Co-Designing Programmable Fidgeting Experience with Swarm Robots for Adults with ADHD

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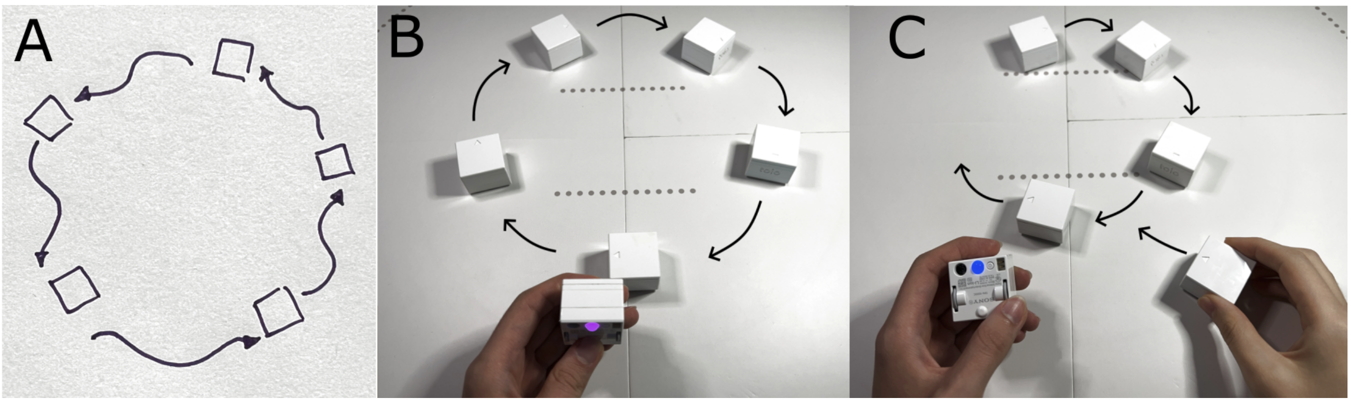

Figure 1: An example of multi-robot fidgeting interaction derived from the co-design process. A: the initial design by a participant from the Design Workshop, B&C: implementation of the initial design with robots. Users can adjust the radius and speed by tilting the controller robot (B). Even when interrupted, a robot can recover (C).

ABSTRACT

Individuals with ADHD grapple with elevated stress levels, emotional regulation challenges, and difficulty sustaining focus. Fidgeting, a behavior traditionally frowned upon, has been shown to help people with ADHD in concentration, emotional and mental state management, and energy regulation. However, traditional fidgeting devices have limited fixed affordances providing cookie-cutter style fidgeting experience to all despite individual differences. Recognizing the uniqueness of individual fidgeting tendencies, we use small tabletop robots to provide a customizable fidgeting interaction experience and conduct co-design sessions with 16 adults diagnosed with ADHD to explore how they envision their fidgeting interactions being changed with these programmable robots. We examine core elements defining a successful fidgeting interaction with robots, assess the significance of customizability in these interactions and any common trends among participants, and investigate additional advantages that interactions with robots may offer. This research reveals nuanced preferences of adults with ADHD concerning robot-assisted fidgeting.

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CCS CONCEPTS

• **Human-centered computing** → *Haptic devices*; **Participatory design**.

KEYWORDS

Co-design, Adults with ADHD, Programmable Fidgeting, Swarm Robots

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1 INTRODUCTION

Attention Deficit Hyperactivity Disorder (ADHD) is a psychiatric conditions that manifests as persistent hyperactivity, inattention, and impulsivity, which can significantly impacting daily life [55]. Fidgeting, commonly seen in ADHD as a symptom of hyperactivity, is often stigmatized as a sign of distraction or lack of focus. However, a growing body of research suggests that controlled fidgeting can enhance concentration and optimize attention [3]. Fidgeting can also aid individuals with ADHD, who often grapple with emotional dysregulation [46], in the regulation of emotional and mental states [22].

Fidgeting varies widely among individuals, influenced by personal habits and sensory responses. While one person may find relief in foot tapping or pen clicking, another might require tactile engagement with specialized tools. In addition to divergent preferences and needs of individuals relating to fidgeting, individuals with ADHD can exhibit both hypo-responsiveness and hyper-responsiveness to sensory stimuli [39]. Hypo-responsiveness refers to having a higher threshold for noticing tactile, auditory, or other sensory inputs, or appearing to be indifferent or unaware of sensory stimuli that would typically provoke a response in others. Conversely, hyper-responsiveness refers to an exaggerated or intensified response to sensory stimuli, such as feeling overwhelmed by bright lights, loud noises, certain textures, or even mild tactile stimuli. Thus, it's essential for fidget devices to be adaptable, catering to the distinct sensory needs and varied fidgeting preferences of individuals.

Currently, there is a diverse assortment of fidget tools available on the market, yet they often lack customizability, being built with fixed parts that support only specific interactions stemming from standardized designs. Although these devices offer some versatility, their fixed nature means users must completely replace them rather than adjust existing parts to suit their changing needs or preferences.

In response to these shortcomings, there has been recent work on creating more dynamic solutions. A notable project by Kim et al. introduced SwarmFidget [25] and demonstrated the potential of using small robots for fidgeting purposes. They utilized swarm robots to implement fidgeting interactions where the users can interact with the robots through touch or gesture to receive haptic, visual, or audio feedback from the robot(s). Using small robots for fidgeting purposes offers several advantages. Robots can be engineered to provide a range of haptic, tactile sensations and interactive experiences by incorporating different materials, sensors, speakers, and displays. The robots can be programmed to deliver different levels of responsiveness from subtle to pronounced sensory feedback based on the user's sensory needs. The programmability of the robots' behavior also enables a wide variety of interactions that are not confined to the constraints of passive mechanical components. Moreover, the programmability of such robots would allow users to fine-tune their interactions, making the fidgeting experience perfectly personalized and effective, thus bridging the gap between traditional limitations and the potential for a more engaging and customizable fidgeting experience.

While SwarmFidget introduced the idea of fidgeting with robots and conducted an exploratory study about the perception and reaction from the general users [25], the potential benefits of fidgeting with robots could be particularly relevant and beneficial to individuals with ADHD by catering to their varied sensory needs, from hypo- to hyper-responsiveness. Customizable fidgeting interactions and the versatility offered by the programmability of these robots provide tailored tactile, auditory, and visual feedback, and help maintain sustained interest and engagement. This is important for those with ADHD who require variety and may either quickly lose interest in unchanging stimuli or find sudden changes too overwhelming depending on their responsiveness. Therefore in this work, we investigate how a group of programmable robots may offer an adaptable and engaging solution, enhancing focus and emotional regulation for ADHD individuals.

Recognizing that individuals with ADHD could especially benefit from dynamic and customizable fidgeting devices and the lack of assistive technologies available for adults with ADHD [49], we adopted a co-design approach. This method enabled us to collaborate directly with adults with ADHD to create fidgeting interactions, incorporating their insights to develop technologies that truly meet their needs.

Our co-design process was divided into two parts. The first part was a co-design workshop conducted in a group setting, where participants explored fidgeting interactions with robots and created their own interaction designs collaboratively with other participants. The second part was an evaluation workshop conducted one-on-one with the facilitator, during which participants had the opportunity to experience and assess the effectiveness of both their own designed interactions and those designed by other participants.

Through our co-design workshops, we explored how different types of feedback during fidgeting interactions with swarm robots could be perceived by adults with ADHD. We describe the interactions that were designed and evaluated by adults with ADHD and present their perceptions of the designed interactions. We also assessed the likelihood of future usage of the designed interactions. We identified components essential for creating satisfying fidgeting interactions and suggested hardware improvements to make the robots more suitable for such interactions. Finally, we presented alternative applications for interacting with swarm robots.

Our contribution is multifaceted: we investigated the needs and preferences of adults with ADHD with regard to the design of fidgeting with swarm robots. Through a co-design process, we generated unique fidgeting interactions with swarm robots and presented key design considerations for swarm robot-based fidget tools, particularly for adults with ADHD. Finally, we outlined potential alternative applications for swarm robot-based fidgeting systems.

2 RELATED WORK

This section provides a more in-depth background of ADHD & fidgeting, followed by coverage of relevant domains such as smart fidget devices, swarm robotics, and designing for people with ADHD.

