals in exercise, as body movements, reactions, and energy expenditure are tracked through participation (Trout & Christie, 2007). This is further investigated in (Anderson-Hanley et al., 2011), where findings have shown significant improvements in attention and working memory and decreases in stereotypical behaviors in individuals with ASD immediately after participating in a 20-minute exergaming intervention.

Motivated by these prior research efforts, this paper aims to extend the existing body of knowledge in technology assisted exercise designed specifically for individuals with ASD by proposing an application that visualizes heart rates in real time to help with comprehension of energy expenditures during physical activity, and to sustain and evaluate exercise intensity. More specifically, informed by prior evaluations of HeartRunner 1.0 (Fu et al., 2020) that supported a multi-user mode for multiple users to compete with one another during an exercise session, we aim to reduce social pressure while promoting effective visual stimuli in HeartRunner 2.0.

6 CONCLUSIONS & FUTURE WORK

This paper presents an application of real-time heart-rate visualization, namely the HeartRunner 2.0 App, which aims to promote engagement and exercise intensity during physical activity for individuals with ASD. The overall goal of the App is to contribute to technology assisted exercises designed specifically for this particular group of individuals who typically lack motivation in exercising, which tends to lead to a cohort of health problems. Through a controlled experiment involving 20 individuals with ASD, we found evidence suggesting the proposed App is effective in helping individuals with ASD to reach higher intensity during exercise and that engagement with the App has likely contributed to elevation in heart rates. However, the findings from this research should be interpreted within the limitations of the experiments conducted. Firstly, it may be argued that music can be a bothersome obstacle for some individuals with ASD, since the experiment shown in this paper was not designed to exclusively measure or quantify the effects of music in such cases, it would be necessary to follow up with additional purposely designed studies to validate potential speculations. Secondly, although the participants who took part in the study shown in this paper were on the ASD spectrum, we did not group these individuals into more refined categories, whereby future experiments with more cultivated user groups may be helpful to further the body of knowledge in this domain. Thirdly, we attempted to collect participant feedback using established usability questionnaires, however, these questions were too difficult for the participants to comprehend, whereby future research could potentially focus on developing more appropriate forms of feedback for individuals with ASD. Furthermore, some variables were not controlled, such as whether the participants had energy drinks before the exercises or collecting heart rate histories of the participants as baselines to compare against the values collected in our study, where future research may potentially investigate.

Nonetheless, the study shown in this paper provides a basis for utilizing real-time heart rate visualization and music to benefit individuals with ASD in technology assisted exercise, future work could collect data from larger sample sizes to analyze in between-subject experiments. In addition, usability studies can be integrated to assess the specific visual components that may be deemed more usable and effective to this particular user group. Furthermore, additional use cases and application scenarios may be investigated to determine the effectiveness of the HeartRunner 2.0 App. Lastly, while the focus of the experiment shown in this paper emphasizes on the evaluation of whether higher intensity can be achieved while supported the HeartRunner 2.0 App, future experiments may investigate whether participants supported by the App would exercise for longer durations than those who did not.

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