FidgIT

A Digitised Fidget Tool

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A dissertation submitted to the University of Bristol in accordance
with the requirements for award of the degree of
Masters in Computer Science in the Faculty of Engineering.
School of Computer Science
December 2024

Word count: 15871

Executive Summary

This paper presents a new and inclusive digitised fidget tool that collect users fidgeting data, FidgIT. Commercially available fidget tools commonly market towards neurodivergent individuals, and purport benefits that improve concentration, anxiety, and stress. However, research has found that the lack of inclusive designs has limited its effectiveness and appeal. FidgIT has an accompanying mobile application that integrates fun and effective manners on improving anxiety. This platform has an integrated hybrid machine learning model that has the ability to predict users' level of anxiety, allowing for a platform that monitors personal health trends and contextualizes environmental stressors and could empowering individuals to optimize their well-being. FidgIT's contributions to better regulate anxiety are important considering the heightened negative long lasting implications neurodivergent individuals have with anxiety. Therefore, this paper has 2 guiding research questions: **(RQ1): To what extent does a fidget tool influence neurodivergent individual's anxiety levels**; and (RQ2): **How well is a machine learning model able to predict users anxiety levels based on their fidgeting patterns**

The accomplishments of this paper are:

- **Conducted Web Ethnography, Online surveys, In-Person Brainstorming sessions, Think-Aloud protocols** to understand neurodivergent individuals requirements of FidgIT
- Designed and implemented FidgIT's hardware through **circuitry design, iterative 3D printing, and implemented software to record user data**
- **Conducted a Trier Social Stress Test** that concluded that FidgIT had **significant positive impact** in users anxiety
- **Designed and trained a hybrid machine learning model** that achieved **94% accuracy** in predicting users anxiety.
- **Created a mobile application** that employs a diary system, iCBT articles, casual gaming, and integration with my machine learning model

To my darling mother,

sine-qua-non.

Acknowledgements

I would like to take this opportunity to give thanks to my supervisor, Anne Roudaut, who provided such sincere guidance, invaluable advice, and unwavering support. I would like to appreciate all participants who took time out of their day to participate in my studies. Lastly, I would also like to show my utmost gratitude to my parents, who always manages to make me feel their support from miles away.

Author's Declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's Regulations and Code of Practice for Taught Programmes and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author.

Charmaine Suah Jia Shyuan
5 December 2024

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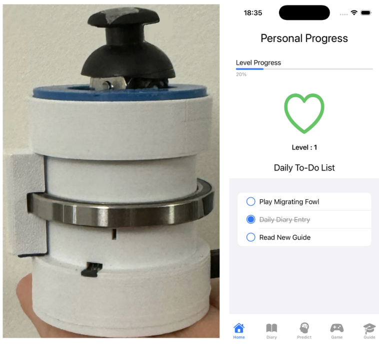


Figure 1.1.: (Left) FidgIT, an interactive fidget that can track user's action and heart rate; (Right) The Fidget app is connected to FidgIT and help end-users to monitor their stress level.

1. Introduction

1.1. Motivations

Fidget tools have gained popularity for their potential benefits, especially among neurodivergent individuals. Studies have highlighted that these tools can aid in improving focus, managing stress, and providing sensory input to users, making them a valuable resource for those with conditions such as ADHD and autism. For example, fidget tools have been shown to increase concentration in children and support emotional regulation, fostering a sense of calm and productivity [23], [24]. This cultural assimilation into everyday use underscores their utility and potential as tools for personal well-being.

However, significant gaps remain in the inclusive design and production of fidget tools. Research suggests that co-design processes involving the targeted user groups promote user-centered designs, address specific problems, and provide valuable contextual feedback [33], [34]. Yet, many commercially available fidget tools marketed to neurodivergent individuals fail to incorporate such inclusive approaches, limiting their effectiveness and appeal [34]. Additionally, contradictory marketing claims create confusion, with some sources emphasizing fidget tools' benefits for concentration while others imply potential distractions for ADHD users [15], [31]. The gap between academic research supporting fidget tools and the practical understanding of their users further highlights an area for improvement [24], [35], [39].

These challenges present opportunities to create more inclusive, effective fidget tools. By integrating accessible technology, such as mobile applications, users can better understand the impacts of their fidget tools in real time. A platform that monitors personal health trends and contextualizes environmental stressors could bridge the gap between research and user experience, empowering individuals to optimize their well-being. This approach can enhance the utility of fidget tools but also align them with the broader trend of personal health monitoring, fostering greater inclusivity and user engagement.

1.2. Aims and Objectives

This project has 3 aims. Firstly, it aims to design and build a fidgeting tool that can help regulate emotional deregulation of neurodivergent individuals. In efforts to better understand and cater to the needs of Neurodivergent individuals, I have used co-design process will to improve inclusion and have a better understanding of how neurodivergent individuals may use the fidget tool. Secondly, it aims to use machine learning models on the real time data collected by the fidget tool to make meaningful contributions by understanding the models ability in predicting users level of anxiety. Thirdly, it aims to bridge the gap between users and the health care providers by providing them an application that can act as a tool to collect trends regarding their mental health, and to introduce fun and helpful ways to reduce anxiety.

To guide the study in achieving its aims and objectives, two research questions has been developed: (RQ1): To what extent does a fidget tool influence neurodivergent individual's anxiety levels; and (RQ2): How well is a machine learning model able to predict users anxiety levels based on their fidgeting patterns

1.3. Deliverables and Method

This study aims to deliver:

- User collected requirements on the fidgeting features and outlook of a fidget tool
- Create and design internal circuitry to digitise the FidgIT features
- Design a new and adaptive casing for FidgIT
- Design and create users studies to evaluate the effectiveness of FidgIT for anxiety
- Design a new hybrid machine learning architecture and train it to predict anxiety levels from labelled fidgeting patterns
- Implement a mobile application as a one stop shop in reducing anxiety

Figure 1.2 illustrates my approach. I started by gathering data from the users and iterating on low-fidelity prototypes. This was done through a web ethnography, online surveys and brainstorming session. I iterated on the prototype, building the circuitry, encasing and associated software. I then proceeded to run a controlled experimentation with end-users to investigate the change in stress level with the use of the prototype. Finally I implemented the application and gathered more data to train the model used in the application. In summary my contributions are the following:

- Implemented a full device, including hardware, software and application
- Run 4 user studies, used in the design phase
- Run one user study to answer RQ1
- Implemented a model to track stress level and evaluated it to answer RQ2.

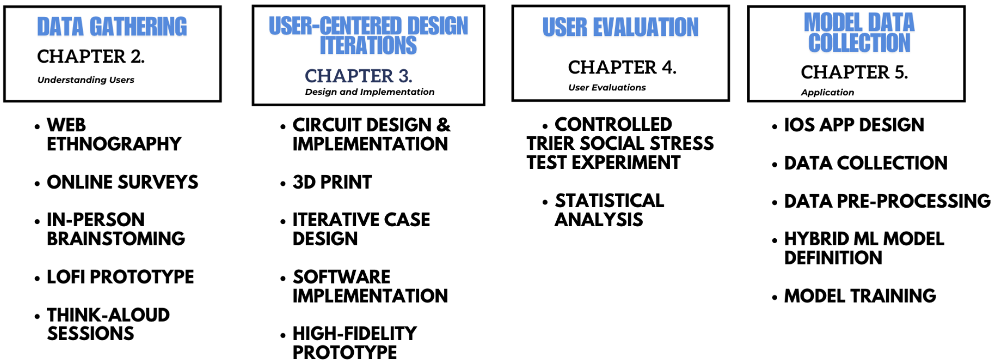


Figure 1.2.: Flowchart detailing the studies and designs delivered in each chapter

1.4. Thesis Layout

This study has 5 chapters including the conventional introduction and conclusion as well as a background section. The core chapters are detailed below.

The chapter **Understanding Users** outlines and describes the different studies used to collect the requirements and feedback from both neurodivergent users and from the internet. I explain the process of Web Ethnography regarding fidget tools from Reddit, and how to narrow down the posts made on the preferred features for a fidget tool. I also illustrate the iterative process of co-designing through surveys and in-person brainstorming sessions to finalise FidgIT design. The final shapes and features for FidgIT is confirmed through the use of lo-fi prototypes and think-aloud session with neurodivergent individuals

In the **Design and Implementation** chapter, I describe the iterative process on how the hardware and software implementations of FidgIT was created. It explains how the design process incorporates collected requirements and highlights the synergy between circuitry components in forming FidgIT. It details the 3D printing process for FidgIT's innovative and adaptive case, focusing on the iterative design approach used to enhance its functionality. Additionally, it outlines how the circuitry was programmed to gather and format data from the fidgeting components effectively.

The **User Evaluations** chapter outlines the methodology and results of the Trier Social Stress Test used to understand if FidgIT played a significant role in users anxiety levels. This chapter seeks to apply statistical analysis on the data collected to illustrate the strength of impact FidgIT has on users and their anxiety levels.

In the **Application** chapter, I illustrate how the hybrid machine learning model was design and implemented for anxiety level predictions, and illustrate key points of each feature on the app. I included a summaries of key features for each anxiety reducing component (i.e. Diary System, iCBT guides, and Casual video games). Similarly, I explain how the fidgeting data was processed and split into training and testing sets for the model, and how the accuracy metric evaluates the model.

1.5. User Walkthrough

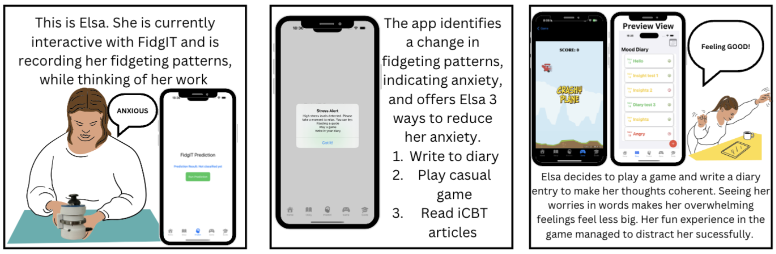


Figure 1.3.: Use case scenario: Anxious Elsa using FidgIT and app.

As a possible use case scenario, Elsa, a neurodivergent university student interacts with FidgIT and uses the app machine learning model prediction function. She anxiously worries about her finals. Resultantly, her fidgeting pattern changes, and the model predicts her pattern to be anxious. As such, the app prompts a notification to Elsa, offering her 3 methods to reduce her anxiety: to write in diary, play casual video game, read iCBT articles. Elsa decides on writing her diary and to play a game. These actions allowed her to be distracted, and reduces her anxiety about school by visualising her worries. Doing these activities increased her in-app point system for Elsa to level up.

2. Background and Context

In this chapter I discuss the current scope of research regarding the increased prevalence of anxiety disorders in neurodivergent groups. Followed by outlining traditional approaches on anxiety management, and how modern alternatives such as fidget tools, technology, and games can be used to further improve the impacts of anxiety.