2.1 ADHD & Fidgeting

Attention Deficit Hyperactivity Disorder (ADHD) is one of the most prevalent psychiatric conditions which affects 3-7% [48] of adults. ADHD manifests as persistent hyperactivity, inattention, and impulsivity [55]. Adults diagnosed with ADHD are more prone to experiencing inner restlessness and an inability to relax. Hyperactivity can be exhibited as excessive fidgeting [16, 54], whereas inattention is often presented as distractibility, a tendency to become easily bored, a preference for variety, and heightened sensitivity to stress [30, 42]. Difficulties with inattention frequently result in challenges in completing academic tasks, consequently leading to lower academic performance in school and in the professional setting compared to peers with similar cognitive capabilities [5, 11]. Furthermore, many adults with ADHD experience mood swings with frequent emotional highs and lows, as well as occasional outbursts of irritability [30].

Fidgeting, prevalent among individuals with ADHD, is acknowledged as a symptom of ADHD by the DSM-5 (The Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition) [2]. Fidgeting is defined as a repetitive, non-goal-directed action [40], and although it is often stigmatized as a sign of distraction or lack of focus, a growing body of research suggests that there is a variety of beneficial effects from fidgeting [7, 29, 36, 41, 56]. Controlled fidgeting, such as using fidget tools or engaging in subtle, repetitive movements, has been demonstrated to enhance concentration and optimize attention [3]. Fidgeting can serve as a means to channel excess energy and restlessness, allowing individuals to redirect their attention more effectively toward the tasks at hand, while also contributing to the management of emotional and mental states [22]. Given that individuals with ADHD may grapple with emotional fluctuations and dysregulation [46], fidgeting can offer a form of self-soothing, helping individuals regulate their emotions and maintain a calmer mental state. Thus, fidgeting offers a multifaceted approach to improving the overall well-being and functioning of those with ADHD by enhancing concentration and assisting in emotion regulation.

2.2 Smart Fidget Devices

There have been various explorations into the development of smart fidget devices. Woodward and Kanjo introduced the iFidgetcube, a device equipped with multiple physiological sensors that can assess user well-being using deep learning classifiers [56]. Karlesky and Isbister created fidgeting experiences through the Sifteo Platform, featuring interactive cubes with touch-sensitive displays and sensors [20, 21]. Ji and Isbister advanced this concept with AR Fidget, an AR glasses-based system that integrates fidgeting techniques like tapping and swiping with immersive visuals and sounds to influence users' emotional states [18]. In a unique approach, Domova proposed a fidget device that interacts with smart lighting systems, allowing users to adjust features like brightness and color [10].

2.3 Swarm Robotics

Inspired by natural swarms, roboticists have pioneered the development of swarm robots: large groups of robots operating in tandem towards a shared objective. These robot swarms provide benefits such as collective intelligence, adaptability, and resilience to individual failures. Certain platforms can mimic swarm behaviors through decentralized intelligence, with some managing up to 1,000 robots [43]. While ample research has delved into the operational facets of swarm robots, like control [1, 6, 45], exploration of direct physical interaction remains limited.

As robots become smaller and more common, it's becoming important to understand interactions with robot swarms, especially given recent work have shown that even the robot's mere presence affects human cognition, emotion, and motivation [23, 24, 35]. Furthermore, HCI researchers are actively exploring swarm user interfaces tailored for interactive applications, spanning data visualization [19, 31, 32, 53], VR haptic feedback [12, 34, 51, 52, 57], and educational tools [15, 33, 38]. While several studies have probed robot motions for interaction, evaluating their influence on user emotions [26, 44] and clarity [28], in-depth examination of bi-directional haptic interactions with robot swarms is scant.

Notably, Ozgur et al. delved into haptic engagements with a singular mobile robot, hinting at the potential for a swarm-scale application [37]. Meanwhile, Kim and Follmer assessed haptic stimuli perception from robot swarms and user-defined haptic patterns for social touch conveyance [27]. Building on this, Kim et al. evaluated the feasibility of swarm robots for bi-directional haptic interactions in fidgeting contexts, probing their dynamic facilitation of fidgeting and user reception of such interactions [25]. In this work, we explore the use of swarm robot-based fidgeting for adults with ADHD, a population who may especially benefit from gaining access to programmable fidgeting experience.

2.4 Designing for people with ADHD

In their comprehensive literature review, Spiel et al. reflected on technologies tailored for individuals with ADHD, highlighting that a significant portion of the studies they examined primarily addressed ADHD in children and adolescents [49]. They noted that the predominant research trend leaned towards interventionist or diagnostic methods, such as LemurDx [4]. Furthermore, many of the interventionist technologies, such as *Blurtline* [47] and *KITA and WRISTWIT* [14], were devised to "mitigate" ADHD behaviors viewed as disruptive compared to conventional behavioral standards. Despite the positive intentions behind these projects, they can perpetuate established societal behaviors, placing the burden on the individual with ADHD to conform. This paradigm emphasizes prescriptive solutions over assistive technologies [50]. Moreover, Spiel at al. stressed the lack of direct engagement with individuals with ADHD in HCI research, instead opting to collaborate with parents, educators, or medical professionals. This could lead to a mismatch between the genuine needs of people with ADHD and the presuppositions held by healthcare practitioners [49]. Recognizing that individuals with ADHD could especially benefit from dynamic and customizable fidgeting devices and the lack of technologies for adults with ADHD, we chose a co-design approach to co-create fidget tools with adults with ADHD. In doing so, we aimed to develop technologies that effectively address the needs of people with ADHD and improve the effectiveness of these technologies by gaining valuable insights from neurodivergent individuals.

3 METHODOLOGY

The co-design consisted of two workshops: the *Design Workshop* and the *Evaluation Workshop*. We conducted four design workshops with 3-5 participants attending each workshop, totaling 16 participants across all workshops (Table 1). The design workshops involved interviewing participants about their fidgeting habits, allowing them to interact with swarm robots, and facilitating the collaborative design of fidgeting interactions with these robots. Each workshop lasted from 2.5 to 3 hours. On the other hand, the evaluation workshops were one-on-one sessions where half (8 out of 16) of the participants returned to experience and provide feedback on the interactions developed during the design workshops. The evaluation workshops lasted approximately 1 hour. All participants were compensated CAD $16.75 per hour in the form of an Amazon gift card. This research received approval from the University's Institutional Review Board, and participants gave their informed consent.

3.1 Setup for Design Workshop

Building on the design space from SwarmFidget [25], we programmed several single-robot and multi-robot interaction prototypes using

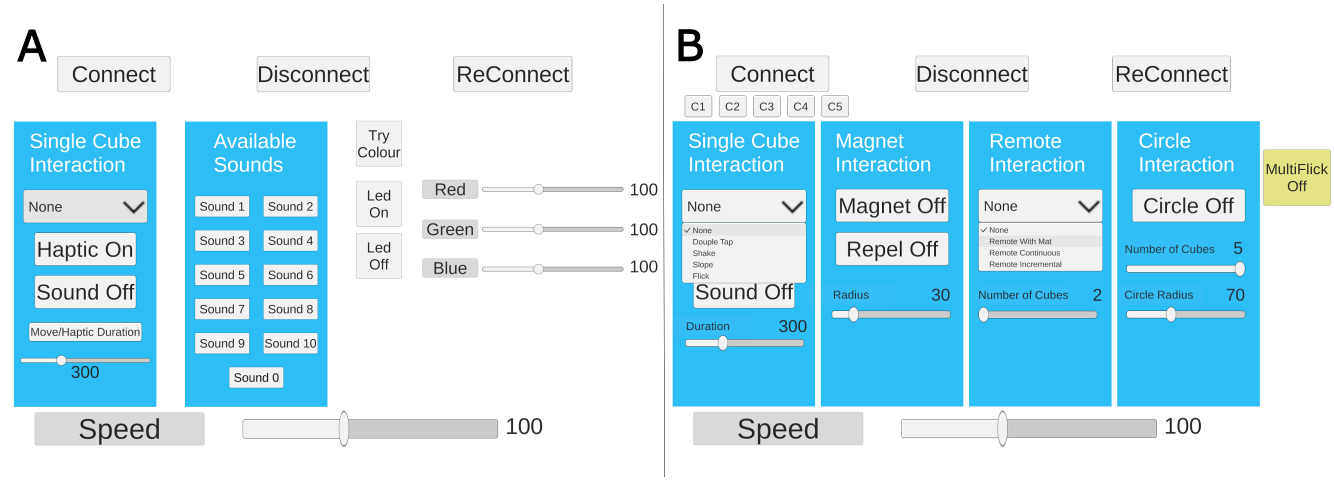

Figure 2: Web-based UI applications for customizing fidgeting interactions: A - UI for modifying single-robot interactions. B - UI for modifying multi-robot interactions.

