SwarmFidget: Exploring Programmable Actuated Fidgeting with Swarm Robots

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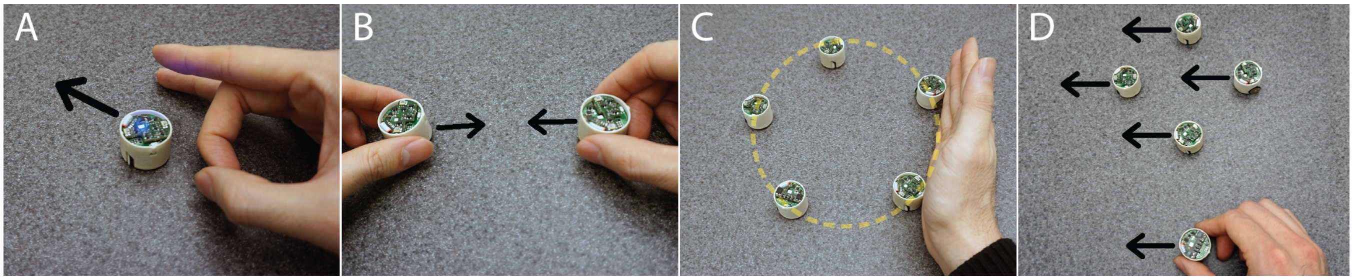

Figure 1: Example Fidgeting Interactions: A) *Flicking* where the robot returns after being flicked or displaced, B) *Magnet* where robots are either attracted to or repelled from one another, C) *Circle* where the robots form a shape and return to the shape when disturbed, and D) *Remote Control* where moving the robot on the bottom moves other robots correspondingly.

ABSTRACT

We introduce the concept of programmable actuated fidgeting, a type of fidgeting that involves devices integrated with actuators, sensors, and computing to enable a customizable interactive fidgeting experience. In particular, we explore the potential of a swarm of tabletop robots as an instance of programmable actuated fidgeting as robots are becoming increasingly available. Through ideation sessions among researchers and feedback from the participants, we formulate the design space for SwarmFidget, where swarm robots are used to facilitate programmable actuated fidgeting. To gather user impressions, we conducted an exploratory study where we introduced the concept of SwarmFidget to twelve participants and had them experience and provide feedback on six example fidgeting interactions. Our study demonstrates the potential of SwarmFidget for facilitating fidgeting interaction and provides insights and guidelines for designing effective and engaging fidgeting interactions with swarm robots. We believe our work can inspire future research in the area of programmable actuated fidgeting and open up new opportunities for designing novel swarm robot-based fidgeting systems.

CCS CONCEPTS

• **Human-centered computing → Haptic devices**; *Collaborative interaction.*

KEYWORDS

fidgeting, swarm robots, tangible user interface

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1 INTRODUCTION

During periods of inattention or mind wandering, people commonly engage in fidgeting [5], defined as a repetitive non-goal-directed action [39]. Fidgeting contributes to the self-regulation of the user's mental and emotional states, their focus, creativity, and energy level to accomplish the task at hand [21]. Fidgeting is performed with the body, such as swinging one's leg or tapping with a finger, or using surrounding multipurpose objects such as a pen or a keyholder, or dedicated fidgeting devices like the fidget spinners or fidget cubes [21]. Attempts were undertaken to enhance fidget devices with advanced technology, such as sensors and displays, and computation power [19, 30, 52]. However, no works exist that explored fidgeting with actuated devices.

Our research work fills this current gap in fidgeting by introducing *Programmable Actuated Fidgeting* and *SwarmFidget* (see Figure 1). Programmable Actuated Fidgeting refers to a type of fidgeting that involves devices integrated with actuators, sensors, and computing to enable a customizable interactive fidgeting experience. Users can input commands through various modalities such as touch or gesture, and the actuators in the fidgeting device will respond in a programmable manner to provide haptic, visual, or audio feedback. This type of fidgeting allows for a dynamic and customizable interaction that can be tailored to individual preferences and needs. SwarmFidget is an instance of a platform that enables programmable actuated fidgeting through the use of swarm robots.

With advances in technology and the exponential growth of artificial intelligence, automation is steadily penetrating our everyday lives. In particular, robots are gaining more autonomy: they start sharing space with humans and work with them in tandem [8]. Autonomous robots are widely deployed in our daily lives in the forms of vacuum robots (e.g., iRobot's Roomba) [14], security robots (e.g., Knightscope, Inc) [35], delivery robots (e.g., Savioke Relay and Starship Technologies) [50], and home assistants (e.g., Ballie by Samsung, Astro by Amazon). As humans tend to fidget with surrounding multi-purpose objects (e.g., pen), we envision that people may fidget with the robots that surround them. Arguably, such fidgeting interaction will be of a different nature, due to the difference between robots and conventional fidgeting objects (e.g., pens, keys, fidget toys, etc.). The latter is passive and yields full control to people while robots can be programmed to various automatic behaviors and responses. We argue that fidgeting with automated objects, although not explored, is possible and worthy of exploration.