2.1. Neurodivergence

Neurodivergence refers to differences in neurological functions, commonly associated with conditions such as ADHD and Autism Spectrum Disorder (ASD) [6]. These conditions, influenced by childhood development and genetics [32], affect up to 7 percent of the global population [10]. While neurodivergent traits vary widely, they often include challenges with executive functions, cognition, and communication, impacting daily activities, relationships, education, employment, and self-esteem [6], [10], [40]. However, neurodivergent individuals also exhibit strengths such as pattern recognition, hyperfocus, creativity, and innovative thinking.

2.2. Self-Regulation

One impact of having a different neurological function is the development of Self regulation (SR). SR is a skill that is developed through key developmental milestones that start occurring from childhood, and continues to evolve through adolescence [10], [26]. It involves goal directed behaviour that is adaptable to incoming feedback from their innate self and from the world, allowing flexible response to the changing world. Adhering to this directed behaviour not only allows for the individuals to represent an internalisation of self-control and autonomy, it further promotes behaviour that is typically socially accepted [8]. These SR skills are further developed and mastered during adolescence by controlling one's behaviour, emotions, and thoughts to pursue long-term goals [42]. However, it may be more challenging for neurodivergent individuals to hone these skills due to their different neurological functions, and unique social and emotional milestones they experienced during childhood[8].

A theory suggested by Eisenberg [13], and Bridges[7], suggests that when faced with social difficulties in particular, neurodivergent individuals are more vulnerable to stress and anxiety because of their poor emotional dysregulation. Emotional regulation is a component of self-regulation theory which controls the modulation of emotional responses by applying appropriate strategies[23]. Emotional regulation is essential for managing affect and temperament-based reaction. As such, when a neurodivergent individual has poor self-regulation and in particular poor emotional regulation, in combination with socially difficult or sill-suited environments, they are more likely to feel stress, anxiety, and fatigue compared to their neurotypical peers [12]. Consequently, to soothe their emotional needs in face of such stressful environments, they would react differently to their neurotypical peers [19]. Research by Hoza [20]found that these behaviours tend to be perceived by their neurotypical peers to be "aggressive" in nature, and rule breaking. Resultantly, causes negative stigmas and detrimental effects such as bullying, poorer quality of life, and increased rates of diagnosis with anxiety disorders [42]. For this reason, it underlines the importance of finding better methods to help neurodivergent individuals in regulating their emotions, in turn reducing their externalised behaviours and preventing the stigma and detrimental effects caused by it.

2.3. Anxiety

Neurodivergent individuals have a higher risk of experiencing anxiety disorders as compared to their neurotypical peers. Anxiety is a natural response that allows the individual to understand the risks and harm of their environment and promotes goal achieving behaviours [11]. However, heightened anxiety beyond the natural amounts can have serious impacts on the individual, such as increase in substance abuse, increased rates of depression and worsened mental health [9]. Whilst Anxiety Disorders (AD) are one of the most common mental health conditions among teenagers, with 1 in 12 reporting anxiety, AD the most common psychiatric disorders, with a 25% comorbidity rate between them and Neurodivergent disorders [10], [11], [25]. In a study by Franceli et al [10] theories that it's the combination of poor self-regulation and emotional dysregulations with pervasive social challenges and daily stressors, contributes to co-occurring mood and anxiety disorder. Considering the prominence of ADs in the neurodivergent population, it is important to understand how their manifestation of anxiety might differ to their neurotypical peers. For example in Lai's [26] research, they illustrated how an autistic individual's emotional and cognitive styles may complicate their experiences and their externalisation of anxiety. Theorising that the alexithymia(i.e. difficulty in identifying, understanding, and describing emotions) and their interoception (i.e. ability to sense the body's internal emotional and physical state) differences to their neurotypical peers might make it more difficult to to identify, describe and convey anxiety-related feelings. Furthermore, an individual's intellectual and communication differences may also modify the expression of anxiety-related feelings[9], [26]. Lai [26] identified that common manifestations of anxiety could be interpreted and perceived by neurotypical peers to be limited verbal expression, mental withdrawal from the stressor, seemingly disruptive behaviour, avoiding crowds or social encounters, and increased sensory-seeking and repetitiveness as coping mechanism.

2.4. Fidgeting

Fidgeting is the act of repetitive motion made from some part of the body, recently commercialised into the act of play with a fidget tool. Fidget tools popularity skyrocketed in the early 2010s [12], [41]. Defined as a tool meant for sensory play [41], there are many different types of fidget tools that concentrate on different fidgeting patterns, such as the Fidget Spinner or the Fidget Cube. Fidgeting tools can be derived from many different materials and shapes and can be found in everyday objects that are not necessarily specified for fidgeting [24]. Many toy companies have monopolised on the demand of neurodivergent population and their rising representation, with many toy companies marketing and promoting their toys to parents as concentration aids, calming aids, anxiety aids and self-regulation tools [24], [44]. Furthermore, with the rising trend of social media, recordings of these fidget tools highlighting its soothing and addictive features further increased the popularity amongst children and adults, leading many parents to believe in its purported benefits despite limited evidence of its benefits then. Despite its marketing targeted towards the neurodivergent population, studies by Motti [33], [34] shines the spot light in the lack of inclusive design processed used in creating of these fidget tools. Their research further emphasise that the need for co-designing principles, that is the inclusion of neurodivergent individuals throughout the designing process is needed for increased inclusivity and understanding on how fidget tools can help neuro-diverse individuals.

There are two main theories attempting to explain why fidget tools have been so widely accepted and used. First theory is by Scheter [41], they elucidate that physical activity, albeit small movements such as fidgeting, releases dopamine and norepinephrine. Dopamine is a neurotransmitter and a type of hormone which is associated with pleasure and satisfaction. It plays a role in regulating mood and can be addictive. Whereas norepinephrine helps regulate arousal, attention, cognitive function, and stress reactions. Moreover, a study by Persia [39] points out that the chemicals produced from the fidgeting provides an enjoyable and subconsciously addictive feature that caused its acceptance in the population. Conversely, theory by DiNocera [12], proposes that fidgeting is subconsciously used as a distraction when the individual is placed under high mental loads. In their research, they found that participants were using fidgeting as a tactic to reduce the mental load from the environment they were placed in, and used these tactics to take a ‘mental break’ - allowing for a heap, smooth, nonintrusive method to take the stress off. This theory relates to the self-regulation and emotional dysregulation perspective, giving a plausible explanation as to why neurodivergent individuals in a highly stressful situation or an ill-suited environment that may be anxiety inducing, may take to fidgeting as a coping mechanism to help regulate their emotions.

2.5. Treatments

Cognitive behavioural therapy (CBT) is the first option of treatment prescribed to neurodivergent individuals for AD. Whilst fidgeting may be an accepted coping mechanism for neurodivergent individuals with AD, psychologists and psychiatrists often prescribe CBT as the first line of treatment for anxiety. This is because of the negative long lasting impacts anxiety medication has on the body [46]. CBT is a cognitive and behaviour hybrid therapy that emphasises on changing the way individuals think and behave. Ways of making CBT more effective and accessible has been extensively studied [22].

One popular branch of CBT is Internet-based CBT (iCBT)[18]. It is the process of conducting CBT on a mobile or computer. Users will be able to choose the modules in this modular based syllabus, decide on the number of and the timings of professional check ins [37]. The process of empowerment created from personal choices in their treatment has been found to have special significance to users as they are given opportunities to influence their treatment and adapt it to their needs [4]. Research has also found that when users of iCBT realises that their own preferences are taken into consideration of their treatment, the effectiveness of CBT increases, treatment completion, and clinical outcomes [29], [43] . The rise of popularity of iCBT accredits the increased use of technology in our daily lives. Similar to other real time in-person health monitoring mobile applications (APP), the availability of technology that records biometric health data and analyses it in real time, and the low entry points of costs and effort to gain accessibility through a smart phone has increased its popularity [30]. Hence, with these affordances given by smart mobiles and apps, it increases the opportunity for some individuals to some form of treatment for their AD, directly addressing the long wait list that causes many individuals to fail to seek treatment.

2.6. Video Game Treatments

To further engage younger users, iCBT in forms of serious game and casual video games has been found to be effective. Considering the growing number of youths experiencing anxiety and the deterrence of receiving treatment due to their social, economic, or logistical reasons, many researchers are concentrating on finding naturalistic approaches of iCBT- specifically in video games. In the United Kingdom, considering that video games are the most popular entertainment outlet, projected video game players will increase to 51.88 million by 2025[14], [45].More importantly, Wilkinson [45] notes that particularly for youths, play is part of their natural behaviour. Hence, by interacting with therapeutic activity through a naturalistic and playful platform, it may offer young people a more comfortable method of receiving support for their mental well being. Research found that therapeutic games (TGs), also known as serious games with Rational Emotive Behaviour therapy (REBT) components, a specific type of CBT, was effectively reducing symptoms of anxiety [1], [5], [21]. REBT emphasises specifically on identifying and reducing irrational beliefs, whilst strengthening rational beliefs [14]. More specifically it views negative emotions to have the ability to be adaptive or maladaptive depending on the individual's underlying beliefs and their concomitant action tendencies [14]. Therefore, when TG uses REBT directly targets the theoretical antecedents of mental health issues[25]. However, when faced with an obviously manipulated storyline in TGs, young users are quick to identify these manipulations are turned off by them and turn to casual video games (CVG) instead [1]. Pine [40] found in their study that whilst CVGs may not have the same theoretical backing as TGs, they were also effective in improving users mood and alleviation of anxiety. CVGs are available through mobile device or social media platforms [28], [40]. Pine categorised CVGs into six categories: casual action games (motor skill), casual puzzle games (logic), idle games (observation), and casual strategy games (strategy) [40]. Pine further highlights that the availability of such variety maximises user choice, autonomy and joy through their ability to choose a game that reflects their mood or interest[38], [40]. Research shows engaging in pleasant activities proves beneficial to those experiencing negative mental health symptoms [28]. Thus, interacting with a CVG simulates an environment that may elevate their mental distress.

2.7. Summary

In summary, while there are research that support the benefits of fidget tools for neurodivergent individuals with anxiety, the lack of co-designing practices might dampen the positive impacts and limit its accessibility. Furthermore, as anxiety is highly prevalent and has long lasting negative impact on neurodivergent individuals, the current research highlights a gap for a tool to bridge these different approaches on managing anxiety. Hence to address the gap, this paper will consolidate these findings by creating a fidget tool that is inclusive in design and has the ability to concurrently collate and sense the user's fidgeting data. In which an accompanying app will have iCBT articles and have casual video games that will further alleviate user's anxiety.

3. Understanding Users

3.1. Overview

This chapter focuses on understanding users through a four-step iterative study process to inform the design of FidgIT.

1. The first step involved a web ethnography, analysing online forums to identify the most desired features of a fidget tool.
2. Building on these insights, an online survey was conducted with 24 neurodivergent participants to further explore user needs. The survey helped narrow down desired features, uncover perceptions of the benefits and physiological impacts of fidget tools, identify key features for a mobile app, and understand factors influencing decision-making.
3. Next, 20 survey participants joined an in-person brainstorming where they used provided materials to create their ideal fidget tool. Observations from their designs and survey findings were then synthesized to finalize features for implementation.
4. Finally, three low-fidelity prototypes were developed to explore different ways of incorporating the identified features. These prototypes were evaluated in a final user study using a think-aloud protocol with 12 participants.