Toio robots (Figure 3) to provide participants with a practical demonstration of how robots can be used for fidgeting purposes and to facilitate initial participant engagement. The single-robot interactions were focused on the capabilities of the individual robots and the core mechanics of the interactions, that is different ways of triggering reactions from the robots. Meanwhile, the multi-robot interactions demonstrated how the core mechanics of the interactions could be extrapolated to involve multiple robots. We also created web-based UI applications (Figure 2) that enabled participants to alter specific elements of the initial fidgeting interactions, thereby facilitating a deeper understanding of their personal preferences for fidgeting with robots.

Toio robots, were used because of the Sony Toio platform's portability and its advanced navigation algorithms that produce fluid, synchronized robot movements. The Toio robots have dimensions of 3.2cm x 3.2cm x 2.5cm and can move at a maximum speed of 35cm/sec. The Toio robots are also equipped with a 6-axis detection system, which allows them to detect movements and orientations across six degrees of freedom, tracking three translational and three rotational movements. They can also identify their posture, detect collisions, recognize double-taps, and sense shaking. The robots can also produce sounds via a piezoelectric speaker and display colors through an indicator button located at their base (Figure 3). Each Toio robot's position can be tracked with an error margin of 1mm by the system through specially designed tracking mats printed with small dots (30cm x 42cm or 56cm x 56cm).

We created separate web-based UI applications for both single-robot and multi-robot interactions, enabling participants to tailor specific aspects of these interactions. These aspects included adjusting robot speed, choosing the number of robots involved, and selecting the type of feedback - haptic, auditory, and/or visual (see Figure 2 for detailed options). This separation into different applications allowed for a simpler and more targeted user experience, specific to each interaction type.

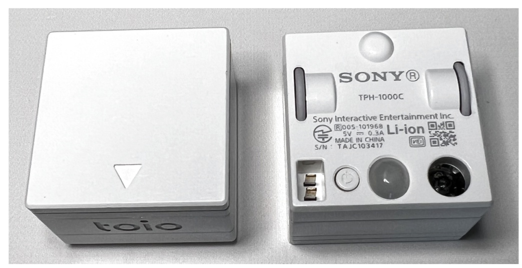

Figure 3: Toio robots which were used in the Co-design Workshops.

3.1.1 Example Single-robot Fidgeting Interactions Used during the Design Workshop. The single-robot interactions were split into two categories. The first category enabled participants to activate robot responses through various triggers: clicking its button, shaking it, tilting its angle, or double-tapping the robot. Depending on the employed trigger, the robot would offer feedback in the form of haptic sensations, sounds, or lights. The feedback combination and intensity were modifiable using the web-based UI application (Figure 2, A). The second interaction category centered on altering the robot's position on the tracking mat, achieved by flicking, pushing, or manually repositioning the robot to a different location on the mat. Once displaced, the robot was programmed to return to its initial position at a speed set by the user, adjustable via the same web application. These interactions are extensions of those from prior work [25] with a few identical interactions, such as the flick interaction where the robot returns to the same location when disturbed, but also several new interactions, including shake/slope where once the robot is shaken/tilted, it reacts with either light or sound.

3.1.2 Example Multi-robot Fidgeting Interactions Used during the Design Workshop. The multi-robot interactions were classified into four categories: Magnet, Shape, Remote, and Conveyor. The web-based UI application (Figure 2, B) allowed users to easily switch between the different types of interactions and to modify certain aspects of the interactions based on their preferences. For each interaction type, participants could alter the robots' speed.

(1) Magnet Interaction: As shown in Figure 4, users could toggle between 'attract' and 'repel' options and adjust the strength of the magnets, determining the distance at which the robots would either attract or repel each other.
(2) Shape Interaction: Robots were positioned in a circular formation and programmed to return to designated locations on the mat if displaced. Participants could modify the number of robots engaged in this interaction, ranging from a minimum of three to a maximum of five.
(3) Remote Interaction: A singular robot was employed to control the movements of the others. Tilting the 'remote' robot dictated the direction and movement of the rest of the robots (Figure 5). The 'remote' robot could also be positioned on the tracking mat to prompt the other robots to move closer to its location (Figure 5, D). Participants had the option to vary the number of robots, with two as the minimum and five as the maximum.
(4) Conveyor Interaction: This was an extension of the single-robot interaction centered on altering the robot's position on the tracking mat through flicking, pushing, or manually repositioning the robot to a different location on the mat. If the leading robot in the line was displaced from its location, it would move to the end of the line, prompting the subsequent robots to advance to the next position (Figure 6).

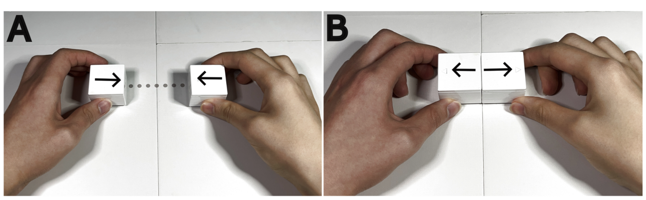

Figure 4: A: Magnet Attract interaction. B: Magnet Repel interaction

3.2 Participants

For the co-design workshops, 16 adults diagnosed with ADHD were recruited from a public institution. For the initial design workshop, the ad was circulated to the institution's list of students with accessibility needs (with the administrator's approval), noting the inclusion criteria of being diagnosed with ADHD. We let the participants decide whether they satisfied this criterion or not. For the second evaluation workshop, the participants from the initial design workshop were asked to participate. In addition to ADHD, two of the participants were also diagnosed with Autism and one was diagnosed with Functional Neurological Disorder (FND). The participants were made up of 8 women, 7 men, and 1 genderfluid person. The ages ranged from 18 to 31, with an average of 23.6 and a standard deviation of 3.5. The participant group was characterized

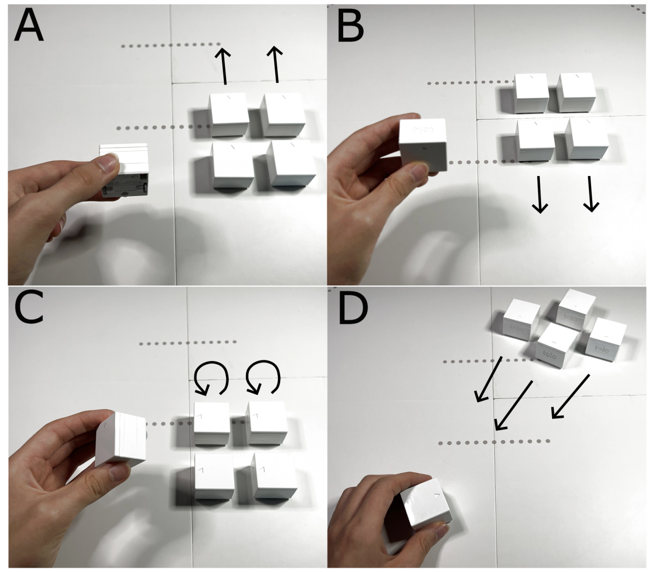

Figure 5: Remote Interaction: A - Robots moving forward controlled by the 'remote' robot. B - Robots moving backward controlled by the 'remote' robot. C - Robots turning left controlled by the 'remote' robot. D - Robots moving towards the 'remote' robot.

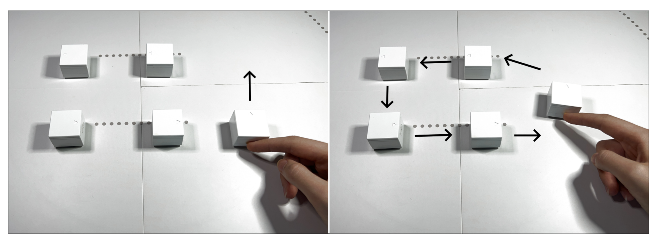

Figure 6: Conveyor: If the first robot is displaced from its programmed position, it will go to the end of the line and the rest of the robots will shift one position forward.

by a diverse range of racial and educational backgrounds. For a detailed description of the participant demographics, please refer to Table 1.

