InteractiBall: a Portable Device to Facilitate Slow, Intentional Movements to Reduce Stress

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Figure 1: The InteractiBall. Figure (a) shows concept art of the InteractiBall in use, while (b) shows a prototype of the device.

ABSTRACT

We have developed a handheld, portable stress reduction device, termed InteractiBall, which employs slow movements as a means of reducing stress levels in individuals. The InteractiBall utilizes a stress-ball-like squeezing motion in order to afford intentional slow movements by changing colour depending on the rate at which it is squeezed. Integrating effective stress reduction practices into daily routines can pose a challenge, as they typically require dedicated time and space. Research shows that slow movements such as deep breathing, stretching, and meditation are effective in reducing stress levels, but the feasibility of incorporating these practices on a small scale can be limited. For example, yoga is a practice which is proven to decrease stress levels through slow movements, but it is not possible to perform such movements on a small scale such as discretely while sitting at a desk. The device also aims to afford persistent use through the integration of a mobile app, since it is very common for people to struggle in making stress-relieving techniques become part of their daily routines. We recorded an average per-use decrease in heart rate of 9 BPM from participants in our study after using our device.

CCS CONCEPTS

• **Human-centered computing → Interaction design**; • **Hardware → Tactile and hand-based interfaces**;

KEYWORDS

tangible interaction, calm technologies, slow movements, stress reduction

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1 INTRODUCTION

Stress reduction and its importance. Due to the pressures and fast pace of the 21st century, almost everyone has experienced stress in day-to-day life. As such, there is a pressing need for effective stress relief methods which are effective, convenient and easily integrated into daily routines.

Impossibility of slow movement in daily routines. Slow movement, particularly exercise or whole body movements like walking or yoga, has been widely regarded in literature as an effective way of reducing stress [34] [33]. However, this approach is not often feasible in office spaces or high-stress environments where individuals may be confined to a sedentary position for prolonged periods. We propose to examine the potential benefits of localising slow movement to hand movements and coupling it with intentional slow breathing techniques to alleviate stress and anxiety. The issue of affording persistent use is also often overlooked in stress reduction methods; we highlight the importance of considering behaviour change research to encourage the prolonged practice of stress relief methods.

Device overview. The InteractiBall is an innovative handheld device designed for the purpose of stress reduction. After identifying the successes and shortcomings of existing methods and technologies through literature reviews and conducting our own studies, we aimed to combine the effectiveness of slow, intentional movements with a handheld device convenient and discrete enough to be used in everyday scenarios. We henceforth introduce the problem space, the research context, and motivate the innovations of our own device.

To use the device, it must be squeezed by the user in a motion similar to that of a stress ball. This choice was made since it allows for the combination of existing research into squeeze motions for relieving tension (outlined in section 2.3), with intentional slow movements (described in section 2.2), both of which are shown to be effective techniques. Sensors in the device monitor this squeezing motion, which sends a continuous signal to the processor. Real-time feedback is constantly given to the user in coloured light form so that the user can adapt their squeezing motion to ensure they are doing slow, intentional movements which they can use to guide their breathing.

Methodology and contribution. This paper discusses the wide research context of stress relief methods and devices and motivates the avenues for development within these contexts with respect to shortcomings of existing work. Section 2 presents research into the problem space in general, including the efficacy of slow movements and breathing techniques. We also give a review of existing research into squeezing motions for relieving stress, and HCI research surrounding best practices in behaviour change. We also give evaluations of related work in section 3, after which we gained insight into user preferences and experiences on both a granular and general level through conducting questionnaires and focus groups in section 4. We then present the development of our device to solve the problem identified, with implementation details given and evaluation studies carried out. These studies showed that the device is effective in both reducing stress and promoting positive behavioural change. Overall, our device contributes a unique and effective approach to reducing stress and promoting well-being on a day-to-day scale.

Research context and innovation. The innovation of the InteractiBall stems from the real-time feedback which guides the user through the best slow-movement practice. While related works such as those outlined in sections 2.5 and 2.6 show promising results in the field of stress-reduction devices, the unique contribution of our device lies in its integration of both convenience as a handheld device and the provision of real-time feedback to the user, a feature that is currently absent in many existing devices. Existing literature predominantly describes devices which measure a user's stress levels and show this to the user, for example, the StressEraser [23] which integrates a display with a pulse oximeter. We propose that it is not necessary for a stress-relieving device to conduct any form of measurement for stress level indication, as our research showed that individuals are fully aware of their levels of stress and would not find it helpful to be told this as a quantitative metric. Other examples of handheld devices in literature lack any form of feedback at all, which is where the motivation for the InteractiBall stems. Other existing works with similar physical devices involving sensing stress balls are designed for rehabilitation or monitoring hand dexterity [16] [14]; the InteractiBall is set apart from these as it is built for the bespoke purpose of facilitating stress-relieving techniques.

2 RESEARCH CONTEXT OF STRESS

2.1 Effects of stress

In modern society, stress is one of the most pervasive issues faced by individuals; the Mental Health Foundation quote a stark statistic that in 2018, 74% of people felt so stressed that they were overwhelmed or unable to cope [4]. The effects of this are documented to extend into stress-related disorders, with 51% and 61% of adults who felt stressed reporting feeling depressed and anxious respectively. As well as the obvious psychological effects of stress on an individual, prolonged high levels of stress can also influence an individual's physical well-being, most notably including the nervous system, the cardiovascular system, and neurological functions [27] [25] [18]. As such, there is a wealth of research dedicated to documenting the effects of stress on physical well-being, which further motivates the need for finding effective methods to alleviate stress. Innovative solutions to combat stress are essential in tackling this growing issue and promoting healthier lifestyles.

2.2 Slow movement and breathing techniques

Countless studies demonstrate the effectiveness of yoga, specifically the aspect of slow movements, in the reduction of stress levels [29] [21]. When the body responds to stress, the hormone cortisol is released by the adrenal gland; because of this, it is often colloquially referred to as the "stress hormone". Cortisol is involved in physiological processes such as heart function, metabolism, and reduction of blood sugar levels, all of which play a role in preparing the body for a "fight or flight" response when a person experiences a stressful situation [13]. Prolonged exposure to stress can lead to consistent increases in cortisol levels, which motivates the need for regulating cortisol levels as a key factor in stress management[36]. An open-labeled study conducted by Thirthalli et al. [34] found that a three month yoga intervention was associated with significant reductions in the perceived stress of participants along with their cortisol levels, in comparison with a control group. Another study conducted by Sullivan et al. (2017) found salivary cortisol levels of participants to significantly decrease after even a single session of yoga [33], showing that slow movements have the ability to take measurable effect on granular scales as well as over periods of months.