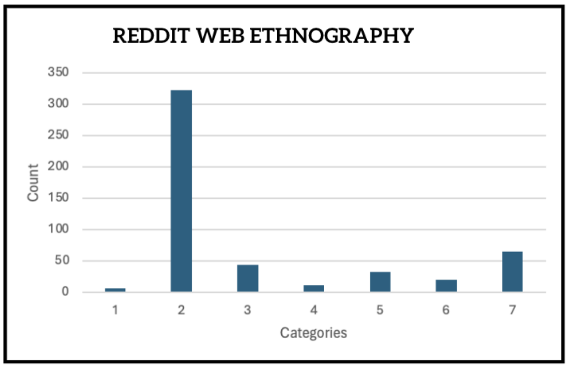
3.2. Web Ethnography

I conducted a web ethnography to identify and group posts that are semantically similar and identify latent topics within the dataset. Fidgeting features identified as most popular will be used as suggestions for users in their requirements of FidgIT.

Data processing: I collected 600 Reddit Posts from the sub-reddit forum "/r Fidgettoys" over the span of two weeks in September 2025. I used Communalytics [16], an online data scraper to collect the reddit posts automatically, and Microsoft Excel to filter and categorise the posts.

Data analysis: Amongst the 600 Reddit posts collected, they were first categorised into overarching categories through identifying common themes within the dataset. After filtering out posts that were looking for Fidget tool recommendations based on the publication of their personal fidgeting styles, these posts were consolidated into a separate list. The most popular fidgeting styles identified were collated on Microsoft Excel and were used as recommendations for the first round of online surveys.

Results: Seven overarching categories were identified, and can be found in Figure 3.1. I found that Category 2, (i.e. Those looking for fidget tools purchase recommendations) were the most popular category. Within the Category 2 posts, I found a common layout that users used to ask for recommendation, users would highlight their own fidgeting styles and ask others for products that address those styles. Hence, through the collation and filtering of these posts, 12 fidgeting styles was identified (as seen from Figure 3.2) and the top five most popular styles were : **Magnetic component, sliders, buttons with tactile responses (clicker buttons), having a squishy component and Spinning components (spinners).**



Categories	Description
1	Question or clarification
2	Looking for recommendations
3	Personal preferences
4	Giving recommendations
5	Seller's promotions
6	Question on purchasing process
7	Review of their purchases

Figure 3.1.: Categories and description of posts identified, and their frequencies

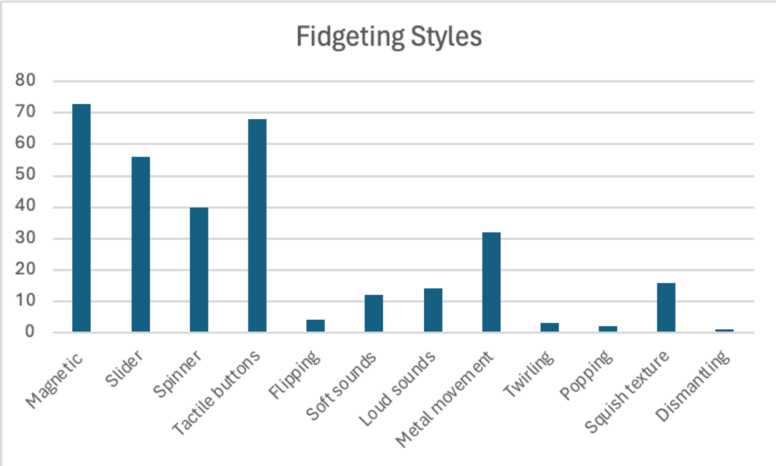


Figure 3.2.: Web Ethnography results: Fidgeting styles identified from Reddit

3.3. Online Surveys

I conducted an online-survey study to look further the feature needed for a fidget tool.

Participants: 24 University students participated in the online surveys. They were recruited through convenience sampling. The mean age of participants was 25 years old.

Materials: Participants were informed of the online survey through an information sheet, and written consent was obtained. An online survey conducted via Outlook Forms, and sought to understand user's comprehension of the purposes and benefits of a fidget tool, illustrate the different factors affecting their purchasing decision for a fidget tool, situations where they seek for a fidget tool, preferred app features for the accompanying app, and the preferred physical features of FidgIT.

Procedure: After collecting the participants' consent forms, they were instructed to follow the link to the online survey on their personal smartphones. It took an average of 4 minutes for participants to complete the survey. Questions to the online survey can be found in Appendix A.

Results: Results from the survey revealed that the top 5 most popular features identified from the survey were clicker buttons, silent buttons, spinners, stretchy components, sliders, and joystick gliders. In addition, participants noted that they are most likely to reach for a fidget tool when they are feeling anxious or stressed, and when it comes to the factors affecting their decision on a fidget tool, its durability and the comfort of the toy comes into play. When the survey asks about digital features that they want implemented into an app, gamification features, in-app notifications, a diary system, and progress tracking were the most popular. Key responses to the survey can be found in Figure 3.3.

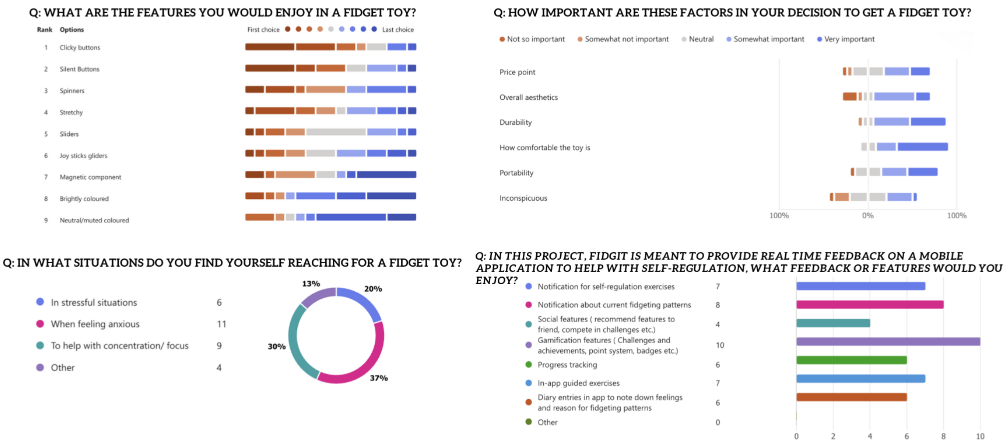


Figure 3.3.: Fidgeting styles identified from Surveys

3.4. In-person Brainstorming

I finally conducted an in-person brainstorming to start ideating and design the shape and features of the fidget tool

Participants: 20 participants who took part in the online survey volunteered to participate in the in-person brainstorming sessions.

Materials: Materials such as clay, popsicle sticks, mini pegs and small wooden sticks were given to create their ideal fidget tool. In addition, to ensure the perception and to understand their creations accurately, they were given pens and a piece of paper to annotate the size, texture, features of the tool they created. Participants were also given opportunities to write notes of their ideal tool if they were unable to recreate them using the materials provided. Participants were given another information sheet and consent form for the brainstorming session.

Procedure: Participants were instructed to create their ideal fidget tool that would match their own fidgeting patterns using the materials provided. They were also instructed to note down key features of their creation or parts of their ideal tool if they were unable to create it physically. Participants did not have a time limit, and took an average of 20 minutes to complete their creation. As part of the debrief, review of the creation and their notes was conducted to ensure accurate understanding. Examples of the participants' creations and their accompanying notes can be found in Appendix A.

Results: Using the written notes of all accompanying creations, the top six features identified (as seen in Figure 3.4) was to have a squishy component, for it to be a palm size tool, joystick gliders, tactile buttons, spinners, and for the tool to be ergonomic.

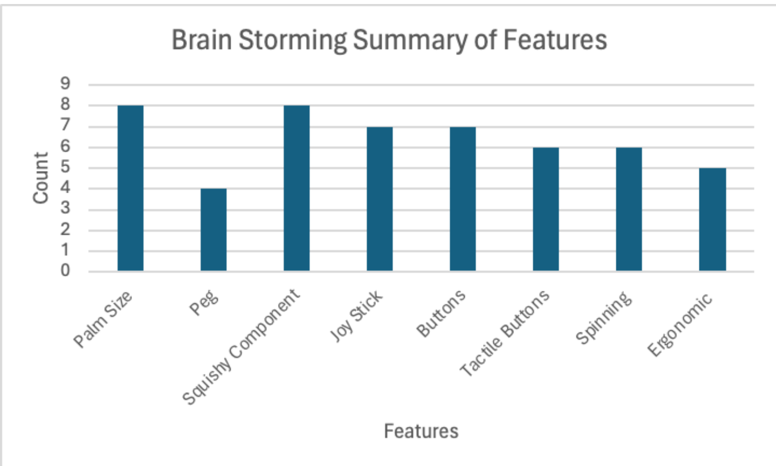


Figure 3.4.: Fidgeting styles identified from Brainstorming Session

3.5. Think-aloud sessions

Following my 3 initial studies, I designed low-fidelity prototypes and conducted a user study to refine the prototype. Notably, as compared to the online survey, there was a discrepancy in the top features identified from the brainstorming. Hence, to have a holistic view on the top five features requested as the basis of the requirements for FidgIT, the top requirements identified from both the survey and the brainstorming session were used. The features identified are: **buttons with tactile responses, a spinning component, a squishy component, joystick, and sliders.** Additionally, considering the physical feel for the tool, I sought to achieve an ergonomic hold to the tool whilst keeping it palm size.

Apparatus: 3 palm sized designs were derived from the implementation of the top five designs and a low fidelity prototype for each design was created using clay and other materials. The overarching shapes of the three designs were inspired by the ideal fidget tools participants created in the brainstorming session.

Design X took the most popular shape from the user creations from the in-person brainstorming session, rectangle (Figure 3.5). The sides of the rectangle are meant to have a distinct fidgeting feature for the participants to use, and the extended surface area also allows for the requirement of an ergonomic hold to be met.

In design Y (Figure 3.5), I tried a different formulation of a rectangular shape that had a wider side. In this design one side of the tool is used for buttons with tactile feedback, and the other for a sliding component. The top of design Y has a sliding feature that flicks open, revealing a spinning component.

Design Z (Figure 3.5) took a different approach with having an overarching circular shape where the top holds a joystick component that can be used to move about and as a clicky button, the base of the tool has a spinning feature and a sliding component on the bottom of the design. Design Z prioritised the ergonomic and size constriction rather than the number of fidgeting features as compared to the other two designs.