3.3 Design Workshop

The design workshops were held in person with groups of 3 to 5 participants to allow for collaboration between participants in the brainstorming and development of new fidgeting interactions with robots. The 16 recruited participants were assigned to these workshops solely based on their availability and schedule compatibility.

The participants sat around a large table with a variety of fidget tools such as a fidget spinner, fidget cube, pop-it fidget toy, stress ball, and a variety of pens laid out in the middle of the table for participants to interact with as needed throughout the design workshops. The provided fidget tools could be used for reference or comparison, or as inspiration for brainstorming new fidgeting

Table 1: Participant Demographics and Workshop Attendance

ID	Gender	Age	Race	Neurological Disorders	Education	Attendance
P3	W	25	South Asian	ADHD	Business	W1, E1
P4	M	31	Middle Eastern	ADHD	Software Systems	W1
P5	M	25	South Asian	ADHD	Business	W1, E2
P6	W	21	Black/African American	ADHD, FND*	N/A	W1
P7	W	24	Middle Eastern	ADHD	Criminology, Political Science	W2
P8	Gf*	20	White	ADHD	French	W2, E3
P9	M	19	White	ADHD	Sustainable Energy Engineering	W2
P10	W	18	Indigenous - Metis	ADHD, ASD*, MDD*, ANX*	Education	W2
P11	W	25	Filipino	ADHD	Interactive Arts and Technology	W3
P12	M	24	White	ADHD	History	W3, E4
P13	M	23	White	ADHD	Physics, Mathematics	W3
P14	M	26	White	ADHD	Communications	W4, E5
P15	M	23	White	ADHD	Computer Science	W4, E6
P16	W	25	White	ADHD	Biological Sciences	W4
P17	W	19	South Asian	ADHD, ASD*	Computer Science	W4, E7
P18	W	30	White	ADHD	Education	W4, E8

Gf* - Genderfluid
FND* - Functional Neurological Disorder
ASD* - Autism Spectrum Disorder
MDD* - Major Depressive Disorder
ANX* - Anxiety

interactions with the robots. The participants were also given paper to jot down thoughts and ideas for new interactions and draw sketches of more complex robot movements that might be difficult to convey with just speech. The design workshops were structured in the following manner:

(1) *Introduction of fidgeting:* Initially, the participants were introduced to the concept of fidgeting through a formal definition and examples (e.g., clicking a pen, tapping a finger, shaking a leg).
(2) *Brief interview on prior fidgeting experience:* This segment involved interviewing participants about their general fidgeting habits, preferred fidgeting tools, and the impact of fidgeting on themselves and others around them. While encouraged to respond to all questions, participants were informed that they could opt to pass on any question. The aim of the introductory interview was to guide participants in reflecting on their distinct fidgeting habits, preferences, and favorite fidgeting objects. We delved into understanding what facets of their fidgeting provided the most satisfaction and pleasure. More than just pinpointing specific tools or experiences, our discussion explored the broader social context, considering the perceptions and implications of their fidgeting behaviors.
(3) *Toio robots and example fidgeting interactions* The session proceeded with a video showcasing Toio robots' capabilities, followed by a video demonstrating example fidgeting interactions with swarm robots.
(4) *Single-robot interactions:* Participants were provided with Toio robots and received a brief tutorial on using the accompanying web-based UI application shown in Fig. 2 to explore various robot interactions. They were also given paper to jot down thoughts or draw sketches of ideas for new interactions. This phase, lasting about 45 minutes, allowed participants to explore, discuss among participants, and brainstorm new interaction concepts. The goal was to provide ample time for participants to experience interacting with a single robot, thereby understanding their preferences for fidgeting with robots and using these preferences to collaboratively develop new interactions. Participants were asked to come up with at least one new interaction or modify at least one of the provided examples based on their preferences. Allowing participants to first focus exclusively on single-robot interactions was intended to help participants better understand the core mechanics of these interactions, laying the groundwork for subsequent multi-robot scenarios.
(5) *Multi-robot interactions:* After ample time with single-robot interactions, the facilitator prepared the setup for multi-robot interactions and introduced the web-based UI application that accompanied the multi-robot interactions. Due to resource constraints, participants shared a single setup for these interactions, taking turns to experience them. This phase also lasted about 45 minutes with each participant having about 2-3 minutes to experience each multi-robot interaction. Here, the participants were again asked to, as a group, come up with at least one new design or build on or modify one of the provided example multi-robot interactions.
(6) *Fidgeting with Robots Interview:* The workshop concluded with a group interview that delved into the participants' thoughts on fidgeting with robots. This included a comparison with traditional fidget toys, a discussion of how the robots' software and hardware could be improved to better facilitate fidgeting interactions, and discussions on any other potential applications they envisioned for swarm robots.

3.4 Analysis of Interaction Designs

Following the design workshops, the facilitator reviewed the participants' written and verbal feedback along with their proposed designs. The goal was to transform these preliminary ideas into specific, programmable interactions for Toio robots. This step was necessary as the participants often described their desired interactions at a high level, lacking the specific details needed for implementation. For example, participant P12 suggested that "the robots should be arranged to be flicked with my left hand" without clarifying the precise arrangement of the robots. Additionally, due to time constraints and to prevent the redundancy of testing nearly identical designs, similar designs were combined to form cohesive interactions.

To systematically analyze the large volume of proposed designs and feedback, the interviews and the rest of the workshop artifacts were evaluated using Thematic Analysis. This qualitative method involved coding the data to identify patterns and themes. Initially, the facilitator familiarized themselves with the data by reading through all the transcripts and notes multiple times. Open coding was then conducted to label significant pieces of data related to participants' fidgeting behaviors, desired robot interactions, and their impacts. These codes were grouped into broader themes such as "Fidgeting in Public", "Fidgeting in Private", "Toio System Limitation", "Achievable in Web App", "Positive Reaction", "Negative Reaction", etc.

Due to the large number of proposed designs, we chose to proceed with only a subset of them. Specifically, the interactions that could be achieved through the existing web UI (e.g., Figure 7 A) were excluded due to lack of significant difference, as were designs that were mentioned by only one participant (e.g., Figure 7 B and C). Subsequently, features and similar designs that received mention from at least two different participants were compiled. These selected designs were then developed into interactions for further evaluation during workshops. To assess the effectiveness of these refined interactions, the original participants were invited back for evaluation workshops. During these evaluation sessions, the participants tested the programmed interactions (described in sections 4.3 and 4.4), sharing their thoughts and reactions. The thematic analysis framework was again utilized to analyze this feedback.

3.5 Evaluation Workshop

The follow-up evaluation workshops were conducted on a one-on-one basis with the facilitator. In these sessions, a total of 8 participants examined the new and modified fidgeting interactions, which were informed by their feedback and ideas from the design workshops. They also completed a survey to systematically capture their thoughts on fidgeting with robots.

Each evaluation workshop spanned an hour, with the initial 45 minutes dedicated to hands-on interaction testing and the remaining 15 minutes reserved for completing the survey. Participants tested 8 interactions in total, 4 single robot interactions (discussed in section 4.3) and 4 multi-robot interactions (discussed in section 4.4). They spent approximately 5 minutes on each interaction. The participants were provided with a noise-canceling headset, which could be used at their own discretion to mitigate the noise generated by the robots' motors. In a sequence echoing the design workshops, they first evaluated the single-robot interactions before proceeding to the multi-robot interactions. After testing all the interactions, they filled out the survey to conclude the session.

During the evaluation workshops, participants were not able to modify the interactions but were encouraged to verbally share their impressions such as likes and dislikes, and suggest improvements. Additionally, a survey was introduced to gather structured feedback on various aspects of the interactions, including the preferred number of robots, desired responses from the robots (e.g., sound, light, movement, vibration), and what aspects of fidgeting with robots they found most compelling and engaging. This approach also enabled us to collect explicit responses on topics that occasionally arose during the design workshops. The survey included short-answer questions covering potential alternative applications for interactions with swarm robots, and the idea of robots initiating interactions autonomously.