The physical poses and slow movements between such postures involved in yoga practice are also shown to stimulate the parasympathetic nervous system, which leads to a response of relaxation and decreased levels of stress hormones [19]. Stabilisation of the autonomic nervous system tending towards parasympathetic dominance in this way is paramount to the long-term reduction of stress. Moreover, research has suggested that yoga may also increase the activity of the vagus nerve, which plays a key role in the regulation of several bodily processes, including digestion, heart rate, and breathing [9]. The stabilizing effects of yoga on the autonomic nervous system can therefore contribute to overall health and well-being.

Research consistently demonstrates that interventions which focus on breathing patterns effectively reduce stress levels. For example, a paper surrounding the effects of slow-deep breathing exercises to reduce anxiety in schoolchildren [30] found there was a considerable decrease in students' anxiety levels after completing 30 minutes of slow deep breathing every day for 45 days. By bringing one's attention to the breath, a greater sense of situational awareness can be achieved which in turn encourages a sense of mindfulness. For this reason, we have created our device in a way which encourages users to turn their attention to their breathing patterns.

2.3 Squeezing motions for stress relief

Stress balls are seen as a beneficial tool that helps reduce stress levels as "they alleviate the physical experience of intense emotions" [7]. Stress balls possess a range of potential applications, however, they are predominantly designed and marketed to alleviate stress and anxiety. The action of squeezing and focusing one's attention on an object helps alleviate stress as the mind focuses on the movement rather than the users' stress [39]. Stress balls help people with high levels of stress by externalising their emotions. "Stress and anxiety is a state of activation, and the person often feels like they need to do something to relieve that tension" [39].

There is a limited amount of research surrounding the efficacy of stress balls with regard to reducing stress in work environments. For example, Alvarez et al. conducted a study surrounding the effectiveness of stress balls and found insignificant results [5] with respect to the reduction of participants' heart rates. However, this paper also evaluated their method of inducing stress in participants to be ineffective, which may have been a cause of these insignificant results.

On the other hand, some studies have investigated the impact of stress balls on individuals' stress levels with noteworthy findings suggesting significant reductions in stress. For instance, Srivarsan et al. (2021) [31] examined the influence of stress balls on university students, reporting a significant decrease in participants' stress levels. However, it is worth noting that the research's methodology relied on self-report questionnaires, which may not provide a comprehensive representation of actual stress levels due to a lack of measured quantitative results.

Stress balls have also garnered attention in medical research, as evidenced by a study conducted by Kasar et al.[17], which investigated the effect of stress balls on mitigating stress among hemodialysis patients. The study revealed a noteworthy decrease in stress levels among patients who used the stress balls in comparison to the control group. This is further supported by the study conducted by Hudson et al.[15] which found that using a stress ball (amongst other distraction-based interventions) reduces a patient's stress when used during conscious surgery. This is again supported by Genc et al.[12] who, in a study surrounding transrectal prostate biopsy patients, found that the use of a stress ball during their procedure decreased patients' physiological responses to stress, including levels of pain, blood pressure, and heart rate.

In another medical study, however, stress balls were found to be ineffective at reducing stress on surgery in skin cancer patients[38].

Another study finds that stress balls have a useful secondary purpose as they are also helpful in retaining focus, especially after consistent use, as shown by Stalvey & Brasell [32].

Stress balls are a cheap and effective stress relief strategy, however, there is room for improvement. If we are able to encourage consistent use of the stress balls, this may lead to it being a more effective counter-measure for stress. This follows from the evidence that users who consistently use the stress balls in Stalvey & Brasell's study had a greater improvement in concentration than the participants who were not as consistent. We hypothesise that this could also be the case for stress relief.

2.4 Behaviour change

One of our aims with this project is to tackle the problem of users struggling to perform stress-reduction practices for sustained lengths of time long enough to allow long-term improvements to emerge. We, therefore, seek to develop a stress ball that can effectively promote and maintain user engagement over a prolonged period. This goal hinges on the ability to influence behaviour change in a user, which is a prevalent area of human-computer interaction (HCI) research.

Research into behaviour change has increasingly become an area of focus in designing technologies aimed at promoting healthy behaviours. Studies in this area often highlight the importance of addressing both psychological and motivational factors to encourage sustained use of interactive devices. Prost et al. present a system design framework shown in figure 2 aiming to encourage context-aware, personalised, and persuasive behaviour change support systems [26]. They stress the importance of adjusting the so-called support system to how each individual user might be motivated. Thus, it is crucial to consider such techniques when designing our stress ball to promote long-term use and, ultimately, effective stress management.

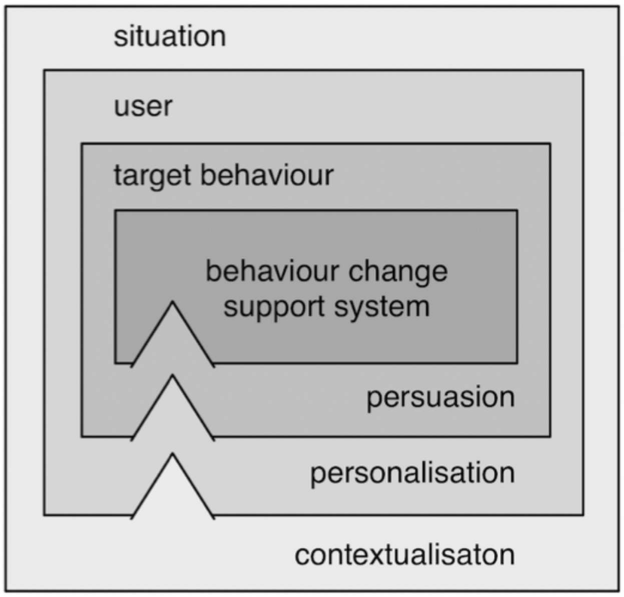


Figure 2: System design framework for behaviour change. Figure taken directly from Prost et al. [26]. Desired user behaviour is motivated by strategies of persuasion, which should be personalised for each user and also to the wider context of the situation.