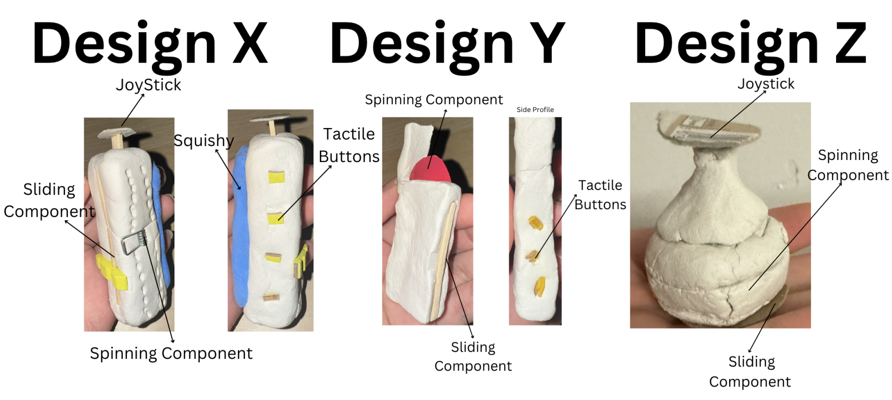


Figure 3.5.: Annotated image of design X, Y & Z low-fidelity prototype

Participants: 12 participants from the original sample who participated in the in-person brainstorming session participated in the think-aloud session. The mean age of participants is 24 years old.

Procedure: Participants could interact with the three low-fidelity prototypes before going around the table to voice out what they liked and didn't know about each of the designs. On average, participants spent 2 minutes voicing out their preferences per design. Preferences about each design were noted down. Once each participant had a chance to think-aloud, the overall shape of FidgIT was decided through a vote. Participants raised their hand in support for the design they preferred. When a final shape was decided, another round of think-aloud was conducted to evaluate the features attached to the lo-fi prototype. Participants were asked to voice out about the current features (i.e. Joystick movement, tactile buttons, spinning feature, and sliding component) in the design but to also include any other features they would like to add or omit.

Results: Main consensus and feedback collected showed that design Z was the most popular, due to the way it holds and the simplicity of the design. Whilst some participants enjoyed the flicking component of design Y, they worry about the stigma and dangers of carrying a design that is like a lighter, further impacting their ability to carry their fidget tools into workplaces, such as schools and their offices. Design X was the second most popular design, however, 8 of the participants felt that whilst the design will have some fidgeting pattern for everyone, that there were too many components for such a small tool and could be overly stimulating for some.

In the second round of the think-aloud session, the majority of participants felt that the joystick with its combination of x-y axis movement and a tactile button was convenient and easy to use, and the spinning portion was a fun implementation. However, many felt that the sliding component would be too distracting and unsafe considering the internal capacity of the tool would be filled with its circuitry. Furthermore, notes were taken that using the bottom portion of the tool would not be the most ergonomic hold for FidgIT. **Hence, the final design derived would only contain 3 different fidgeting patterns (i.e., joystick, tactile button, spinning component) and take on a cylindrical shape**.

3.6. Iterative summary

In summary, the process to achieve the final shape and confirmed feature for FidgIT was accomplished through the the accumulation of iterative studies. Starting with web ethnography which provided the widest possibilities of features and acted as the basis for the online survey questions. Consequently, through the survey and the in-person brainstorming, participant feedback allowed me to narrow down the requirements and inspire my lo-fi designs. These lo-fi prototypes in turn are used as the subjects for my think aloud sessions. During which participants notes will act as the new set of requirements and allow me to adjust my prototypes as required.

4. FidgIT Implementation

4.1. Overview

In this chapter I cover the decision process employed for the creation of both hardware and software implementations of FidgIT based on the findings of the previous chapter. Figure 4.1 illustrate the high-fidelity prototype as my final product.

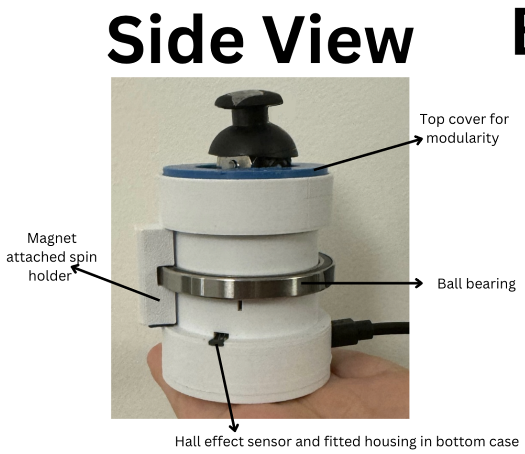


Figure 4.1.: Annotated side and bottom view of FidgIT high fidelity prototype

4.2. Circuit Design and Components

The circuitry of FidgIT needed to balance two roles: to mimic the traditional fidgeting features previously decided on (i.e., a joystick with a tactile button and a spinning component) and to track and record the fidgeting patterns of the users. FidgIT embeds a ESP2866 low cost WiFi micro-controller, and reads data from a Hall effect sensor, joystick (via ADS1115 – a programmable gain amplifier), and a heart rate sensor. Figure 4.2 illustrate the circuit and I describe in the Table 4.1 all the components used.

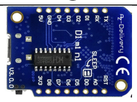
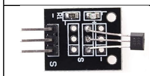
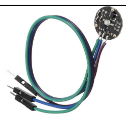
	ESP8266	The ESP8266 is a low-cost WiFI microcontroller that can be used for a wide variety of purposes.It is ideal for this project as it supports both digital and analog I/O. The board has built-in Wi-Fi, which allows for easy data transmission over networks and its ability to wirelessly transmit data to an IOS app increased its suitability. For this project, the ESP8266 reads the different sensor data and outputs it through the serial port to a connected computer for visualisation in Excel using PLX-DAQ and as JSON format.
	Hall Effect Sensor	The Hall effect sensor was selected for its ability to detect magnetic fields and is commonly used for measuring speed, such as the rotational speed of a wheel and other motor shaft. This sensor is ideal because it's response to nearby magnetic fields and provides reliable data every time a magnet passes by the sensor. In this project, a magnet was connected to a ball bearing that passes the hall effect sensor. Each of these pulses are counted to calculate the speed of rotation of the ball bearing component in terms of revolutions per minute.
	Joystick (ADS1115)	The joystick is used to get 2D position data from using two potentiometers for the X and Y axes. Since the ESP8266 only has a single analog input and limited GPIO pins, I used the ADS1115 analog-to-digital converter (ADC). The ADS1115 is a 16-bit ADC with synchronous, multi-controller (I2C) interface that allows reading the joystick's X and Y values as separate inputs, which are then mapped to a range for further processing.
	Heart Rate Sensor	The heart rate sensor measures pulse rate by detecting blood flow changes in the finger or wrist. It outputs an analog signal proportional to the detected pulse, which is read using the analog input pin of the ESP8266. The heart rate data is captured and displayed in real-time using the PLX-DAQ interface.

Table 4.1.: Table depicting the purpose of each internal circuit components

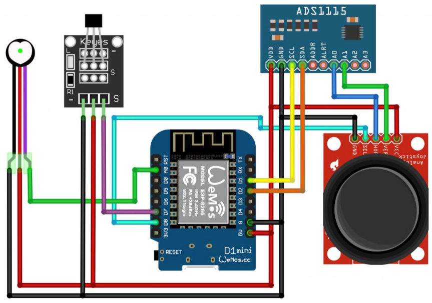


Figure 4.2.: Schematic illustration of FidgIT's internal circuitry

4.3. 3D Printed Case

Based on the findings from the previous chapter, I determined FidgIT's overall shape and the placement of the electronic components. Creating an adaptive 3D-printed case was the most practical approach to meet the specifications. Using a digital caliper, I measured the dimensions of each component and drafted a computer-aided design (CAD) in Shapr3D, a 3D modeling application, to create the casing.

The design is divided into two parts: the top and bottom casings. The top casing houses the joystick module and the hall effect sensor, while the bottom accommodates the microcontroller, amplifier, and heart rate sensor. The heart rate sensor is attached to the microcontroller inside the bottom case but is positioned externally on the bottom cover, connected through a small hole for the wires. The hall effect sensor is exposed on the sides of the top case, where a 3D-printed needle bearing with one magnetic needle interacts with the sensor to create a magnetic pulse. CAD designs are in Appendix B.1.

Considering the tool's playful intention and user requirements (as shown in the survey results 3.3), the design emphasizes durability and sturdiness. The prints are configured to ensure precise shapes and holes for the components, using a 20 per cent infill density with a grid infill pattern in PLA material. This configuration results in each shell being

0.8 x 0.8 mm thick. However, some design flaws emerge during testing, prompting an iterative design process to refine and improve the casing. Annotated versions of the final designs are shown in Figures 4.3, 4.6, 4.5 & 4.4.

4.4. Iterative Case Design

There were 3 difficulties that I had to overcome with the design of FidgIT. *Firstly*, the hall effect sensor was supposed to be embedded in the top casing, however the sensor could not stay in place without a base. I also originally soldered onto the circuitry via a 10k resistor. But parts of the component kept getting caught in the wires thus dislodging it when the buttons were pressed. As such I decided to redesign the internal circuitry to use a hall effect sensor module and decided to embed it into the sides of the bottom casing. In addition, the initial design was to 3D print a custom ball bearing that will be lodged between both the top and bottom casing. The plan was for the ball bearing to have one magnetic ball and the remainder filled with printed custom balls, which should cause a magnetic pulse when the magnetic ball passes the sensor. However, after much advice and research into this approach, I found an error in practice. The magnetic ball would be too far from the hall sensor causing the sensitivity of the pulses to be weak, and having printed balls in a printed ball bearing case showed to have too much friction preventing the free spinning effect as desired. Hence, in the final design, a pre-made ball bearing was used. Despite the ball bearing not having the exact width as desired due to its internal diameter of 45mm, a holder with a magnet was connected to it, allowing for accurate and fast detection of the magnetic pulses every rotation the magnet made. Images of the of the magnet holder is found in Figure 4.3.

Secondly, with the custom ball bearing having a supplementary purpose of holding both cases together had changed, the integrity of the design had to be altered for both parts to stay together securely. The initial design meant for the custom ball bearing to

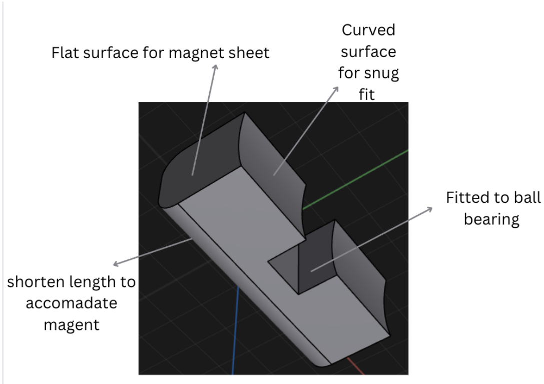


Figure 4.3.: CAD design of the magnet and ball bearing holder

be of the same width of the connecting portion of both cases and was meant to hold both cases together snagged. However, with the new ball bearing size, it was not able to hold both cases together when the device was played with. Hence, I designed 4mm circular joints on the connecting portion (see Figure 4.5), when both pieces clicked into each other, the length of the joint gave enough support for it to be played with.