4 RESULTS & DISCUSSION

In our study, we presented some of the needs and challenges of fidgeting behaviors of adults with ADHD as they relate to fidgeting interactions with robots, and presented and evaluated new fidgeting interactions designed by adults with ADHD during our design workshops. We also conducted a survey to see if the participants felt the interactions they tested during evaluation workshops could be considered as effective fidgeting interactions, with the findings illustrated in Figure 8. Moreover, we identified the key elements that adults with ADHD deem essential for an engaging fidgeting experience. Finally, we outline the factors essential for satisfying fidgeting interactions as identified by adults with ADHD, propose hardware improvements for the robots to enhance their suitability for fidgeting, and explore other potential applications for interacting with swarm robots.

4.1 Fidgeting Experiences & Preferences

The in-depth interviews focusing on participants' fidgeting behaviors highlighted the highly personal and individual nature of fidgeting. Participants expressed a wide range of fidgeting actions, such as playing with hair, feeling different textures, tossing objects, twisting pen caps, and swiping between phone screens, to name a few. These preferences were influenced by personal inclinations, lifestyle factors, and the availability of fidget tools. For example, P18 and P8 frequently fidgeted with water bottles because they were always at hand, whereas P15 preferred selecting from a diverse box of fidget items at home, indicating a desire for variety to suit different moods or needs. Similarly, P13 expressed a tendency to quickly tire of fidget tools, often trading them with friends. This finding largely echoes results from prior work that indicate the need for personalization and customization for fidgeting [8, 13, 17, 21] and reaffirms the need for programmable fidgeting devices such as the swarm robots we leverage in this work.

Participants also discussed the challenges of restraining their fidgeting, particularly in situations where it might be perceived negatively, such as during public speaking events or job interviews. They described an internal conflict between the urge to fidget and the need to appear professional, noting that suppressing their fidgeting often hampered their ability to concentrate.

These insights extend to their envisioned interactions with fidgeting with robots. In public settings, participants favored small, unobtrusive interactions to avoid drawing attention and disturbing others around them. In contrast, in private settings, they were open to more varied and unrestricted fidgeting interactions with robots, showing a preference for satisfying experiences.

4.2 Fidgeting with Single vs Multiple Robots

All participants universally categorized the single-robot interactions as suitable for fidgeting (Figure 8), noting "robot in itself is still capable of a satisfactory number of fidgeting interactions" (P12).

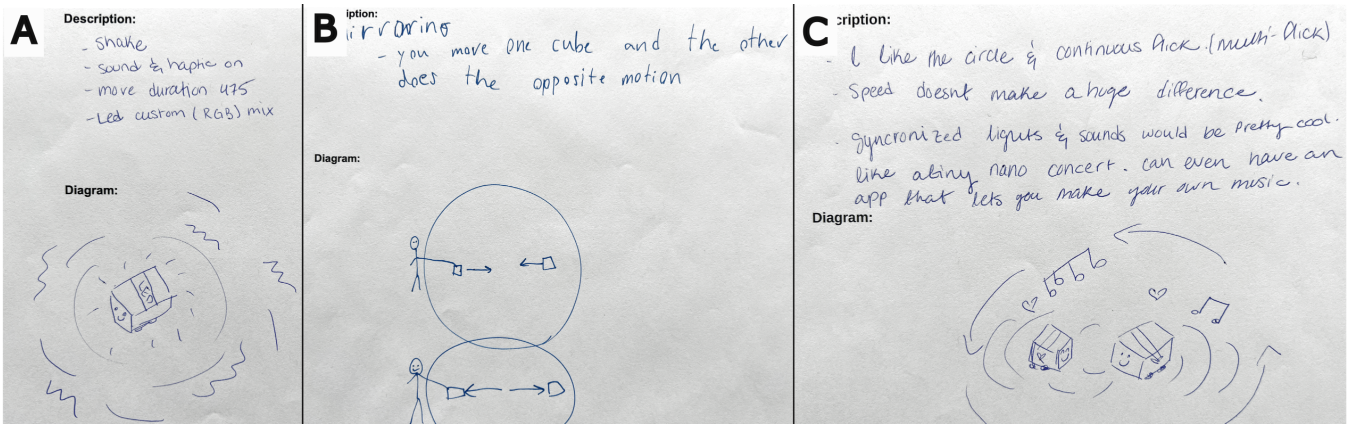

Figure 7: Examples of unimplemented designs. A is an example of an interaction that is feasible with the current UI shown in Fig 2, while B and C are ideas that were mentioned by only a single participant and thus were not chosen for implementation.

However, individual preferences played a big role in whether the participants deemed the interaction satisfying. For instance, P18 expressed "I think because they are all relatively simple, I would say they are good for fidgeting, although I did not like all the interactions".

Individual preferences also influenced how participants interacted with the robots, especially in terms of their preferred triggers and responses. For example, while a double tap or shake was most popular among participants to trigger responses like spinning or vibrations, respectively, some expressed a desire for alternative triggers, such as gently dropping the robot (P17) or tossing it (P5). Furthermore, there were specific aspects of the interactions that certain participants found enjoyable. In particular, P3 said, "I like the spinning one, but I would like to be able to feel it happening on my finger. Like I would linger my finger on top of it while it [spun]." Due to being indifferent to haptic feedback, P15 commented regarding the Vibration Pattern interaction (detailed in section 4.3) "I would shake it then [put] it onto the table and let it move back to me, and I could focus on something else with the motor as the audio cue on when to move it again."

The perception of whether multi-robot interactions can be classified as fidgeting seemed to depend on several factors: the simplicity and predictability of the interaction, the familiarity of the interaction, and each participant's individual perception of the interactions' stimulation level. The conveyor interaction (Figure 6), which consisted of five robots moving in unison in a predictable pattern, was unanimously deemed as fidgeting due to the briefness and simplicity of its movement, which did not overwhelm or overstimulate observers. The magnet interaction (Figure 4) served as an example of a familiar interaction. Since the robots were programmed to mimic the behavior of magnets, participants, already familiar with such interactions, required minimal focus for the interaction. For the more complex interactions evaluated during the evaluation workshops, opinions varied on whether they were considered fidgeting, largely due to the differing levels of stimulation perceived by each participant.

Therefore, the design of fidgeting interactions with robots must be carefully tailored to balance stimulation and familiarity, ensuring that they cater to the varied preferences and sensory thresholds of individual users. These findings are consistent with the studies by Diets et al. and Kim et al., which found that human perception of robot interactions is significantly influenced by factors such as speed, smoothness, and synchronization, impacting how emotionally stimulating or positive the swarm motions are [9, 26].

It is important to note that even if some interactions were not considered fidgeting by the majority of participants, there were always outliers who enjoyed these interactions and deemed them suitable for fidgeting. This is particularly significant in the context of fidget tools, which are often developed with the preferences of the majority in mind, thereby overlooking the needs of the minority. However, programmable actuated fidgets offer a unique solution, accommodating a wide range of preferences. This inclusivity allows anyone to engage in fidgeting in their preferred way, ensuring that even those with unconventional preferences can find satisfaction and utility in these tools.