Literature in the field of cognitive psychology offers concrete definitions of encouragement and motivation [37], both of which are possible methods of persuasion (to address the second-most inner section of figure 2). Moving away from such concrete definitions, motivation is discussed to a great extent within self-determination theory (SDT). In such literature, autonomous motivation denotes the intrinsic drive to engage in activities as a result of interest, valuation, and volition, as highlighted by Ryan & Deci [10]. An individual is deemed autonomous when they willingly engage in their actions without the overwhelming influence of external pressures. Combining these widely accepted concepts of SDT with the framework proposed in figure 2, it is clear that methods of influencing the continued use of our interactive device must not only be personalised and consider wider contexts but should also encourage an individual's autonomy and intrinsic motivations. Therefore, it could be beneficial to allow users to set their own goals for sustained use of the device rather than enforcing strict guidelines, which would not only influence a sense of autonomy but would allow users to set goals which take their daily routines and levels of free time into account.

3 RELATED WORK

3.1 Slow breathing devices

Here we outline some of the most prevalent existing devices which encourage slow breathing for stress reduction. While these devices can be effective in reducing stress in the short term, they fall short in addressing the issues of long-term engagement and behaviour change that our project aims to tackle.

(a) (b) (c)

Figure 3: Existing slow-breathing devices. Figures (a) (b) and (c) respectively depict the Melo [1], the Shift [2], and Balanced [35].

The Shift [2] is marketed as a breathing device to help reduce stress and anxiety, which claims to be developed by psychotherapists. Alongside the aim of stress reduction, the creators of the shift state that the device is able to increase focus, help the user achieve better sleep, and lower the user's heart rate. This is achieved through the user taking a long, deep breath in through the nose and exhaling through the handheld device, which is shaped similarly to a disposable vape as seen in figure 3(b). The focus of this device is very much pinpointed to slowing down exhalation in order to encourage deep breaths; the Shift device solely focuses on regulating the user's breathing rate, without providing any feedback or means of encouraging sustained use.

Melo [1] is a breathing and meditation handheld device also aimed at lowering levels of stress and anxiety on a per-use scale. While the shift attempts to provide a physical limitation on the regulation of breathing rate, Melo uses the expanding and contracting of light rings together with subtle vibration pulses to guide the user through breathing exercises. The interaction is customised through the three modes of beginner, intermediate and advanced; the device was developed with user-friendliness as a focus to ensure that the controls are intuitive and the design is simple, such that users are able to benefit from the device irrespective of their skill level with meditation and breathing exercises. This encourages the sustained use of the device, since such user-centric design follows the criteria set out in human-computer interaction literature which stresses the importance of users feeling a sense of competence when using the device. The haptic feedback and visual cues produced by the device are purely output-based, and as such are not dependent on any input from the user to the device; the Melo acts only as a breathing guide and does not respond to any kind of touch or squeezing motions from the user.

Van Der Lugt et al. (2019) propose Balanced [35], a device aimed at measuring and encouraging slow breathing in day-to-day situations. The authors discuss the role of smart garments for stress reduction, with the aim to combine body movement with encouraging slow breathing. Balanced utilises the embroidery of conductive yarn into clothing as seen in figure 3(c), which uses vibrations to guide the user's hands over their thighs and inhale or exhale depending on this positioning. The device has a major constraint of the requirement to be ingrained into an item of clothing, making it very difficult for everyday use since this would require implementing the device in every item of clothing owned by the user. Furthermore, the action the user undertakes is arguably more obvious than interactions with a handheld device, which might discourage users from performing the required movements in office or school environments.

Many stress-reduction tools which provide real-time feedback have a clinical, serious appearance, which has the potential to detract from their mainstream appeal and limit their potential for widespread adoption. For example, the Stress Eraser[24], which is a handheld device that measures the user's heart rate and provides some analysis on this in order to guide breathing. This device is an aid for deep breathing exercises whereby looking at the display, you are told when to inhale and exhale, and in turn, this is meant to alleviate stress. As the device aids breathing, it can also help with sleep quality in users. A study [11] has shown that the Stress Eraser significantly improved sleep quality compared to a no-treatment control group. Along with those that want to improve their sleep quality, those that suffer from insomnia may benefit from the device as well. The big downside of the Stress Eraser is its price point. At $399, this is not an accessible device for society in general, so while it might help reduce stress levels, users will not have any experience with the device.

In contrast, a stress-reducing device which offers a friendly, non-clinical appearance may have greater potential for effectively combating stress, potentially increasing the likelihood of sustained use and overall effectiveness, and as such we have designed our device with these considerations in mind.

3.2 Interactive fidgets

The Squegg [3] is a stress ball which connects to a mobile app to allow users to improve their grip strength and track their progress. The creators market the device as a tool for improving hand strength, but also strongly note that it also provides benefits in terms of stress reduction. One potential issue with this is the lack of real-time guidance provided; our research has shown that individuals are more likely to benefit from a device which specifically encourages slow movement and breathing techniques which are shown to relieve stress levels effectively. While the physical act of squeezing the Squegg may provide a temporary distraction, it does not compare to the potential longer-term effects of the tailored squeeze interactions we propose.

Other stress balls in literature utilise other forms of sensory feedback to combat stress. For example, Aroma Cue [22] releases scents which are associated with relaxation and positive memories as an approach to reducing stress levels. Studies show the effectiveness of scent-based interventions, for example, it has been proven that exposure to lavender scent resulted in a significant decrease in cortisol levels [6]. The aroma stress ball fails to address the need for a device which can be used in day-to-day scenarios, however, since there are many high-pressured environments individuals might find themselves in where releasing scents would not be appropriate, such as in an office or on public transport.

While each of these existing approaches can be useful in certain scenarios, there does not currently exist an interactive device which both guides the user through the most effective slow-movement practices while providing feedback discrete enough to be used in any situation. The lack of a device fulfilling these requirements creates a gap in the market for a new interactive device that can provide users with guidance and feedback for effective stress reduction practices, irrespective of their environment or situation. Additionally, there is a research opportunity to explore how the design of an interactive device that effectively integrates into everyday life could influence behaviour change and promote long-term use for stress reduction.

3.3 Stress balls for rehabilitation

There are also stress balls that exist as rehabilitation and physical therapy aids for upper-limb rehabilitation. Since physical therapy is a long process and inaccessible to many, these devices allow users to recover at home.

The RehaBall[16] provides a gamified form of physical therapy, where the user can play a 3D car game through interaction with an oval-shaped stress ball. Users interact with the stress ball by squeezing and holding it at specific angles, which controls the movement of their car avatar, and they receive haptic feedback in the form of vibration. There is also an aspect of adaptability, where if the user's hand condition is bad, the speed of the game is reduced, and when their hand condition is improving, the speed is increased to become more challenging for them.

Another rehabilitation ball is displayed by Hsiao et al.[14], where they present a game called "Throw & Catch" guiding proper arm-swinging movement through the use of an "encouraging sound" when completed correctly.