Lastly, my initial version lacked mounts to secure the circuitry, allowing components to move freely within the casing. This resulted in frequent wiring disconnections and components shifting out of place, which introduced noise during data collection. To address this, the updated design incorporates joints that utilize the existing mounting holes on the microcontroller and hall effect sensor, securely locking these components in place. For the joystick module and its tactile button, it was most suited to be placed on a flat surface, allowing for better control and easier manipulation. I designed a semi-circle base for this purpose, a mount was also added to secure the module in place. This design enable to fit a platform for the button without implicating the wires connected on its side (Figure 4.4 for the joystick base, Figure 4.5 for other mounts).

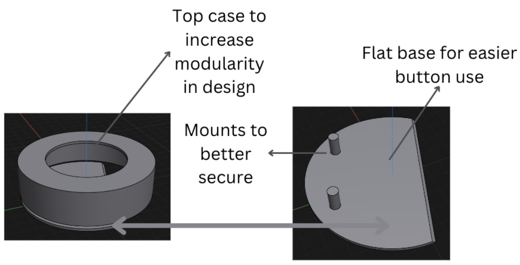


Figure 4.4.: Modular CAD design for the joystick base and cover

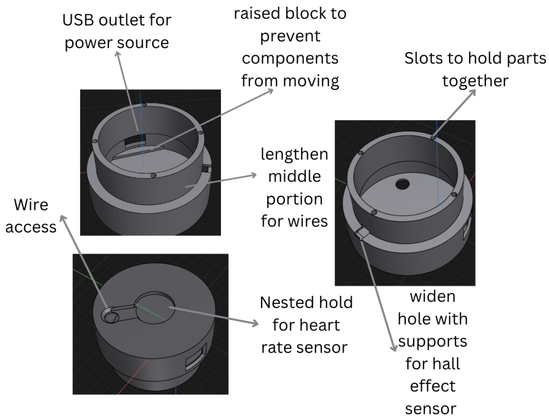


Figure 4.5.: Annotated CAD design of the bottom casing

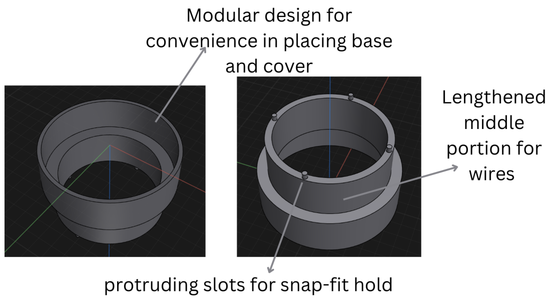


Figure 4.6.: Annotated CAD design of the top casing

Sensor	Initialisation	Recording Logic

Hall Effect Sensor	• GPIO pin 13 = Digital pin 7
	• 4 Variables created to collect
	  ○ hallPulseCount: Magnetic pulse counter
	  ○ intervalHall:Time interval to record speed of rotation
	  ○ previousMillisHall: Previous time recording of speed was updated
	  ○ Interrupt function
		When a magnetic pulse is detected, the code calls for an interrupt to increment the counter.
		At every regular intervals of 1000ms, RPM is calculated based on pulse count, and resets before the next interval
		$\text{RPM} = \frac{\texttt{hallPulseCount} \times 60}{\texttt{intervalHall}}$

Joystick Module	• GPIO pin 12 = Digital pin 6
	• Variables created to collect
	  ○ joystickButtonPressed: state of button
	  ○ joystickButtonCount: counter increments every press
	  ○ currentJoystickX and currentJoystickY: current coordinates of joystick
	  ○ intervalJoystick: time interval for recording
	  ○ previousMillisJoystick: previous time of recording
		The code converts the data received from the ADS1115 from analog to digital signals. Digital signals are mapped to a range of -32768 to 32767 to have a uniform output.
		
		As the button is a digital signal, when the signal goes low, the count increments.

Heart Rate Sensor	• Connected to microcontroller Analog pin 0
	• Employs PulseSensor library
	• Variables created to collect
	  ○ isRecording \& recordingStartTime: ensures that heart rates are only recording if data lasts longer than 2 seconds
	  ○ bpmSum: cumulative beats to make a minute
	  ○ bpmCount: number of recording
	  ○ currentBPM: keeping track of cumulative heart rate during interval
	  ○ IntervalHeartRate: 1000 ms
	  ○ previousMillisHeartRate: time of previous recording
		Using the Pulse Sensor Library method pulseSensor.sawStartOfBeat(), the heart rate sensor will detect heart beats. The real-time heart rate collected is stored temporarily if detection lasts longer than 2 seconds, preventing noise in data. During each recording, if the time of recording is less than a minute, the beat is multiplied to one minute. Once the recording window is over, the beats per minute is stored in currentBpm.

Figure 4.7.: Overview of each sensor's variables and recording logic

4.5. Software Implementation

Figure 4.7 describes the variables created to assist in the recording logic of the Hall effect sensor, Joystick Module, and the Heart rate sensor. The sensor data is exported as a JSON file via a WiFi access point created by the device. This direct connection ensures reliable, wireless communication between FidgIT and its mobile application without requiring external WiFi infrastructure, enabling seamless use of the machine learning model. The setup supports up to 254 devices, each with a unique IP, and directs all communication to the HTTP server on the ESP8266 microcontroller. An HTTP server handles requests within FidgIT's network. It uses defined "routes" to respond to user requests, such as verifying connectivity or retrieving sensor data in JSON format. This structured format simplifies data processing and integration with FidgIT's machine learning model, enhancing functionality and usability.

5. User Evaluation

5.1. Overview

This chapter focuses on the study conducted to address the research question: "To what extent does a fidget tool influence the anxiety levels of neurodivergent individuals?" I employed the Trier Social Stress Test (TSST), a gold-standard method for inducing stress in a controlled setting [3], with nine neurodivergent university students as participants. During the TSST, participants' heart rates were monitored as they interacted with FidgIT. These heart rate measurements were then compared to the participants' heart rates recorded during naturally occurring stressful situations. Statistical analysis of these comparisons provides insight into whether FidgIT can alleviate the physiological effects of stress. Furthermore, the study examined fidgeting behaviors across different stress conditions, highlighting how varying levels of stress influence fidgeting styles and offering deeper understanding of the tool's potential impact.ents can affect our fidgeting styles.

5.2. Method

Participants: A total of 9 neurodivergent university students participated in this study, ages ranging from 22 to 27. Amongst the participants 6 identified as female, 2 identified as male, and 1 as non-binary. The participants were sampled using a self-selection sampling through an invite to the University's Neurodivergent Society. As the TSST was designed to collect paired data, all participants were assigned to the TSST condition.

Trier Social Stress Test: I used the Trier Social Stress Test to induce stress in a controlled environment. The heart rate sensor attached to FidgIT was used to collect the heart rate of the participants. The TSST consists of 2 portions, a 10 minute speaking test and a 5 minute arithmetic test. The speaking test includes an additional 5 minutes preparation time where participants will have to prepare a speech convincing the experimenter they are the ideal candidate for a hypothetical job of their choosing. The arithmetic test requires participants to subtract 17 from 6233 as fast and accurately as they can. Participants are to restart the count from the beginning if they have made a mistake.

Materials: The materials for the TSST included two online survey forms to be completed pre-test and post-test, and were administered on Microsoft Forms. Written information sheets regarding the purpose of the study, the potential harms and the ethical considerations applied, along with consent forms were provided for the participants. During the study, a windows computer with an Arduino IDE with pre-filled code for FidgIT, a PLX-DAQ macro enabled excel sheet, and the attached FidgIT was provided on a table for participants. After the study, a debrief information sheet noting down key information about the truth in data collections as provided for participants.

Procedure: The TSST would take an estimate of 20 minutes to complete, hence each participant had a reporting time of 25 minute intervals. Four days prior to the study, each participant was video called using Outlook Teams, informing them of the study through the information sheet, and to gain consent for their participation. During the call, the participants were also tasked with completing the pre-test survey. Questions within the survey included demographic questions, questions regarding their neurodivergent identities, questions about their anxiety, and the collection of their heart rate during a stressful or anxiety provoking environment. This heart rate collection would be used as the control variable.

On the day of the study, each participant was asked to enter the room and sit across from the experimenter. On the table between them, holds a computer and the attached FidgIT. The experimenter will ensure that the FidgIT is working and start the data collection process before leaving the tool on the table, preventing biases on how to hold the tool. Instructions and the structure of the test then be vocally conveyed to the participant. The experimenter will inform the participants that the start of the prep time has begun and are not allowed any other interactions, they are also not allowed to prompt the participants unless they make a mistake during the arithmetic test; during which experimenters will need to ask participants to restart their count. At the end of the study, participants will attend the debrief which will highlight that the true data collection was of the sensors within the FidgIT and not of their responses to the spoken and arithmetic test. Questions to the pre and post surveys can be found in Appendix A.3

5.3. Results

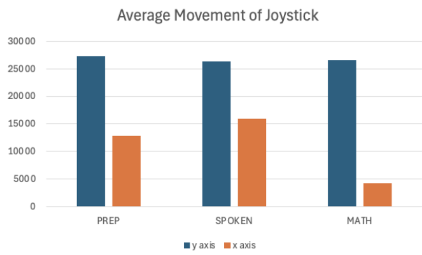
5.3.1. Main Results

I used the Kolmogorov-Smirnov normality test on the heart rate data. Result shows p<0.05 for all participant. Thus the data collected does not follow a normal distribution. I thus used a Wilcoxon Signed Rank Test on the mean heart rates for both conditions in both studies to identify if there were a significant difference. I used a Cohen effect test to compute the effect size.

For the TSST, the mean levels of heart rates of all participants collected pre-test (M= 85.7, SD= 7.14) and during the TSST (M=64.33, SD=15.07) were calculated. The Wilcoxon signed rank test conducted to identify if there were any significant difference in heart rates in a controlled stress environment or a naturally stressful environment revealed that there was a significant difference, $V = 1$, $p = 0.007812$. Given that the *p-value* is less than the conventional levels of 0.05 , indicating that there was a significant difference in the heart rates in both conditions. Referencing Cohen's rule of thumb (1988) [27], effect sizes for the difference in heart rates d= 1.35, indicates a large effect size.

5.3.2. Fidgeting Trends

The mean of each sensor type was also collected to identify trends for each portion of the test. To remove directionality and focus on the magnitude of movement created by both the X and Y axis, the data collected was converted to absolute values before the mean and standard deviation was collected in Figure 5.1. Mean and standard deviations were also calculated for the button and spinning data (shown in Figures 5.2 & 5.3). As seen from the three diagrams created, I found that participants interacted with all three components at a higher rate during the preparations. However, when the speaking and arithmetic portion of the test, the usage of both the spinning component and the buttons reduced, ultimately showing limited spins during the arithmetic portions. Despite the reduction of usage in the two components as mentioned, the joystick movement along the y axis maintained a similar usage throughout the study.