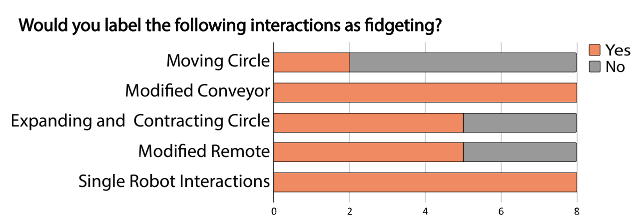

Figure 8: Overview of Interactions Deemed as Fidgeting by Participants

4.3 Single Robot Interactions Derived from Design Workshops

Based on the concepts developed during the design workshops, four unique single-robot interactions were implemented and evaluated in the subsequent evaluation workshops. The majority of the designs for single-robot interactions were minor modifications of the sample interactions that could be configured using the web UI

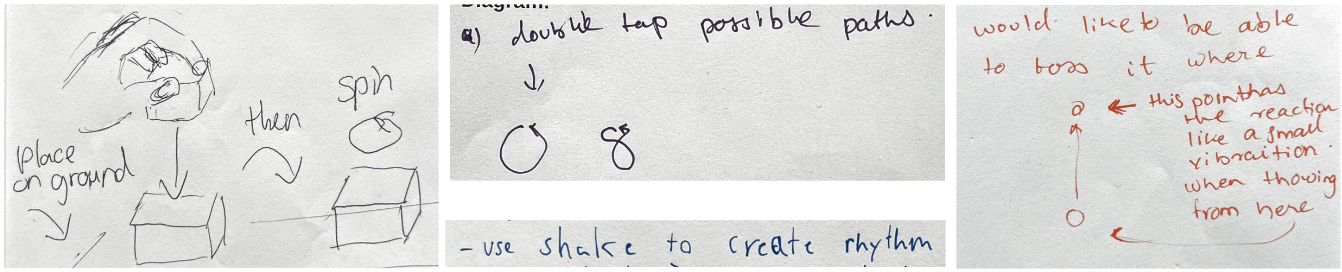

Figure 9: Examples of single-robot interaction designs: The left figure depicts the Spin interaction, the middle top figure is a sketch for the Infinity Loop interaction, the middle bottom figure contains the written description for the Vibration Pattern interaction, and the right figure shows the pictorial and verbal description of the Toss interaction.

(e.g., Figure 7 A). For this reason, we selected designs that could not be realized through the web UI alone. Figure 9 depicts some of the ideas from the design workshops that were used to implement the single-robot interactions.

(1) Infinity Loop: When the user double-taps the robot, it commences movement in a path resembling an infinity loop, as shown in Fig. 9.
(2) Spin: If the robot is lifted and then placed on a surface or double-tapped, it initiates a spinning action, altering directions after each rotation, completing a total of four turns, as shown in Fig. 9.
(3) Vibration Pattern: By shaking the robot, users can initiate a vibration pattern. This pattern can be changed to a different rhythm by pressing the button located at the base of the robot.
(4) Toss: Tossing and subsequently catching the robot triggers sound feedback, as shown in Fig. 9.

4.4 Multi-robot Interactions Derived from Design Workshops

Four multi-robot interactions were programmed based on participant feedback during the design workshops and were evaluated during the evaluation workshops.

4.4.1 Expanding and Contracting Circle. A controller robot is used to alter the radius of the circle formed by five other robots (Figure 10). Users can increase the radius by tilting the controller upward, decrease it by tilting downward, and toggle haptic feedback on the controller with a double-tap function. This setup allows users to directly manipulate the robots' formation and feel corresponding vibrations through the controller.

From the evaluation workshops, five out of eight participants found this interaction appropriate for fidgeting (Figure 8). P5 enjoyed the visual aspect and simple interaction with the controller, and P18 appreciated the haptic feedback and control over the circle's dynamics. However, P15 felt it required visual attention to be satisfying, thus, not aligning with their concept of fidgeting.

4.4.2 Modified Conveyor. In this interaction, any robot's displacement from it's position will trigger a shift in the positions of the robots. Additionally, the setup was altered to accommodate left-handed use, allowing the dominant hand to remain free for other tasks. The updated robot configuration is shown in Figure 11.

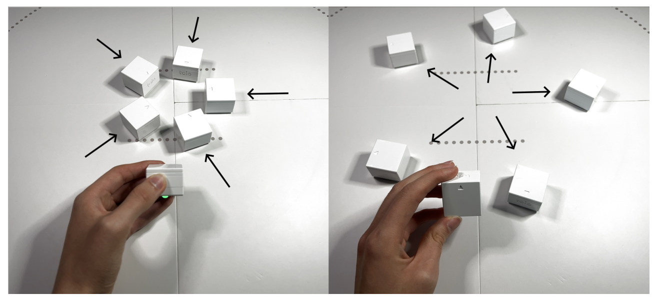

Figure 10: Expanding and Contracting Circle: Tilting robot down to decrease the radius (left). Tilting the robot up to increase the radius (right).

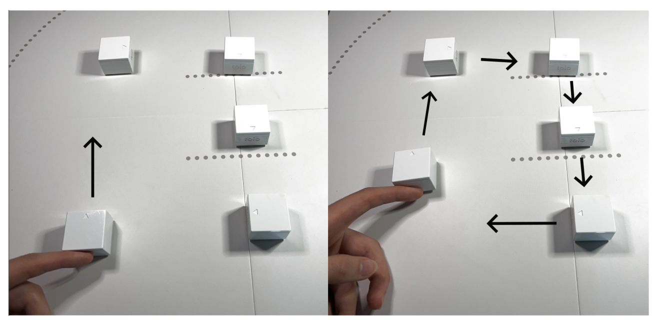

Figure 11: Modified Conveyor Interaction: Displacement of any robot causes the shifting of the robots. This interaction was modified to be used with the left hand so that the right hand is available for the primary task.

All participants from the evaluation workshops found this interaction appropriate for fidgeting due to its simplicity and the predictable movements of the robots, which allowed for undivided attention on primary tasks (Figure 8). P14 valued the left-handed design for multitasking. P15 enjoyed the ease of passive engagement, stating, "I could passively flick it without looking at it, and the audio cue would let me know when to flick it again." P17 appreciated the non-disruptive nature of the interaction, remarking, "I can flick it and not focus on whether the robots would fall off or be misaligned."

4.4.3 Modified Remote. The Remote interaction was modified to mitigate issues identified in the design workshops, such as robots rolling off the table and requiring excessive attention. Movement was restricted to 5cm advances or retractions and 90-degree rotations, simplifying control and aligning with the interaction's fidgeting intent (Figure 12). These changes prevent loss of control and minimize distraction, allowing users to focus on their main tasks while engaging with the robots, which can now be arranged in various patterns for visual or auditory feedback with minimal attention required.

Five out of eight participants from the evaluation workshops found this interaction appropriate for fidgeting (Figure 8), focusing on the remote's use and the white noise from the robots' movement. However, three found its versatility overly engaging. P15 commented that "a lot of focus and brain power was devoted to what cool patterns I could make and how to tweak the patterns to be better."

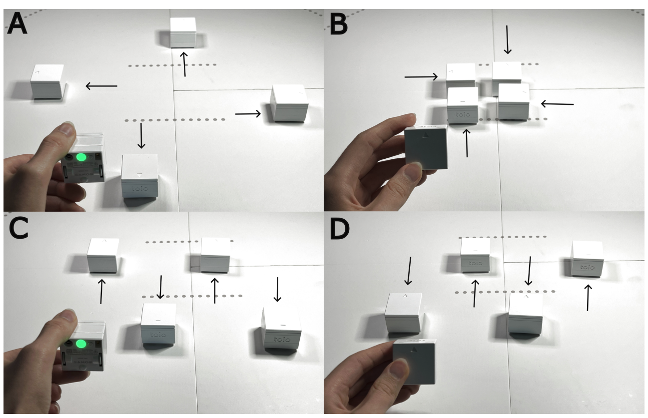

Figure 12: Modified Remote: Allows users to arrange robots in a desired pattern and more them using the controller robot

4.4.4 Moving Circle. Five robots move synchronously in a circular formation, maintaining a uniform distance from one another. They are controlled by a sixth robot that starts, stops, and alters the speed and the radius of the circular movement. Users can interact by disrupting the pattern for tactile and visual feedback or by using the controller for auditory feedback through changes in motion speed (see Figure 1).

From the evaluation workshops, two participants considered the Moving Circle interaction appropriate for fidgeting (Figure 8). Others, found the interaction enjoyable but felt it was too complex for fidgeting, with P3 citing the multitude of components and P8 and P5 likening it to playing. However, some, like P12, enjoyed specific aspects, such as observing the effect of their actions on the 'moving circle'.

4.5 Likelihood of Future Usage

We were interested in assessing participants' attitudes toward the future usage of the evaluated interactions. A Likert scale, ranging from 1 (Very low) to 7 (Very high), quantitatively captured participants' intentions to continue using the fidgeting interactions (Figure 13). These ratings fare similarly or slightly higher than the ones from the exploratory study in SwarmFidget, potentially due to our interactions being co-designed with participants [25]. Single Robot Interactions were well-received, with most participants indicating a high likelihood of future use. The Modified Conveyor interaction stood out among multi-robot interactions, with the majority rating the likelihood of future usage as 6 or above. Similarly, the Modified Remote interaction also received favorable ratings. In contrast, the Expanding and Contracting Circle interaction had mixed responses, and the Moving Circle interaction received comparatively lower ratings, with several participants neutral about future use. Overall, with all interactions averaging above 4, the results suggest a positive trend in accepting and continuing to use robots as fidget devices.