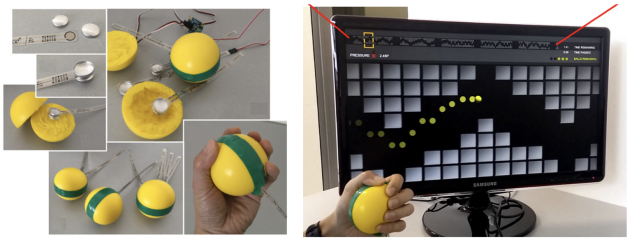
3.4 Squeeze interactions

This section examines existing technologies which utilize the action of squeezing as a means of interaction. A review of the strengths and limitations of existing technologies can help to identify potential design solutions for the interaction aspect of our device and evaluate their effectiveness in addressing our specific needs and goals.

Lee et al. (2016) discuss in great depth design possibilities for squeezable interactions [20], focusing on the eventual interaction implications of using novel squeeze interactions and how the utilisation of such actions can lead to different application possibilities. The authors also document the construction of a prototype shown in figure 4(a), which is a squeezable ball providing a means of continuous input to be used as a game controller as shown in figure 4(b). Technologies used in this design proved useful in influencing the design of our own device.

4 PRELIMINARY STUDIES

Prior to beginning the design phase of the device, we conducted two studies to generate user-centric data to gain an understanding of how best to address the device's objectives effectively. Through insights into how users currently tackle stress on a day-to-day basis, we sought to ensure that the resulting device would be tailored to the user's needs and offer a satisfying experience which would sustain over long periods of time. This user-centric design approach is consistent with best practices in human-computer interaction research and emphasizes the importance of understanding user



(a) (b)

Figure 4: Squeeze-ball prototype. Figure (a) depicts the creation process of the device, while (b) shows the device in use to provide continuous input for a game. Figures taken from Lee et al. [20].

needs and preferences to produce an effective product through minimising researcher bias.

4.1 Questionnaire

Objective. To establish a foundation for our research, we sought to gather a comprehensive understanding of the levels of stress experienced by university students. Hence, we designed a structured questionnaire consisting of questions pertaining to aspects of stress including its causes, manifestations, and typical coping mechanisms. The questionnaire was designed to elicit quantitative data to facilitate analysis and identification of patterns and trends in stress levels among university students. The use of a structured questionnaire ensured that our data collection process was standardized and replicable, allowing for greater accuracy and reliability in our analysis of the data.

Initial questionnaire findings. After giving their consent to be a part of our study, respondents were asked to rate their frequency of experiencing stress or anxiety on a scale of 1 to 10, 1 being not stressed and 10 being extremely stressed. Following this, respondents were queried about their awareness of anxiety or stress-reducing techniques and were asked to enumerate such techniques, if any. Subsequently, respondents were questioned regarding their utilization of stress-reducing devices and techniques to alleviate anxiety or stress. We received 18 responses. The average answer for how stressed or anxious participants were was 6 out of 10. Breathing was the most common answer in regard to what anxiety/stress-reducing techniques exist. Our first questionnaire did not gather data on our participants, which is something we wanted to rectify in our second questionnaire.

Follow-up questionnaire findings. Our second questionnaire once again gathered consent from our participants, but this time asked about their age group, their gender and occupation. We received 20 responses where 85% are full-time students who are aged between 18 to 25 years of age and received a perfect balance of male and female participants.

Follow-up questionnaire results. The questions regarding stress-reducing devices and techniques were kept the same, however, this time we included a section focusing on the impact of their phones and their environments on their stress levels, whether they believed slow movements or aggressive and/or exerting actions would be more helpful, whether a slow breathing device would aid

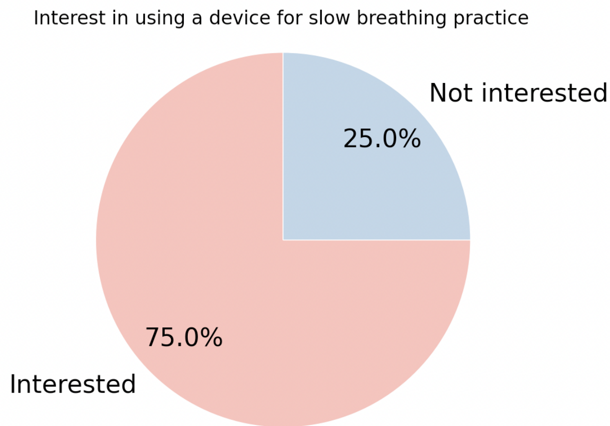


Figure 5: Chart illustrating if participants find a breathing device helpful. Figure created from questionnaire answers illustrating whether participants reported that they would find benefit in a breathing device to help control breathing

with their stress, and if it would be useful to have a device they could use in public to help reduce their stress. All the participants agreed that their environment affects their stress levels and that taking a step back and slowing down would calm them down when stressed. 75% of the participants answered that having a breathing device that helps your breathing would be helpful. 85% agreed that it would be useful to have a discrete way of reducing your stress in public.
Once again, these answers supported our reasoning for creating our product, showing that university students are interested in ways to reduce their stress levels in a discrete manner.

4.2 Focus groups

Objective. During the design phase, we aimed to identify features and elements which would prove most effective in facilitating stress reduction through a handheld interactive device. To achieve this objective, we employed a mixed-methods approach incorporating both group and individual interviews.

Participants. We gathered 15 participants, all engineering students at the University of Bristol, and divided them into smaller focus groups of varying sizes, with our smallest group being an individual, and our largest being 4 participants. We opted for focus groups of different sizes because we wanted to create varying levels of influence among participants. We realised that a larger group may foster more creativity but could also lead to 'groupthink' and very similar ideas, while a smaller group may offer more individual contributions but potentially limit the diversity of their ideas.

Within our set of participants, we talked to a mixture of both masters and bachelors students, and one PhD student. However, this group was slightly less diverse in other areas, in particular gender, as we interviewed fourteen males and only one female.

Methodology. Participants were encouraged to engage in brainstorming sessions where they were asked to draw their "ideal" stress-relief device so that ideas and practices could be discussed.

We performed this process before giving any information about our current design process, such that ideas would be uninfluenced and non-biased towards our approach. This allowed participants to showcase not only what their current methods for stress relief are but encouraged conversations surrounding how each method achieved the goals or fell short. Such discussions encompassed a range of topics, including but not limited to: commonplace stress-reducing movements, the comparative effectiveness of distractions versus direct coping mechanisms, and the potential benefits of slow breathing or movements in reducing stress.