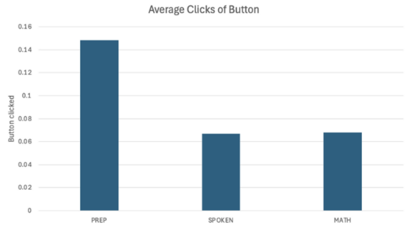


	PREP	SPOKEN	MATH
Y Axis			
Mean	27289.5205	26300.1520	26604.6482
SD	17663.6580	18990.8982	18181.6651
X Axis			
Mean	12872.7882	15908.9056	4287.5714
SD	11914.9811	11913.0824	11139.2134

Figure 5.1.: Graphical trends of **Joystick** Data, and its calculated mean and standard deviation

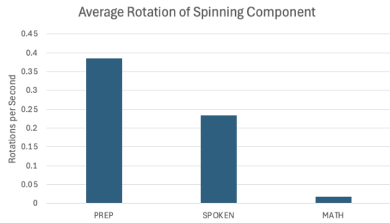
5.4. Discussion

In summary, I found that there was a significant difference in participants heart rates. This means that during stressful or anxious provoking environments, the use of FidgIT would help users regulate their emotions and promote a positive change in their physiological



	PREP	SPOKEN	MATH
Mean	0.1481	0.0667	0.0679
SD	0.3452	0.2501	0.2524

Figure 5.2.: Graphical trends of **Button** Data, and its calculated mean and standard deviation



	PREP	SPOKEN	MATH
MEAN	0.3860	0.2339	0.0185
SD	0.7841	0.6166	0.1752

Figure 5.3.: Graphical trends of **Spinning** Data, and its calculated mean and standard deviation

responses as shown from the decreased mean heart rates. Despite the main difference that the study conducted by Kirby [44] and Persia [39] were on schooling children and the use of fidgeting jewellery respectively. Their study both found significant improvements of anxiety when using fidget tools. This positive change brought by FidgIT is beneficial towards neurodivergent individuals facing daily stressors and stressful environments as it helps in the reduction of their physiological and emotional responses to anxiety. FidgIT provides a form of self-regulation in its sensory and repetitive movement elements which is effective in promoting comfort and relaxation. This aligns with coping mechanisms which are often employed by neurodivergent individuals who are in an anxiety provoking or stressful environment or situations [26]. Therefore, by making full use of FidgIT as a stress management tool, improved emotional self-regulation can be fostered amongst neurodivergent individuals, along with a healthier and more supportive alternative to stress and anxiety management for those in need of it.

Despite the design of my study showing significant improvement for anxiety, a limitation identified is the under utilisation of fidgeting features. Based on the qualitative trends identified from the participant's mean movements on the FidgIT, I identified that the joystick component was the only component that was consistently utilised throughout the three stages of the test. A theory that might explain the under utilisation of its other components could be due to the effort needed to operate. As the spinning component protrudes from the body of the FidgIT, proper hand placement is needed for it to spin and track where the holder for the spinner might be to continue to spin it. Furthermore, despite the button of the joystick to have good tactile feedback, it produces a relatively loud sound. These impacts could have been distracting to the users during the spoken and arithmetic tests which needed participants to concentrate on their thoughts to convey their ideas and the correct answers accurately in a stressful environment.

6. Application

6.1. Overview

This chapter begins by detailing how various features—such as a Diary System, iCBT-guided articles, casual gaming, a gamification system, and a prediction service powered by the FidgIT machine learning model—are integrated into a multi-functional app designed to reduce anxiety while meeting user requirements.

It then addresses the second research question: “How effectively can a machine learning model predict users’ anxiety levels based on their fidgeting patterns?” The chapter outlines the collection and processing of longitudinal data, the development of a binary decision machine learning model using a hybrid architecture combining Long Short-Term Memory (LSTM) layers and Convolutional Neural Network (CNN) layers, and the conversion of the model into iOS Core ML format for integration into FidgIT’s companion app, FidgIT Mobile. Initial application layout plans are included in Figure 6.1.

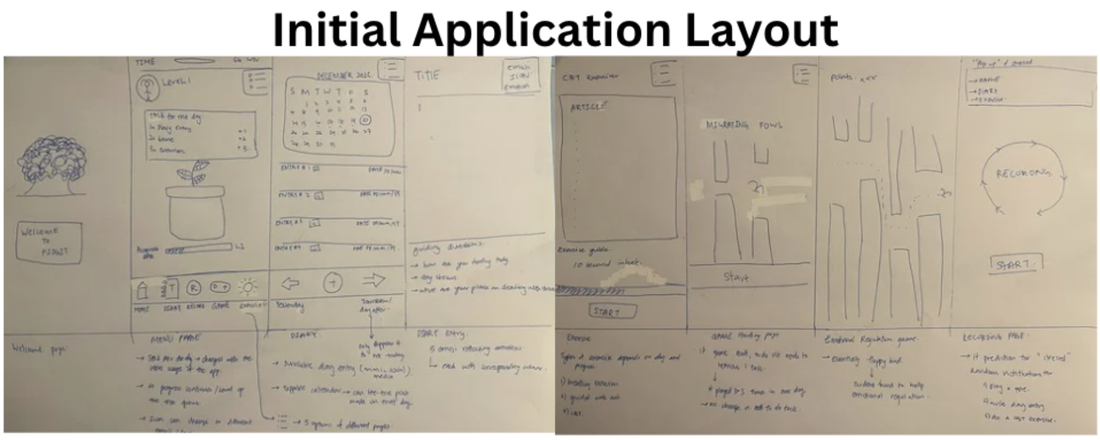


Figure 6.1.: Initial mobile application layout plans

6.2. IOS App Implementation

Diary System The diary system consists of a property list store to keep track of each entry, an interface for users to write their thoughts down and choose an emoticon that reflects how they feel. These entries are matched to their date of creation in an in-app calendar that shows a monthly overview (see Figure 6.2 for pages relevant to Diary System) [1]. As requested to be a feature through the requirement survey described in Chapter. 2 Designing FidgIT. Each entry has 3 possible emoticons attached to it, a text box, and an identifying string and is operated through the addMoodView. When an entry is successfully added by clicking on the "Add to diary" button, it will be stored to the MoodModelController store for persistent storage of the entry. Similarly, because of persistent storage and unique identifying string, users are easily able to edit and update their entries or delete their entries through the overarching preview page containing all the past entries. Each emoticon has an associating colour (i.e. happy = green, neutral = grey, unhappy = red) which is stored in each entry. This feature allows for the entries to be colour coordinated and provide convenient identification of trends when shown from the diary preview page. Furthermore, the calendar view also has the ability to show each entry's emoticon. The calendar view was custom designed to combine the format of the date, week, and days. The custom view was implemented to allow for the emoticon of the first entry of the day to be shown under their corresponding dates, allowing for a monthly overview of emotions. These features allow for users to easily identify the trends of their emotions and how they are feeling, and can be used as a tool to show their healthcare providers the trends in their emotions.

[1] An open source implementation of a mood diary was modified to fit the specification of this project, created by Nelglez [36]

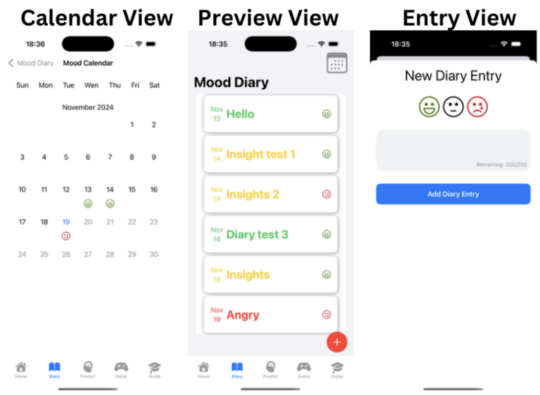


Figure 6.2.: Simulator pages of Calendar View, Diary Previews & Diary Entry view

iCBT Insights To provide users with an iCBT component, CBT articles on helping anxiety are found in the guide tab, along with a separate insights component for users to write their reflections regarding the content. Similar to the diary component, the insights are saved in the same persistent store and have a similar lay out. All insights entries are colour coded as yellow. These insights can be written from within the link to the articles or from the preview page of the available articles. Insight entries can be re-read and edited similar to the diary. However, a pull-to-refresh button has to be completed by users to update the entries to show. This is because of the lack of a separate database used to store these entries, and an action was needed to retrieve the entry previews from the stores.

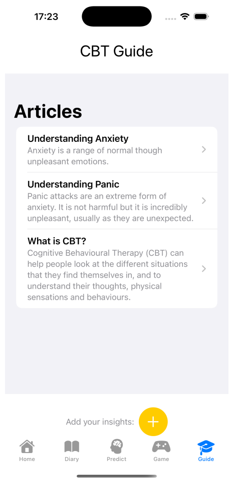


Figure 6.3.: Simulator view of iCBT article previews

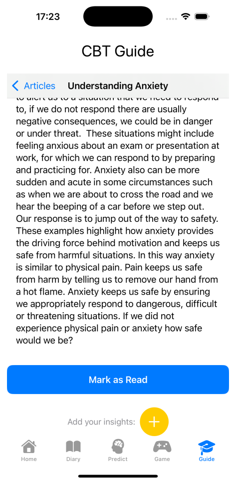


Figure 6.4.: Simulator view of the details within the iCBT articles

Casual Gaming The game flying plane, inspired by " Flappy Bird" , was implemented as a casual video game to help lower users' anxiety levels. As identified by Pallavicini [38], their study found that Flappy Bird was successful in lowering user anxiety levels in users with Generalised Anxiety Disorder. As such, using the format of the game, Flying Plane was created to emulate the same effects [2]. The main character of the game is a plane that flies through obstacles, users are expected to tap on the plane to help navigate through the mountains.

The physics behind each character such as movements, gravity, and collision were implemented using Apple's SpriteKit, a framework meant for 2 dimensional game technology animations. By creating the bird to be an SKPhysicsBody , and the boolean method affectedByGravity I was able to set that the bird would be at a free falling state unless the user taps the screen, during which the method isDynamic was used to defy gravity and fly upwards. Similarly, as the SpriteKit has methods for detecting collision

[2] An open source tutorial on implementing a 'flappy bird' game was followed, and was created by HackWithSwift project 36 [17]

between two physicObjects, I casted each mountain to be an object and detected it for collision. When they collide , the game would stop and only re-play when users tap on the restart button.

Gamification System A gamification system where users gain points to level up each time they complete a task was used to engage users and encourage interactions with the different features of the app. A daily list of tasks users are encouraged to complete are placed in the home page, every tick off the list increases their points by 2. Similarly, to encourage users to actually complete the task (i.e., reading an article, playing the casual video game, and use the prediction function for FidgIT), additional 5 points are added when users verify the completion of these tasks. These tasks are reset at midnight every day to encourage daily usage. Verification for each task differs. For instance, when the article is read to the end, there is a verification button to mark the article as read. Points are only added if participants start the game, marking one successful round of play. In terms of the predictions, the points are only given 10 seconds post the start of the predictions, allowing for one successful round of data collection and predictions to be formed.