Investigating fidgeting with automated objects could shed light on the users' preferences and behaviors and help design better fidgeting tools and more advanced human-robot interaction in the future. For this project, we focus on tabletop swarm robots - robots resting on the top of the desk while people engage with knowledge work at that desk. The fact that both grown-ups and kids tend to fidget with surrounding objects (e.g., pens, clippers, erasers) while performing knowledge work [7, 21] makes us believe that people might fidget with co-present tabletop robots. The goal of this project is to explore such programmable actuated fidgeting interaction with small tabletop robots.

Swarm robots are autonomous robots with sensing and communication capabilities that can act on tasks collaboratively. Swarm robots exist in a variety of designs and implementations [4]. Tabletop swarm robots are small wheel-propelled robots with position and touch-sensing capabilities capable of acting as a display, initiating actions, and reacting to the user's input, see, for example, Zooids [28]. Users tend to interact with tabletop swarm robots with gestures, as well as through physical contact - touching, grabbing, pushing, etc [22]. Tabletop swarm robots are intended to be co-present on the table while a person is doing knowledge work, where the application cases can vary from haptic notifications [24] to visual display [23, 41] to data physicalization [28, 29].

By using a swarm of mobile tabletop robots, we aim to provide a more engaging and interactive fidgeting experience that takes advantage of the collective movement and dynamic physicality of the robots. We explore the design space of fidgeting interactions enabled with swarm robots, ranging from simple repetitive movements to more complex and dynamic behaviors, which are discussed in the Design Space section. Our study involves a user-centered design approach, where we work closely with participants to elicit potential fidgeting interactions with swarm robots. We then conduct a series of interviews and a demo of six example fidgeting interactions to explore the usability, user experience, and areas for improvements of the actuated fidgeting with swarm robots.

Our contribution is twofold: first, we introduce the concept of *Programmable Actuated Fidgeting* and *SwarmFidget* to demonstrate the potential of swarm robots as an instance for realizing programmable actuated fidgeting. Second, we provide preliminary insights and guidelines for designing effective and engaging fidgeting interactions with swarm robots, based on our study. We believe our work can inspire future research in the area of programmable actuated fidgeting interaction and open up new opportunities for designing interactive robotic systems for fidgeting.

2 RELATED LITERATURE

The most relevant related areas of research to this work include fidgeting, the design of fidgeting devices, smart fidgeting devices, and swarm robotics & swarm user interfaces.

2.1 Fidgeting

Fidgeting is a non-goal-directed activity, which is usually repetitive or patterned and is both self-initiated and self-sustained [10, 39]. According to Mehrabian and Friedman [31], fidgeting is likely to occur when one's physical activity is constrained by another focal task. Fidgeting is typically initiated subconsciously - a fidgeting person may be aware or unaware that they are fidgeting, but fidgeting is usually terminated, resisted, or permitted intentionally and consciously [39].

Fidgeting has been typically considered to be indicative of mind-wandering [5], a lack of attention [16], and decreased memory [45]. On the other hand, a growing body of studies reports a variety of beneficial effects caused by fidgeting. In particular, authors advocate that fidgeting can assist in sustaining focus and optimizing attention [2, 21], reducing stress [39], increasing playfulness and creativity [36]. Moreover, fidgeting can act as a means of exercising [27] and improving motor skills [6], as a mechanism to trace depression [40], and as a tool to track mental states [52].

The literature differentiates between small or micro-fidgeting, which refers to fidgeting with one's hands or fingers, and macro-fidgeting, which involves movements of body parts or the entire body, e.g., pacing back and forward, bouncing one's leg or rocking in a chair [12, 36]. For diagnostic purposes, hand fidgeting movements are of specific interest; researchers differentiate between movements with a specific trajectory pattern (repetitive movements), and small movements whose trajectory lacks clear spatial direction (irregular movements), e.g., fiddling with one's fingers [40]. Da Câmara et al. [7] argue that fidgeting can be of two categories: 1) body movements without engaging objects, and 2) repetitive hand movements manipulating objects. Perrykkad and Howvy [39] outline different modalities of fidgeting: visual, vestibular, tactile, etc. Nyqvist [36] differentiates between low-focus, i.e., subconscious, fidgeting and high-focus fidgeting; low-focus fidgeting is likely to increase focus and benefit convergent thinking whereas high-focus fidgeting increases mind wandering and benefits divergent thinking.