Results. One of the biggest takeaways from the study was that 94% of participants preferred distraction-based stress reduction over specific coping mechanisms. Additionally, since 9 out of the total 11 participants designed devices which included tactile elements tailored for relieving tension, our design process was guided into considering the integration of such elements into our handheld device. These results identified the need to ensure that the tactile element of our device was satisfying and comforting to use in order to enhance its effectiveness in affording persistent use. Three of the participants' designs involved some form of harsh motion, for example, one participant proposed a soft hammer which could be hit on a table to relieve tension in the user. These designs were always met with appreciation by other participants in the group, which showed us that many people find that relieving tension with harsh physical movements can be effective for stress relief. Due to the gender skew towards male participants in our study, further research must be done to draw conclusions as to whether this finding extends to the general population. However, we deem the results significant enough that we decided to design our device to withstand excessive degrees of force.

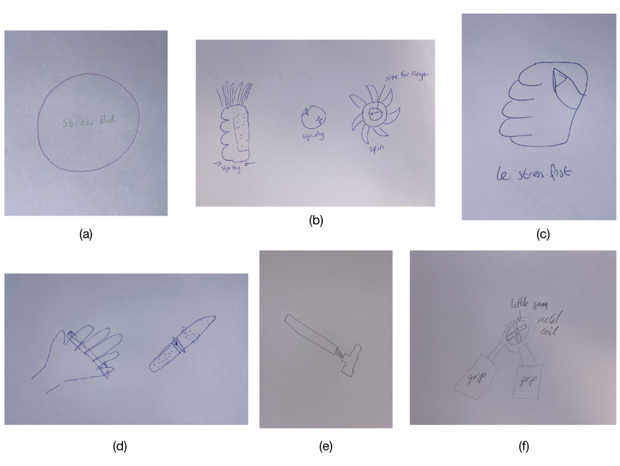


Figure 6: Drawings by focus group participants. Figure (a) is a stress ball. Figure (b) shows 3 different ideas for reducing stress. Figure (c) is inspired by the stress ball but in fist form. Figure (d) is something you stretch to reduce stress. Figure (e) is inspired but the fidget spinner.

4.3 Study summary

Overall, participants were insightful into what type of device was best suited to their type of stress e.g. every day stress rather than specific stress. The results from the questionnaire were well linked to our research and helped confirm our hypotheses about stress levels among university students. The results from the focus groups helped us come up with our initial idea, and aided us to think of features we had not thought of while doing our initial brainstorming sessions. Every focus group was asked if they would use a device to encourage slow movement, and participants said that they would be keen to use our proposed device as long as it is portable and silent, so they'd be able to use it in the library and to avoid sensory overload with too much feedback from the device. The focus groups also helped us realize that something tactile could be more helpful as visual feedback might be more distracting, and gentle tactile feedback might allow users to keep doing their tasks while using the device to calm them down.

5 DEVICE IMPLEMENTATION

To reiterate, the aim of our device is to decrease stress in an individual by facilitating intentional slow movements and breathing regulation. The prototype we produced to accompany this paper was developed as a proof-of-concept, to be used in an evaluative user study.

The key functionality which we sought to capture in the prototype was to have a squeezable device which uses a rate-of-change pressure sensor to react when the user squeezes the device too quickly, in the form of visual cues.

5.1 Device hardware

For the sensing aspect of the device, we present a purpose-built pressure sensor which is small and robust enough to fit inside a squeezable structure. Figure 7 shows a flowchart of the development stages of this pressure sensor. Within this flow chart, figure (a) depicts a flat 3D printed structure, onto which two pieces of copper tape connected with copper wire are soldered. Figures (b) and (c) respectively depict the pressure sensor wrapped in velostat and conductive foam, which serve the purpose of giving the device its squeezable nature.

The resistance of velostat and conductive foam decreases when a force is applied, meaning they can be used as a force-sensitive resistor (FSR). The velostat alone did not vary resistance enough to calculate an accurate and reliable rate of change, motivating the use of both velostat and conductive foam. We connected this bespoke FSR to a 10k pull-down resistor to construct a potential divider and linked this output voltage to one of the Arduino's analogue input pins.

For the casing of the device, we made a 3D-printed container as a first iteration (see Figure 8). The problem with this case was that it had limited squeezing potential because only one side had conductive foam. It was also uncomfortable to hold because it was not ergonomic. The design also did not take into account that women's hands are on average smaller than men's, therefore, it was not accessible to some people. We ended up creating a 3D-printed panel (see Figure 9) which we assembled the electronics around. This was advantageous as it provided a consistent and

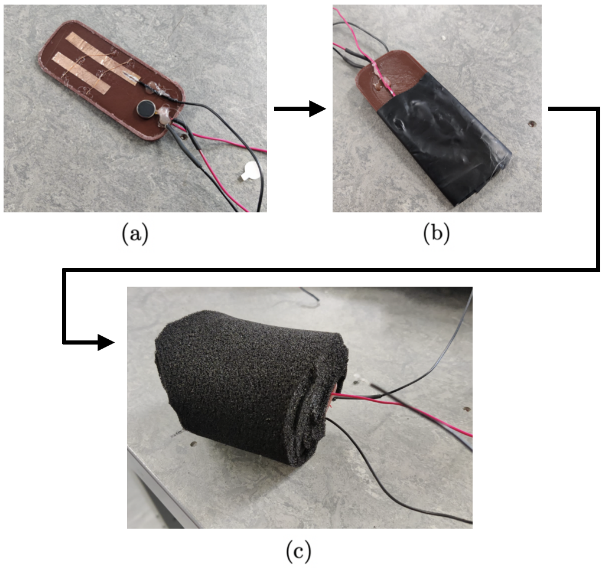


Figure 7: Flow-chart of prototype development stages. Figure (a) shows the purpose-built pressure sensor, while (b) shows the sensor having been wrapped in velostat, and (c) shows the pressure sensor with its squeezable conductive foam casing.

reliable contact with the velostat to help prevent the readings from fluctuating. We made the decision to separate the electronics from the device since it was a prototype and the Arduino is too big and would negatively affect the compressibility of the device. We also did not want to risk damaging the Arduino by squeezing it. The box also helps protect the wires from breaking by using built-in strain reliefs.

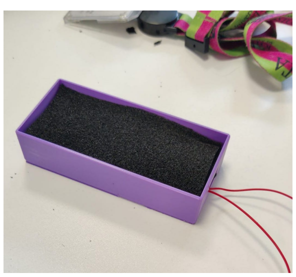


Figure 8: First casing for the circuitry.