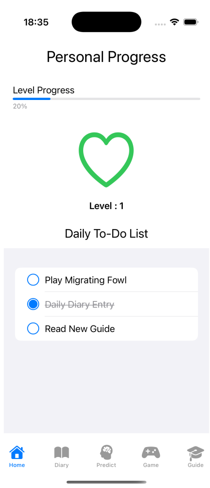


Figure 6.5.: Simulator view of progress bar, current level, and to do tasks

Predictions & Notifications To implement the model created into an IOS mobile application, the model needs to be recreated using Core ML format. With a working model with weights saved from the training file, and the data input shape (i.e. sliding window 10,4 input shape) which is further explained in section 'Machine Learning Model', the model was converted using Apple's Coremltool library in Python. The function ct.convert allows for an IOS model compliant format through the input of these values, and saving it as a mlpackage allows for simple integration into an app.

Users are able to interact with this model by connecting their mobile phones into FidgIT's wifi access point and a click of a button. The interface shows the classification results and a button to start the model's predictions. When the model predicts anxiety, an alarm will prompt the users to interact with the other tools in the app to reduce their anxiety levels. The button was implemented to allow users the autonomy to track when their data from FidgIT was being used and manipulated. Similarly, the instant alarm notifications allow for real-time intervention by using other features.

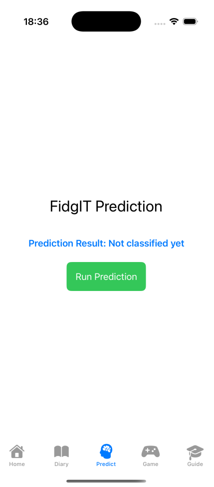


Figure 6.6.: Interface for users to start model prediction

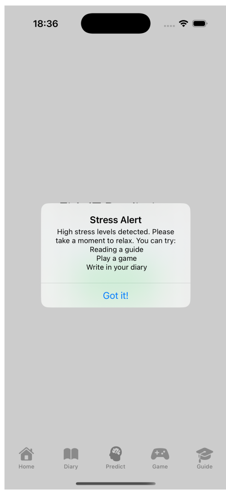


Figure 6.7.: Alarm notification when anxiety is predicted

6.3. Machine Learning Model

6.3.1. Data Collection

To collect naturalistic data on fidgeting patterns, a take home diary study was conducted. 4 participants (3 Female, 1 Male) amongst those who participated in the TSST study volunteered to take part in the take home diary. Their consent was obtained and they were given their information sheet regarding the study. Participants were given the actual FidgIT tool, an online compressed file consisting of all the required software for data collection (i.e. Arduino IDE and PLX-DAQ micro enabled Excel sheet), an online diary with prompts for the tasks they were doing, their anxiety levels, and their stress levels when they were using the FidgIT tool. The study started with an in-person tutorial to teach users on how to operate the tool and how to successfully connect the software to collect their data in the correct format. Participants were also given a troubleshooting document as a precaution for any technical difficulties. They were given instructions to connect the tool and use it as they liked, and to take note of their anxiety levels whilst completing daily tasks. At the end of the study, we received a list of each participant's fidgeting patterns over the span of the 3 days and could match anxiety levels to times the fidgeting patterns were active. For data points that were considered anxious, they are marked as category 1, and not-anxious in category 0.

6.3.2. Data Preprocessing

From the data collected, we used Python's Numpy and Panda libraries to categorise each time stamped data, format the excel sheet into JSON format, create data sequences of the data and their labels, and split the data into training sets and testing sets. The purpose of processing the data is to ensure the raw JSON data sets can be manipulated into structured inputs and labels required for sequence based-machine learning models. The code starts by ensuring that the data is indexed using a dateTime format, which allows for a standardised time-based index for temporal analysis and easier manipulation. Subsequently filtering out valid data points that had a category of 0 or 1. Through the filtered data points relevant features such as the input for each of the sensors and their category were extracted. A sliding window mechanism of 10 time steps was tailored to implement input sequences and corresponding labels for temporal pattern analysis. A sliding window mechanism prepares the data in an overlapping sequence to capture the temporal dependencies within the sensors that might change over time. This mechanism also maintains data granularity by ensuring the overlapping sequences do not lose key information during the change in time steps. To further ensure class balance of the two categories was maintained, and for the reusability of the data split, a stratified split with a random seed was used to split the data processed arrays for both training and testing of the model in future steps.

6.3.3. Hybrid ML Model Definition

The model is designed for binary classification, making predictions on the input sequence of 10 time series data of 4 different sensor inputs, that corresponds to one of two categories (i.e. anxious or not anxious). Taking inspiration from studies by Woodward and Kanjo [47], both studies identified that a hybrid model architecture consisting of 1D convolutional layers with Long Short Term Memory layers was the most accurate in identifying emotions. FidgIT's model employs a combination of convolutional layers, recurrent layers, and fully connected layers to effectively process sequential data and extract temporal patterns. Further details on each layer and component can be found in Table 6.1.

This model was compiled for training by specifying the Adaptive Moment Estimation (ADAM) optimizer, the binary cross-entropy loss function, and its accuracy metric; which in combination is ideal for its efficient learning abilities and minimised error for binary classification tasks while providing a strong metric to evaluate the effectiveness of the model. The ADAM ensures smooth optimization for our hybrid architecture as it allows for adaptive learning rates for each parameter. It adjusts the rates according to the first and second moments of the movement gradients from the different sensor inputs. Whereas the binary cross-entropy loss function $-[y \log(p) + (1 - y) \log(1 - p)]$, where y is the true label, and p is the predicted probability, is specifically suited for binary classification tasks as it penalises incorrect predictions. This penalisation occurs by computing the negative log likelihood of the true label and encourages output predictions to be closer to 0 or 1, therefore, improves the classification certainty for binary categories.

Component	Description
Input Shape	Input shape of (10,4) corresponds to sequences of 10 time steps with 4 features (e.g., button, X_Axis, Y_Axis, Spin_Rate).
Conv1D Layers	First layer applies a 1D convolution with: • 64 filters and a kernel size of 3, which scans over temporal data to extract short-term patterns. • ReLU activation ensures non-linear transformations.
MaxPooling1D Layers	Reduces the dimensionality of the convolutional output using a pool size of 2, retaining essential features while improving computational efficiency.
Dropout Layers	Strategically placed after convolutional and LSTM layers to prevent overfitting, with a dropout rate of 30% (0.3).
LSTM Layers	Two LSTM layers process sequential dependencies: • The first LSTM layer with 64 units returns sequences to feed into the next LSTM layer, capturing richer temporal dynamics. • The second LSTM layer with 32 units outputs the final sequence embedding, effectively summarizing temporal relationships.
Dense Layers	Fully connected (Dense) layers refine the embeddings: • A hidden Dense layer with 32 neurons applies ReLU activation for intermediate feature extraction. • The output Dense layer with 1 neuron uses a sigmoid activation for binary classification, producing a probability score for one of the two classes.

Table 6.1.: Model Components and Descriptions

6.3.4. Model Training

The output of the model training class informs us about the models ability to accurately predict and categorise fidgeting patterns into its two categories, tells us the model's ability to generalise predictions to unseen data, and illustrates the trends in predictions. Information from the output allows us to evaluate the effectiveness and accuracy of the model. 20 training sessions (epochs) took place to train the binary classification model, the accuracies and losses can be seen in Figure 6.2. The initial epoch achieved a high training accuracy of 92.6% and validation accuracy of 94.42%, indicating the model's ability to already capture meaningful patterns in the data. However, the initial loss value of 7.3050 suggests room for improvement as the model continues to learn and optimise its weights. As the training continues, the model's ability to adapt its learning rates is obvious from both the training and validation loss steady decrease. Its decrease indicates that the model is effectively learning to minimise classification errors and improving its accuracy. This is evident with the final training accuracy reaching 97.7% and validation accuracy reaching 98.64% at the last epoch (Epoch 20). Further proving the impacts of the ADAM optimisation, and penalise framework from the binary crossentropy loss function as previously mentioned in Section. Model Definition. The epoch's loss decreases to 0.0774 for training and 0.0523 for validation. The validation sessions are used to demonstrate generalisation of predictions. Our results show that the model not only predicts the training data well, but also generalises effectively to unseen validation data. Furthermore, the validation accuracy remains consistently high throughout training, rarely dropping below 94%. This demonstrates that the model generalises well to unseen data without significant overfitting. Likewise, its peak validation accuracy at 98.65% highlights the reliability of the model for the binary classification task. These results of high accuracy and low loss output from the model training demonstrate that the model's hybrid architecture of convolutional and recurrent layers effectively captures both short-term and long-term dependencies in the data.

Epoch	Loss	Accuracy	Val Loss	Val Accuracy
1	7.3050	0.9260	0.1060	0.9442
2	0.2799	0.9421	0.0869	0.9442
3	0.1653	0.9428	0.0823	0.9441
4	0.1177	0.9433	0.0822	0.9442
5	0.0897	0.9512	0.0732	0.9591
6	0.0886	0.9607	0.0778	0.9540
7	0.0844	0.9657	0.0601	0.9737
8	0.0849	0.9658	0.0739	0.9599
9	0.0859	0.9652	0.0707	0.9597
10	0.0825	0.9665	0.0760	0.9627
11	0.0751	0.9700	0.0711	0.9727
12	0.0752	0.9728	0.0588	0.9724
13	0.0617	0.9755	0.0566	0.9826
14	0.0692	0.9746	0.0490	0.9839
15	0.0725	0.9741	0.0448	0.9865
16	0.0694	0.9757	0.0854	0.9457
17	0.0889	0.9621	0.0585	0.9853
18	0.0691	0.9766	0.0635	0.9806
19	0.0713	0.9736	0.0562	0.9856
20	0.0774	0.9770	0.0523	0.9864

Table 6.2.: Training and validation Metrics Over 20 epochs

7. Conclusions and Future Works

7.1. Summary of Findings

This work sought to understand the effects on neurodivergent individual's fidgeting patterns when placed in anxious provoking environments, and if machine learning models were able to infer and predict anxiety levels from trends in fidgeting patterns. Based on our research study (TSST) discussed in Chapter 4. User Evaluations, we found significant decrease in physiological responses to anxious environments when using FidgIT, suggesting that the tool created did reduce anxiety. My findings are in agreement with current research [2], [12], [23], [39], [41], further validating the benefits fidget tools have on anxiety are applicable on both neurotypical and neurodivergent individuals. Furthermore, in Chapter 5. Application discussed the creation, training and evaluation of our hybrid machine learning model that employs both Long Short Term Memory layers and Convolutional 1D layers to predict anxiety levels based on labelled fidgeting patterns. Using the accuracy metric to evaluate the probability of correct predictions, my model had a peak accuracy of 98.65% and validation accuracy rarely dropped below 94%, indicating a strong ability to generalise the predictions to unseen data and have a high reliability for binary classification tasks. Similar to the research conducted by Woodword and Kanjo [47], who was able to use machine learning to predict an individual's emotions, our model and its accuracy demonstrates its abilities to predict anxiety level from fidgeting patterns.