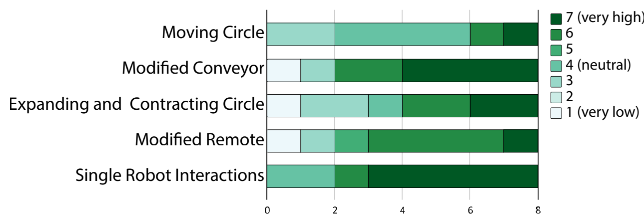

Figure 13: Participants' ratings of the likelihood of future usage for different fidgeting interactions.

It is important to note that these attitudes toward the likelihood of future usage were based on our implementation of programmable actuated fidgets, considering all of its current flaws identified by the participants. We expect that if the suggested hardware improvements (discussed in Section 4.8) are made and a system is developed that allows users to easily create and modify their own fidgeting interactions, the attitudes toward programmable actuated fidgeting would become even more positive.

4.6 Importance of Customization

The survey from the evaluation workshops, combined with the participants' comments, has emphasized the importance of customization in fidgeting interactions with robots, which is aligned with findings from prior work [8, 13, 17, 21]. The data, as illustrated in Figure 14, clearly displays a wide range of participant preferences. This is particularly noticeable in categories such as robot speed, where the choices of participants cover the full spectrum. In haptic feedback, most participants preferred medium to very strong intensity, although there were exceptions, with one participant favoring minimal feedback (Figure 14).

Furthermore, participants' comments also provide deeper insights into their satisfaction levels when interactions align with personal preferences. For instance, positive feedback was given when robot speeds matched individual preferences, with remarks such as "It feels like it's going as fast as my brain" (P3), "I found it

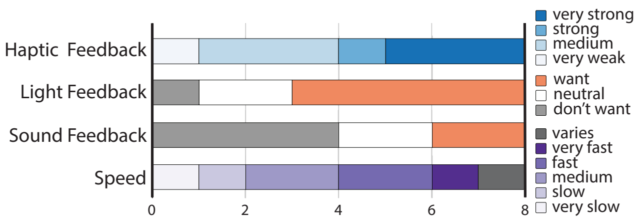

Figure 14: Participants' preferences on the intensity of haptic, light, and sound feedback, and robot speed.

quite satisfying when it moved slowly" (P15), and "slow is soothing" (P5). Additionally, haptic feedback was highly regarded by participants like P17, who described it as "satisfying." Visual stimulation from light feedback also received positive comments, such as "I want to be able to see light variability" (P12) and "the light feedback is cute" (P3).

Conversely, less preferred aspects, such as certain speeds and sound feedback, elicited strong negative reactions. Participants expressed discomfort with comments like "I hate slow things; they bug me" (P8), "I found the sound feedback very annoying" (P18), and "it's shrill, distracting, and hurts my head" (P14). These negative reactions highlight the dissatisfaction that arises when interactions fail to meet individual preferences.

These findings illustrate the diverse needs and preferences in fidgeting interactions with robots. The extensive range of both positive and negative feedback regarding the robots' speed, sound, haptic, and light feedback highlights the emotional impact of these fidgeting experiences. The strong preferences and reactions, especially toward the speed and sound, might be explained by hypo- and/or hyper-responsiveness since people with ADHD might exhibit hypo- or hyper-responsiveness to certain stimuli [39]. The diverse preferences observed reinforce the importance of customization, emphasizing that for fidgeting interactions with robots to be truly engaging and effective, they must be tailored to meet the unique preferences of each user.

4.7 Features Essential for a Satisfying Fidgeting Interaction with Robots

The design workshops, along with evaluations of new and modified fidgeting interactions, identified the immediate response from robots as the most essential feature for a satisfying fidgeting experience, as shown in Figure 15. Any delay or inconsistency between the user's action and the robot's reaction significantly diminished satisfaction. This critical need for prompt responsiveness was corroborated by a survey in which 7 out of 8 participants deemed it necessary for satisfying interactions, while one participant preferred it as an optional feature.

The design workshops revealed that users valued the synchronicity and precision of movements in interactions involving more than one robot. Concerns arose when the robots' movements were unrestricted, as participants worried about accidentally dropping them. This led to a need for constant vigilance to prevent the robots from rolling off surfaces or colliding with objects. In the survey, as shown in Figure 15, four out of eight participants indicated that they wanted uniform movements as an option, and three out of eight indicated that uniform movements are necessary for satisfying fidgeting interactions.

The quietness of the motor and speed emerged as more significant factors. Participants found the motors of the robots to be too loud when the robots were moving at higher speeds; four out of eight participants indicated in the survey that the quietness of the motor is essential for a satisfying fidgeting experience. Additionally, four out of eight participants expressed a desire for the option of faster speeds during their fidgeting interactions, and P8 considered faster speeds essential due to their pronounced distaste for slower speeds (Figure 15).

The inclination towards uniform movements may stem from the potentially distracting effect of non-uniform movements, which can be overwhelming for effective fidgeting purposes, as mentioned in prior work [25]. The comments regarding the noise generated by the motors of the robots echo results from prior work indicating that people avoid fidgeting objects that are too loud [36].

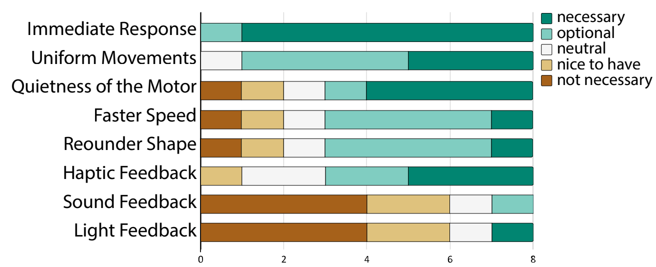

Figure 15: Overview of features essential for satisfying fidgeting interactions with robots.

4.8 Hardware Improvements

During the design and evaluation workshops, participants were interviewed and surveyed about potential hardware improvements to enhance robots for fidgeting purposes. From this feedback, three prominent themes for enhancement emerged: focusing on the robot's physical texture, stability features, and the addition of customizable elements, each contributing to a more tailored and satisfying fidgeting experience. The robot's physical characteristics, such as appearance and tactile qualities, play a significant role in shaping the user's fidgeting experience. Many participants indicated a preference for a softer texture, suggesting a shift from hard plastic to a softer, rubbery material, which was also mentioned frequently in prior work [8, 21, 25]. They also favored a rounder form or rounded edges to enhance ergonomic comfort and facilitate a more pleasant tossing experience. These suggestions align with prior work by Karlesky and Isbister, as well as Nyqvist [21, 36]. Additionally, feedback suggested improving the robot's light visibility by moving the light source from the bottom to the top of the robot.