Figure 9: Final casing for the circuitry.

The biggest challenge involved in the creation of the prototype was the process of noise reduction in the homemade sensor. Since we needed the prototype to be used in our evaluation study with multiple participants, it was important that the sensor worked to the same extent between participants. Therefore, significant time was put into ensuring that the pressure sensor was able to deal with differences in grip strengths, hand sizes, etc. One hardware improvement which facilitated this was to automatically calibrate the device to each user when they first pick up the device. This was achieved by taking an initial reading of input pressure and comparing subsequent fluctuations in pressure to this initial measure. We did implement thresholds for rest and active states to ease the transitions of the LED, nevertheless, the device still calibrates to each user.

We originally implemented haptic feedback into our device as an input sensor for the user, however, we realized that the vibrations from the haptic motor introduced more noise into the system than we could remove, due to the limitations of using a homemade pressure sensor instead of an off-the-shelf sensor. Upon realizing this, we removed the haptic feedback and only used the LED in our proof-of-concept prototype.

5.2 Device software

The outputs of the pressure sensor seen on the right side of figure 7 (c) are connected to the breadboard containing the circuitry of the device (shown in figure 11), which consists of an Arduino micro, resistors, and a red-green light emitting diode (LED).

The circuitry was programmed such that the rate of change of pressure is continuously calculated, using a buffer which stores the last 6 differences over readings taken 200ms apart and calculates the average. Before these differences were calculated, our readings were passed through our own implementation of a low-pass filter, that uses discrete time sampling. This allows the LED to light up corresponding to whether the user needs to slow down their movements or speed them up in order to adhere to the best slow-movement practice.

To determine the cutoff values for the colour thresholds, we had people squeeze the ball and found a value that works for everyone. This was important as grip strength varies naturally based on many factors such as gender, hand size, etc. We then assigned red the value -1 and green 1. We stored the outputs in a buffer and averaged them to get a definitive result on whether users were squeezing the device too fast or the right amount to further help classify the speed at which they were squeezing. If the final result was greater than 0 the LED would turn green otherwise if it was less than 0 the LED would turn red.

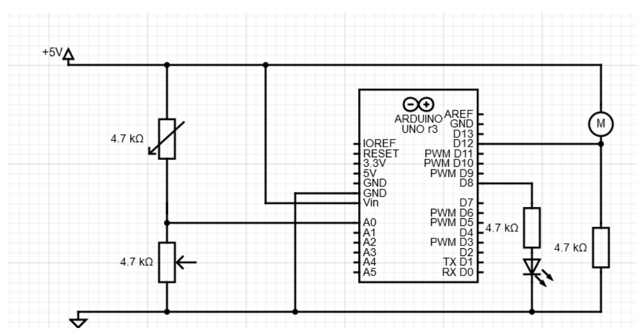


Figure 10: Circuit diagram of the device. This diagram illustrates how the InteractiBall is connected to the LED.

5.3 Previous software iterations

In this section we'll give a brief overview of the design process of the software which we created to control the colour of the LED.

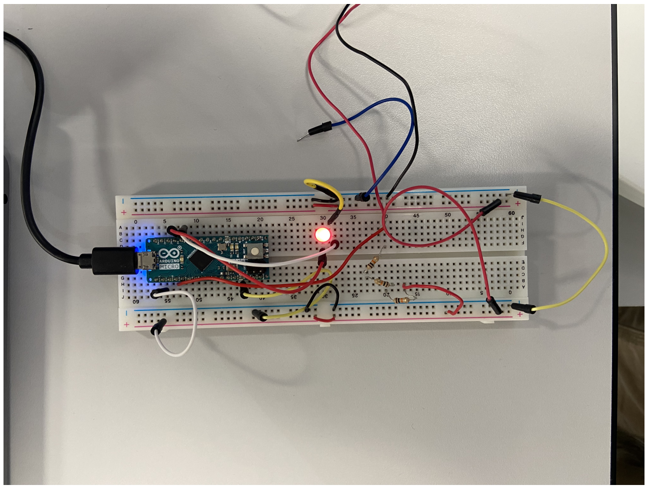


Figure 11: Breadboard connected to the InteractiBall. This circuitry connects the InteractiBall to the LED, which is facilitated by the Arduino seen on the left of the image.

Our initial approach was to take the analogue readings and find the highest and lowest values, and then to map them to the corresponding max/min brightness for the LED. The main problem with this was that the output was related to the force applied rather than how quickly you were applying it. Therefore the user does not have a definitive measure of whether the ball was being squeezed too fast or not which led to our second iteration.

The second iteration simulated a Finite State Machine (FSM). Using the highest and lowest values used in the previous iteration we recorded when the ball was squeezed and returned to the same position. After calculating the time taken, we compared it to the cutoff value for being too fast and set the output accordingly. The problem with this implementation is that it was not adaptable enough to various people. By recording the time taken the device assumed the device was squeezed a certain amount and therefore did not calibrate at all to their natural grip strength. The user's resting position might also trigger the timer if their natural grip strength was strong enough. Further developing this iteration would require adding many more states which would have led to a complex system that would be prone to bugs and accidentally transitioning states due to noise. Additionally, the output would only be provided at the end of each squeeze action which meant the feedback was delayed and therefore harder for the user to implement. This led us to our final solution described in section 5.2 which provided continuous sensing and feedback and was a much simpler and elegant system.

5.4 Device in action

Figure 12 shows the device being used. The prototype uses an external LED in place of the proposed internal lighting of the stress ball, however, it serves the same purpose of reacting to the rate of change of pressure imposed on the device by the user; the LED glows red if the user squeezes and releases the device too quickly and green if slow movement is being done correctly.

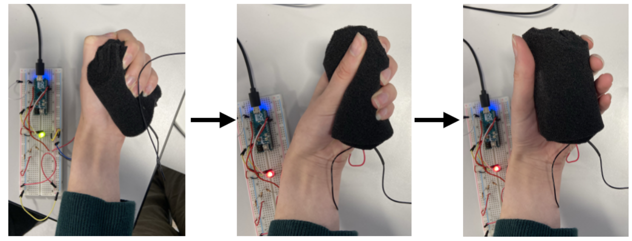
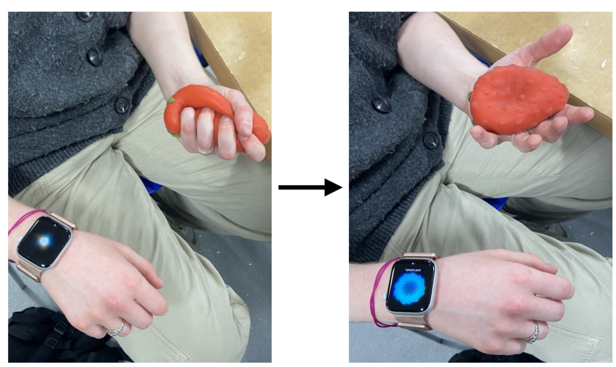


Figure 12: Flow-chart of squeezing the device. In the bottom left, an LED can be seen changing colour as it reacts to the rate of squeezing of the device.