Key Contributions:

- Conducted multiple studies to **collect and understand the requirement**s needed by Neurodivergent Individuals
- **Co-design** FidgIT with Neurodivergent Individuals to ensure the features and

designs are aligned with their wants

- Designed and produced a **fully functioning internal circuitry** of FidgIT to collect 4 different fidgeting styles and their heart rates

- **Designed and 3D printed** a size restricted casing for FidgIT

- **Collected fidgeting pattern data** from Neurodivergent Individuals using FidgIT through series of studies (i.e. TSST and take home diary study)

- **Designed and train a hybrid architecture machine learning model** that produced a peak 94% accuracy in predictions

- **Converted and implemented the machine learning model** to Apple's CoreML format

- Designed and created and IOS mobile application to include other **holistic methods found to have reduce anxiety levels** (i.e. Diary System, iCBT modules, casual video game)

7.2. Future Works

Despite having a working tool that showed significant improvement in reducing physiological reactions to anxiety levels, and a high accuracy model that can predict anxiety from fidgeting patterns. There is still room to improve on the hardware, methodology in evaluation studies, the variability of data used for training, and improvements on the mobile applications.

Hardware

FidgIT is currently limited to a wired connection to a computer as a source of power, a recommendation for future works is to make it self powered and wireless. Allowing for a wireless connection can increase its portability and make it more convenient for users to use. Furthermore, as FidgIT's wire is currently attached to its side, it could be difficult for some users to hold. By removing the connected wire, it can further adhere to the requirements suggested by the target audience of it being ergonomic and palm sized.

Evaluation Study (TSST)

To better improve the methodology in further data collection, research into participants' natural environment and the use of a medical grade heart rate sensor should be explored.As a suggestion, further analysis can be done to understand how users might interact with FidgIT in a natural environment, allowing for natural trends on fidgeting patterns to be identified. Especially considering the artificially created social stressors in the TSST might be different to the stressors neurodivergent individuals may face in reality. In addition, based on my observations conducting TSST, I noticed participants did not place their fingers directly on top of the heart rate sensor, this could have implicated the recordings of the heart rates. Similarly, the pre-test heart rate data was self administered by the participants, leaving room for inaccurate data collection. Hence, in future implementations of the study, a separate medical grade heart rate sensor could be utilised to gather accurate data for analysis for both conditions.

Machine Learning Model

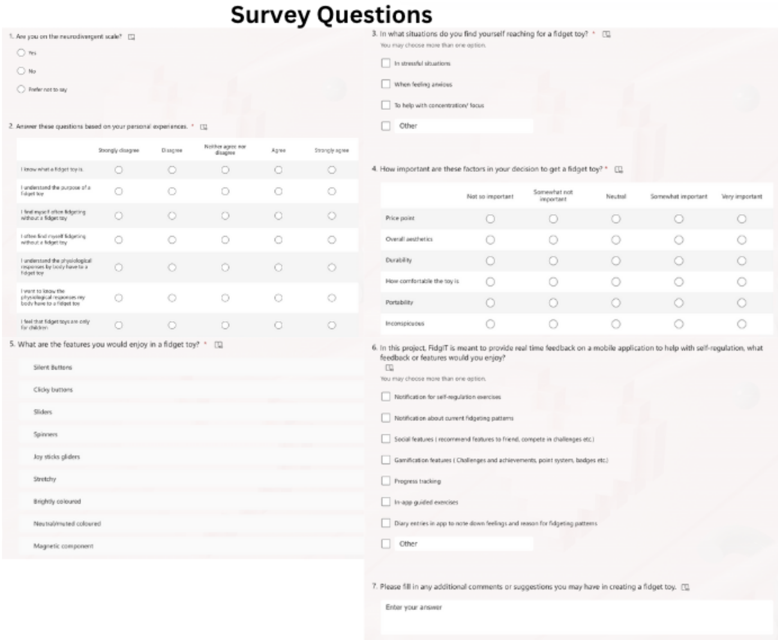
The data used to train and test the model were collected from four neurodivergent individuals who have anxiety, recommendation for future works is to recruit and collect data from a wider range of participants. The current data used to train the model are from users who have learning disabilities, however the range of neurodivergent developmental and learning disabilities are wide and varied. Getting more data from a wider sample of the neurodivergent population can increase the variability in fidgeting patterns. Moreover, training the model with a wider set of data can improve its reliability and validity of its predictions. Similarly, as the recruitment of neurodivergent individuals were difficult for the data collection process, an immediate improvement could be to recruit more participants. More participants would be able to provide a more robust statistical analysis and detect smaller subtle effects in fidgeting trends.

Mobile Application

One key factor in the success of iCBT is the ability to have fixed to healthcare providers while participating in the treatment syllabus, one recommendation is to embed a communication line to health care providers from the app. Currently FidgIT mobile comprises a diary system, casual video games, and parts of the iCBT syllabus. Each component has been found to play a role in the reduction of anxiety. However, research by Mewton [30] reinforces that these components still require therapist contact for maximum effectiveness. As such, as a recommendation, having a portal in the app for contact time with a therapist could be effective. Furthermore, with details regarding their emotional well being that has been stored through their diary entries, and the overall trends of the month found in the app, it could help therapists to better understand how the individuals.

A. Appendix: Study Materials

A.1. Online Survey Questions



Survey Questions

1. Are you on the neurodivergent scale?

- Yes
- No
- Prefer not to say

2. Answer these questions based on your personal experiences. *

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
I know what a fidget toy is.					
I understand the purpose of a fidget toy					
I find myself often fidgeting without a fidget toy					
I often find myself fidgeting without a fidget toy					
I understand the physiological responses by body have to a fidget toy					
I want to know the physiological responses my body have to a fidget toy					
I feel that fidget toys are only for children					

5. What are the features you would enjoy in a fidget toy? *

- Silent Buttons
- Clicky buttons
- Sliders
- Spinners
- Joy sticks gliders
- Stretchy
- Brightly coloured
- Neutral/muted coloured
- Magnetic component

3. In what situations do you find yourself reaching for a fidget toy? *

You may choose more than one option.

- In stressful situations
- When feeling anxious
- To help with concentration/ focus
- Other

4. How important are these factors in your decision to get a fidget toy? *

	Not so important	Somewhat not important	Neutral	Somewhat important	Very important
Price point					
Overall aesthetics					
Durability					
How comfortable the toy is					
Portability					
Inconspicuous					

6. In this project, FidgIT is meant to provide real time feedback on a mobile application to help with self-regulation, what feedback or features would you enjoy?

You may choose more than one option.

- Notification for self-regulation exercises
- Notification about current fidgeting patterns
- Social features (recommend features to friend, compete in challenges etc.)
- Gamification features (Challenges and achievements, point system, badges etc.)
- Progress tracking
- In-app guided exercises
- Diary entries in app to note down feelings and reason for fidgeting patterns
- Other

7. Please fill in any additional comments or suggestions you may have in creating a fidget toy.

Enter your answer

Figure A.1.: Survey Questions implemented on Team forms

A.2. User Creations and Notes

A.3. TSST Materials

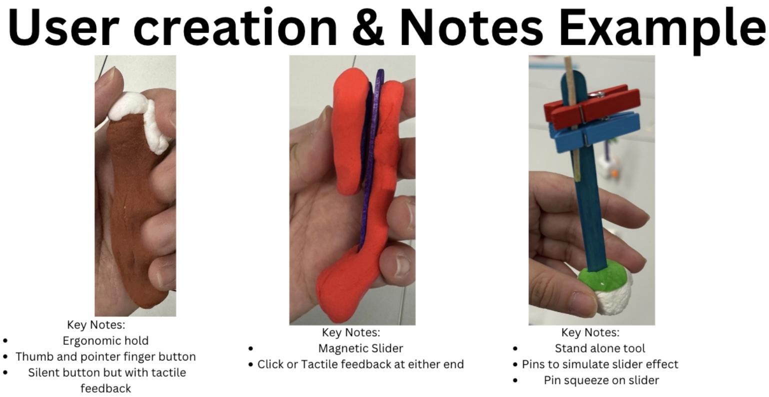


Figure A.2.: Three examples of user creations and their notes

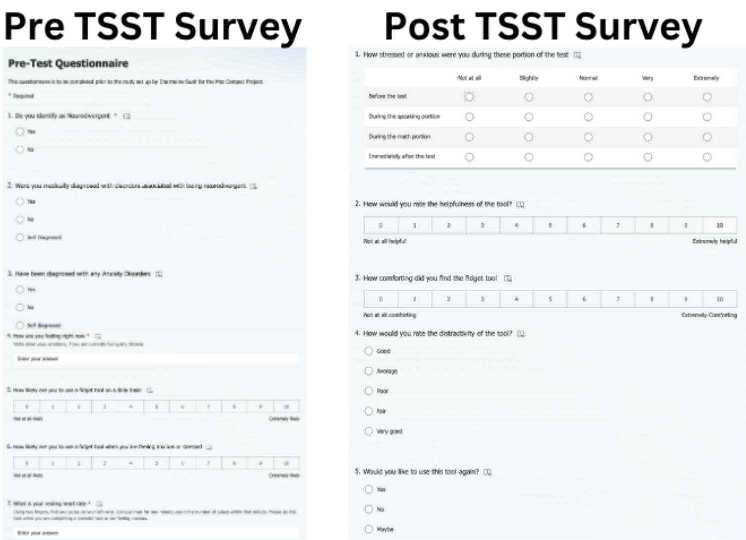


Figure A.3.: Pre and Post survey for TSST participants

B. Appendix: Design process

B.1. Initial CAD Designs

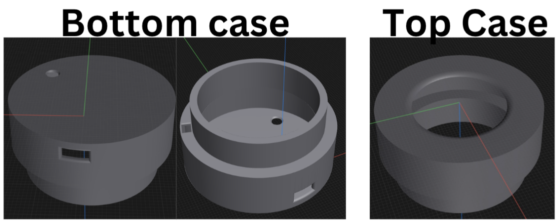


Figure B.1.: Initial CAD designs before Iterative practice

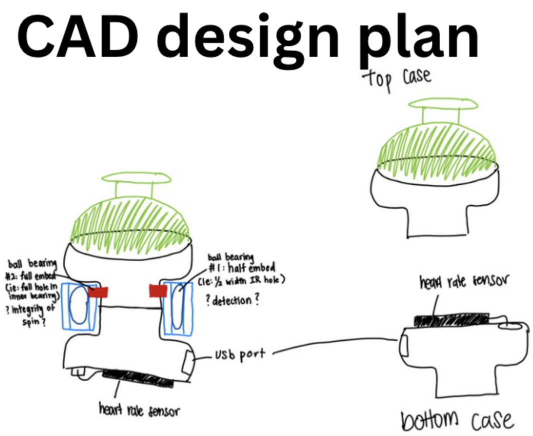


Figure B.2.: Image illustrating the CAD iterative design process for improvement

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