Stability and addition of customizable elements were also identified as areas for improvement. Participants noted that the robots should have increased weight or an improved weighting system to maintain balance, especially for interactions that involve altering the robot's position on the tracking mat, typically achieved

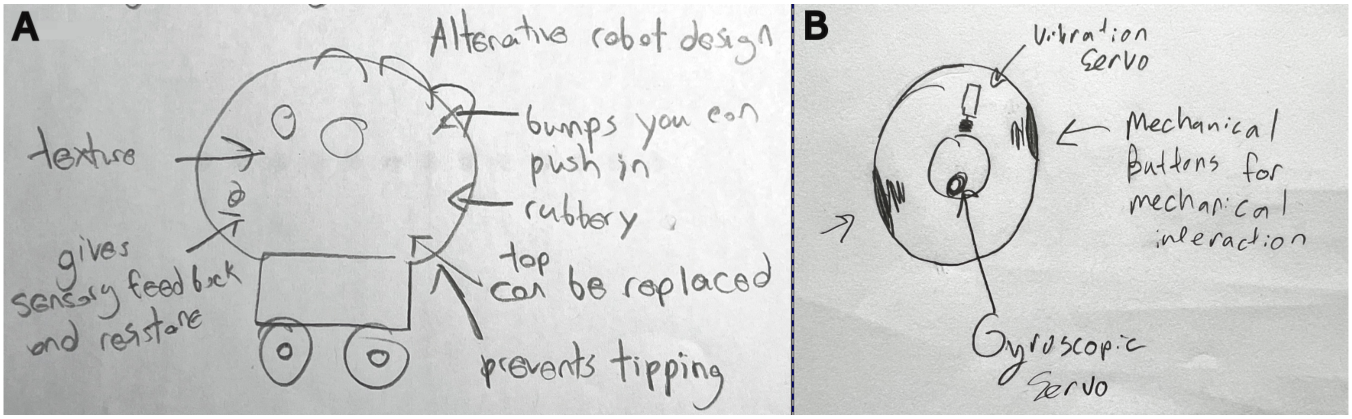

Figure 16: Suggested physical design for robots intended for fidgeting. A shows a rubbery sphere being attached to the top of the robot, while B shows a sphere that contains all the mechanisms necessary inside.

by flicking or pushing. Furthermore, there was a strong interest in customization, with ideas ranging from 'sensory stickers' (P11) to 'cat ears' (P17) and 'googly eyes' (P5, P17, P3). P18 proposed a unique concept of attaching a removable and replaceable stress ball on top of the robots for stress relief and stability enhancement, as shown in Figure 16 A. P13 suggested a spherical body for the robots with a gyroscopic servo at the center of the sphere and a vibration servo at the top of the sphere shown in Figure 16 B. Participants also expressed a desire for more color options, with P17 and P3 showing interest in colors beyond the standard white, indicating a preference for robots that can reflect users' personal styles.

4.9 Other Potential Applications of Interacting with Swarm Robots

During the design workshops, participants conveyed that their interactions with swarm robots had a calming effect. This experience prompted them to contemplate scenarios where engaging with these robots could become a focal activity, rather than a secondary one complementing a primary task. The interactions were found to be so enjoyable that discussions about wanting to interact with the robots as a primary task emerged naturally in every design workshop. These insights compelled us to survey participants at the end of the evaluation workshops about other potential uses for swarm robot interactions and their preferred number of robots for such interactions. Additionally, inspired by Kim et al.'s observation that robots could proactively initiate interactions [25], we included questions in the survey to gauge participants' interest in this feature and to identify situations where it would be beneficial for swarm robots to autonomously initiate interactions.

4.9.1 Soothing or Relaxation. The uniformity of movement, unique to interactions with robots, stood out for participants and was frequently described as "calming" (P14) or "soothing" (P18), with the robots' coordinated and predictable motions as well as the white noise created by the motors providing a sense of relaxation. Consequently, participants envisioned using robot interactions for relaxation, such as "playing and de-stressing after a day" (P8). P17 further emphasized this potential, noting the relaxing effect of slower movements: "If the robots are slower, it can be good to relax since you can just look at the patterns made by the robots." P5 and P15 saw potential in swarm robots for "meditation" and "meditative purposes like soothing or de-stressing," respectively. Some participants commented that they could use the interactions in more severe situations like "getting through an anxiety attack" (P18). P6 found the interactions to be "a nice distraction and a rhythm or pattern seems to make you feel like you are in control still" and therefore could be used as a distraction if they were "feeling anxious or panicky". Interestingly, the preferred number of robots for interactions aimed at soothing purposes was higher than for fidgeting, with most participants favoring at least four robots (Figure 17).

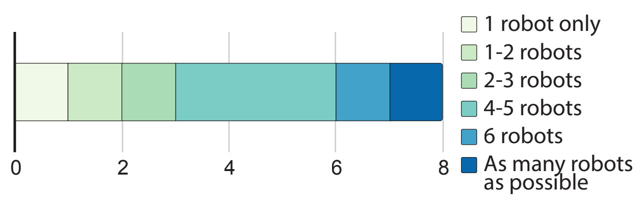

Figure 17: Participants' preferred number of robots for interactions meant for soothing purposes.

4.9.2 Means of Intervention. The survey revealed substantial interest in the robots' potential to initiate interactions as a means of intervention in a variety of scenarios. Five out of eight participants expressed interest in the robots initiating interactions to intervene in situations such as "panic attacks or self-destructive behavior like doom scrolling" (P15). P3 recognized the potential for robots to detect and respond to "anxious behaviors" or to vocal expressions of distress. P12 saw the robots acting as reminders to move, especially for individuals who have been sedentary for extended periods during work. However, not all participants were in favor of such proactive interactions. P17 had concerns about privacy, while P14 expressed a general mistrust of technology. P8 preferred to self-manage the use of fidgeting tools, stating, "I feel I'm good at knowing when [and] what I need for fidgets." While the prospect of robots autonomously initiating interventions was met with interest and perceived as beneficial by many participants, it also raised valid concerns about privacy and autonomy, highlighting the need for careful consideration and customization in their implementation.

5 LIMITATIONS & FUTURE WORK

For the current study, we chose to use a specific robot platform, Sony Toio robots, for its simplicity. However, this platform also presents several technical limitations for fidgeting in terms of its features and design. First, the shape of the robots was not perceived as ideal for fidgeting indicating that ergonomics and design could be improved to enhance the fidgeting experience. The robots also lacked an internal motor for vibration prompting the need to rely instead on wheel movement to create haptic feedback. This forced the participants to hold the robots in a manner that would not obstruct wheel motion, rather than in their preferred way. Additionally, the position tracking of the robots was constrained by the size and shape of the accompanying mat, limiting their movement and interaction space.

Concerns were also raised relating to the sensitivity of the robots' triggers. Instances were noted where taps that were too light or movements that were too rapid resulted in non-detection, specifically for interactions where one of the robots was used to control other robots, pointing to the need for enhanced responsiveness in future robot iterations.

Moreover, the process of setting up, turning on the robots, and placing the mat on a suitable surface, was found to be cumbersome. This could be seen as a possible deterrent that keeps potential users from utilizing these robots in their daily routines due to the perceived hassle. Conversely, the use of a single robot for rudimentary interactions, such as shaking or tossing, was acknowledged as sufficiently portable, suggesting its adaptability in various scenarios.

In our co-design study, we focused solely on adults with ADHD, gaining valuable insights into their specific needs and preferences. However, the small sample size of our study limits the generalizability of the results to all adults with ADHD across different demographics and especially to older adults as most of the participants were between the ages of 18-31. Future research should also aim to contrast the needs and preferences of adults with and without ADHD to enhance our understanding of how to optimally design swarm robot-based fidgeting tools for both groups.

Looking ahead, there are several promising directions for future exploration. One intriguing direction is examining the potential of swarm-robot-based fidgeting to enhance previously known fidgeting benefits like creativity [21], concentration [3], and emotion regulation [46]. It would be worthwhile to compare the impact of these advanced, tailored swarm-robot fidget devices against the effectiveness of standard, one-size-fits-all fidget tools. Building on our co-design exploration, conducting longer-term studies to investigate the long-term efficacy and usability of swarm-robot-based fidgeting devices among individuals with ADHD will be beneficial.

Another important area for future research is identifying the optimal conditions for robots to autonomously initiate a fidgeting interaction. Given that participants have shown interest in using robots for relaxation, it may be particularly beneficial for robots to initiate interactions during moments of distress. Additionally, it will be interesting to explore the preferred modalities of interaction initiation (e.g., visually via lights or movements like spinning, aurally via sound, or haptically through physical touch) and how these preferences vary among adults with ADHD.

6 CONCLUSION

Through the co-design study, we demonstrated that there is a great diversity in the perceptions and preferences of adults with ADHD in relation to fidgeting with swarm robots. The diversity observed in participants' preferences demonstrated the need for customizability of fidgeting interactions, to allow individuals to tailor their interactions according to personal preferences and environmental constraints. Moreover, we identified the essential components needed to create satisfying fidgeting interactions with swarm robots. The study also highlighted areas for potential hardware improvements of the robots. Beyond the primary scope of fidgeting, we discovered other potential uses for swarm robots, as relaxation aids or interventions in certain scenarios. These findings demonstrate the potential of swarm robots for use as assistive technologies for adults with ADHD. We hope these findings can inspire future research in the area of assistive technologies utilizing swarm robots.

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