6 EVALUATION STUDY

6.1 User study with imitation of device

Experimental setup. As a way of imitating the use of our device to facilitate a study to record its effectiveness in reducing stress, we used a standard stress ball paired with a smartwatch with a built-in mindful breathing guide. We first measured participants' heart rate and recorded their perceived stress level on a scale of 1 to 10, 1 being not stressed and 10 being extremely stressed, before asking them to squeeze the stress ball in time with the breathing app. This mimics the intended functionality of the InteractiBall, where the breathing app on the watch is in place of the colour-changing feature of the stress ball. After two iterations of the guided breathing practice, we once again recorded participants' heart rates and perceived stress levels. We deliberately did not manipulate the environments the participants were in while they took part in the study to mimic the intended use cases of the InteractiBall; this meant that it was common for participants to be talked to during the study and could have been distracted by external factors.



(a) (b)

Figure 13: Stress ball and breathing app study. Figure (a) shows the participant squeezing the stress ball as the app shows a closed flower. They then slowly open their fist and release the stress ball as the flower opens, as shown in figure (b). They are told to breathe in as the flower opens and they open their hand, and breathe out as the flower closes and they squeeze the ball.

Participants. We conducted the study with seven participants of an equal gender split, all of whom either work or study at university.

Results. Table 1 gives quantitative results gathered from the study. We saw conclusively that the method of guided breathing with the addition of the intentional slow squeezing motion saw a reduction in the stress levels of participants. The average per-use reduction in heart rate of participants was 11 beats per minute.

Participant		(a) Before	(b) After
1	heart rate	151	119
	stress level	8	4
2	heart rate	93	73
	stress level	10	6
3	heart rate	80	72
	stress level	10	6
4	heart rate	100	95
	stress level	3	2
5	heart rate	85	69
	stress level	6	5
6	heart rate	62	67
	stress level	5	5
7	heart rate	87	83
	stress level	2	1

Table 1: Imitation study results. We give heart rates and perceived stress levels of participants before and after using the stress ball mimicking our device.

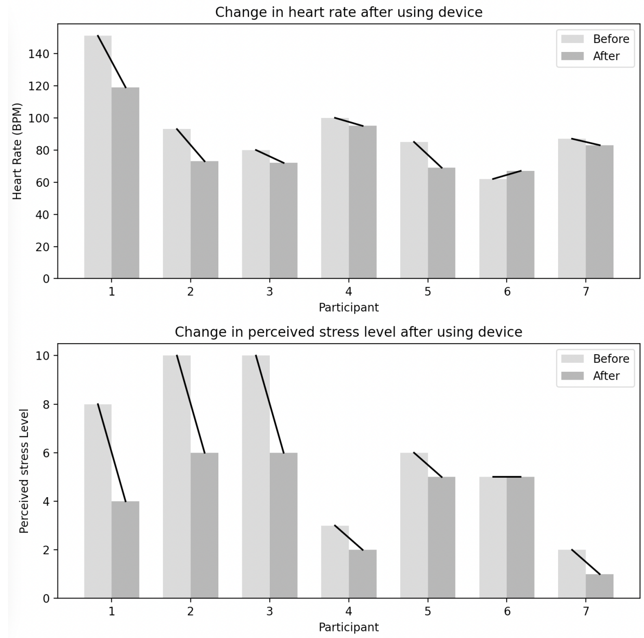


Figure 14: Visual representation of imitation study results. Black lines above bars represent the change in heart rate (top chart) and perceived stress level (bottom chart) before and after using the device. Heart rate is measured in beats per minute (bpm).

Evaluation. In order to determine whether or not there is a significant decrease in heart rate before and after the smartwatch stress ball experiment, we performed a one-tailed paired t-test with a .05 significance level. Our null hypothesis is that there is no significant decrease in heart rate after the experiment. Our alternative hypothesis is that there is a significant decrease in heart rate after the experiment.

With 6 degrees of freedom, our t statistic is 2.47, which corresponds to a p-value of .024. Since we are using a .05 significance level, we have $.024 < .05$, so there is sufficient evidence to reject our null hypothesis. The results of our paired t-test indicate there is a significant decrease in heart rate after completing the experiment. However, it is important to consider that the results may be skewed by a very small sample size, as we only had 7 participants.

Furthermore, it is pertinent to note that all but one of our participants perceived themselves to be less stressed after this experiment, with none feeling more stressed.

6.2 User study with our prototype

Experimental setup. Following suit of the study with the device imitation in section 6.1, we once again measured participants' heart rates and recorded their perceived stress level on a scale of 1 to 10, 1 being not stressed and 10 being extremely stressed, before asking them to use our device for three minutes. This way, our results will be directly comparable to those of the previous study.

Participants. We conducted the study in a busy lab environment at the University of Bristol, with seven participants, all of whom were students. This meant that all participants were likely to be stressed at the beginning of the study, and the environment is representative of the real use cases we imagine for the device.

Results. Table 2 gives quantitative results gathered from the study using the InteractiBall. These results show a general decrease in both the heart rate and perceived stress level of participants after using the device, with an average heart rate decrease of 9 bpm.

Participant		(a) Before	(b) After
1	heart rate	93	85
	stress level	6	3
2	heart rate	80	75
	stress level	6	3
3	heart rate	70	62
	stress level	7	3
4	heart rate	76	65
	stress level	7	6
7	heart rate	77	76
	stress level	4	3
5	heart rate	100	87
	stress level	10	6
6	heart rate	65	66
	stress level	3	3

Table 2: InteractiBall study results. We give heart rates and perceived stress levels of participants before and after using the InteractiBall.

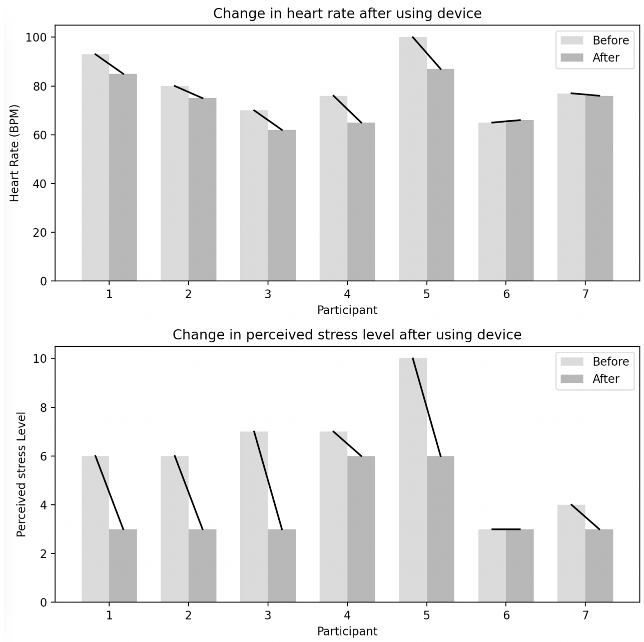


Figure 15: Visual representation of study results. Black lines above bars represent the change in heart rate (top chart) and perceived stress level (bottom chart) before and after using the device. Heart rate is measured in beats per minute (bpm).

Evaluation. In order to measure whether or not there was a significant decrease in our participants' heart rates before and after using our device, we again performed a one-tailed paired t-test with a .05 significance level. Our null hypothesis is that there is no significant decrease in heart rate after using our device. Our alternative hypothesis is that there is a significant decrease in heart rate after using our device.

With 6 degrees of freedom, our t statistic is 3.34, which corresponds to a p-value of .008. Since we are using a .05 significance level, we have $.008 < .05$, so there is sufficient evidence to reject our null hypothesis. The results of this one-tailed paired t-test indicate there is a significant decrease in heart rate after using our device. Again, we need to consider the effect that a small sample size has on this result.

Furthermore, similarly to our mimicked study, all but one of our participants' perceived stress levels were reduced, with no participants' stress levels increasing.

6.3 Concluding remarks

In this section, we will extract the meaning of the results gathered by our user studies. To reiterate, we conducted two studies with the aim of proving the efficacy of our proposed method of stress relief. The first study combined a smartwatch with a standard stress ball to mimic the InteractiBall, while the second used the InteractiBall prototype which we described in section 5. Both studies produced the statistically significant result that a device to encourage slow movement localised to the hand is capable of reducing stress levels. Before we carried out these studies, the research question as to whether localising slow movements to the hand is effective was open. However, our results show that there is the possibility for this method to be effective in reducing stress. This motivates further research to be done in the field of small-scale slow movement, some possible avenues of which we outline subsequently.

7 FUTURE DIRECTIONS

While our studies have shown that the motivations for the InteractiBall have promised to transpire into a device fit for the purpose of day-to-day stress relief, more research needs to be done in order to validate the design choices made and to explore other innovative avenues of development.

High-fidelity prototype. While our prototype showed promising results in user studies, the extent to which the device could facilitate stress relief might have been limited due to the unpolished design of the prototype created. For example, future research and design iterations into refining the tactile feedback of the device to make it as satisfying as possible to use might have measurable impacts on device effectiveness. Having the device be completely self-contained would also aid portability which would facilitate using the device in public settings. To do this we could use a different integrated circuit (IC) and use surface-mount technology (SMT) to create a very small printed circuit board that would fit in the device and would not affect the compressibility.

Ablation studies. In order to further validate the effectiveness of the InteractiBall as a stress relief device, it would be of value to perform ablation studies to gather quantitative evidence of how much difference each element of the device contributes to relieving stress in users. Examples of such studies might include adding haptic feedback to the device, to serve purposes such as guiding the user in terms of timing, or vibrating when the user is going too quickly. Results of each study should be gathered with every other parameter kept the same, allowing for a p-value to be obtained to determine if the addition of haptic feedback would improve user experience with statistical significance.

Adding other forms of feedback. Aside from the addition of haptic feedback, there are other methods of real-time feedback we could consider adding to the device to make it more satisfying to use. In our preliminary studies, many participants stressed the importance of a device being satisfying to use; future work could explore satisfying forms of feedback such as clicks, pops, or pulses, and experiment with other materials which could be more satisfying for a user.

Persistent use study. One aspect of our proposed device which we were not able to evaluate in this paper is its ability to afford prolonged, persistent use. Should the long-term effects of such a stress-reduction device be investigated, multiple prototypes should be created and given to participants over a period of at least two weeks, in order to evaluate whether participants were intrinsically motivated to use the device persistently. We would be able to determine persistent use by having participants download an app synced to our device via Bluetooth. This feature is provided in some

Arduino models. Participants would create an account to monitor their usage of the device and there would be a feature to have reminders to use the device if they are stressed. The app would also tell them when to inhale and when to exhale in order to aid stress relief.

Shape-changing technology. Advances in the field of SCIs (Shape Changing Interfaces) [28] [8] facilitate the potential of creating a device which changes shape when in use to further enhance the user experience of stress-reducing devices. For instance, an inflatable stress ball could be developed which expands and contracts in response to the user's breathing pattern, similar to the InteractiBall's current use of light feedback. This technology could offer a more intuitive and immersive way for users to engage with the device, as well as provide an additional tactile element to the stress-reducing experience. Further research would be needed to assess the feasibility and effectiveness of this approach, as well as explore the design considerations and technical challenges involved in developing such a device.

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A TEAMWORK

With respect to diversity and inclusivity, our team had a varied set of skills and experience that we took advantage of in the development of our project.

When undertaking this project, we organised an in-person meeting twice a week and provided each other with consistent progress reports outside of these meetings using our Teams channel and WhatsApp as our means of communication. These aided in upholding a distributed workload, and asking for help from other members when it was needed. This was especially important, given that we were struggling with being a smaller team, having lost two of our originally six members before the project even started. With respect to equal contribution in group discussion, there was no issue with members not contributing, given that we feel comfortable with each other, having been friends before starting the project.

With respect to taking advantage of our member's skill sets, we assigned roles and tasks relating to these self-identified strengths. For example, one of our members is confident in leadership roles, and so naturally fell into this position. This was useful in giving our meetings structure, and fairly assigning tasks. Another one of our members had previous experience working with Arduino and circuitry, and so took the lead on building the actual device. Other members have confidence in their write-up ability, and so lead the report write-up and the creation of surveys and questionnaires.

We had some initial disagreements on the nature of the project, with a split of members being very enthusiastic about different ideas. However, we compromised on a project we were all happy with.

B VIDEO LINK

https://youtu.be/rF6lSfW1zjE

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