2.2 Design of Fidgeting Devices

A body of work focuses on identifying people's fidgeting tendencies and preferences in fidget toys' design. Several projects highlight that fidgeting preferences are very personal and propose customized or adjustable fidgeting artifacts. For example, Fogal et al. [13] designed a teardrop-shaped fidget device with adjustable fidgeting features. In the project by Hansen et al. [17], students designed a personalized hand-held fidget to use in a classroom with the goal of increasing focus. Nyqvist [36] summarizes that, although fidgeting preferences are personality-dependant, people tend to avoid too loud or too childish-looking objects. The study of Karlesky and Isbister [20] revealed that, for fidgeting devices, tactile and tangible experience plays the central importance, that is effective combinations of materials and interactivity would cause satisfying in-hand stimulation and experiences. Da Câmara et al. [7] identified that a) children (age between 6 to 11) prefer fidgeting with multipurpose devices of softer materials that make subtle sounds, b) children engage in pressing-clicking-tapping interaction when they are bored or in the middle of a concentration-demanding cognitive task, and squeezing interaction when they are angry or stressed. Based on the findings, there is a clear need for programmable actuated fidgeting devices as they provide programmable tactile feedback that can tailor to different user preferences.

2.3 Smart Fidgeting Devices

A variety of automation-related aspects were explored in relation to fidgeting. In particular, several research studies investigated tracking the user's state by embedding sensors into fidget toys. For example, Woodward and Kanjo [52] developed iFidgetcube - a device that, in addition to fidget features, embeds several physiological sensors; analyzing sensor data using deep learning classifiers allows inferring the user's well-being. Some sensing fidgets also provide feedback. For example, BioFidget [30] is a biofeedback device that integrates physiological sensors and an information display into a smart fidget spinner for respiration training. Several authors explored the usage of more advanced technology for fidgeting. For example, Karlesky and Isbister [19, 20] designed several fidgeting experiences using Sifteo Platform - a set of interactive cubes comprising a touch-sensitive display and a variety of sensors. Ji and Isbister [18] developed AR Fidget - a system based on AR glasses that combines fidgeting strategies (tapping and swiping) with interactive AR visual and auditory experiences to guide users toward a desired emotional state. In an attempt to interconnect fidgeting with home automation, Domova [9] designed a fidgeting device concept that, in addition to conventional fidgeting, allows interacting with smart light and fidgeting with its properties, such as brightness and color.

Although a variety of smart fidgeting tools were developed, they mainly focus on the sensing aspect like touching behavior and emotion tracking and do not support programmable actuated fidgeting. In contrast, SwarmFidget can enable programmable actuated fidgeting through the use of swarm robots.

2.4 Swarm Robotics & Swarm User Interfaces

Roboticists have drawn inspiration from biological swarms to develop swarm robots, where a large group of robots is coordinated to achieve a common goal. Swarm robots offer many advantages, including swarm intelligence, flexibility, and robustness to failure. Some swarm robotic platforms can emulate swarm behaviors using distributed intelligence and fully autonomous agents, with as many as 1,000 robots [41]. While many studies have examined the functional aspects of swarm robots, such as control [1, 3, 44], fewer have focused on the physical interaction with them. With robots becoming more abundant and smaller, it is important to investigate how to interact with a swarm of robots.

There has been a growing trend among HCI researchers to develop swarm user interfaces for interactive applications such as data visualization [28, 29, 49], haptic feedback in VR [11, 47, 48, 54], and education [15, 38]. While many studies have examined the use

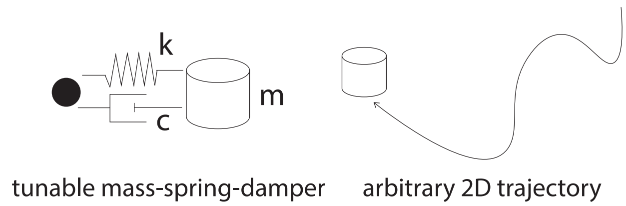

Figure 2: Programmable Behavior is one of the primary features of programmable actuated fidgeting. In the context of SwarmFidget, as shown on the left, we show that a robot can be programmed to behave as if it was connected to a point via virtual spring and dampener where the mass (m), spring constant (l), and damping coefficient (c) are allprogrammable. As shown on the right, robots could also move in any arbitrary 2D trajectory.

of robot motions for interaction and how they impact user perception like emotion [23, 42] and legibility [25], fewer studies have focused on haptic interaction with a swarm of robots, particularly in bi-directional haptic interaction. Ozgur et al. investigated haptic interaction with a handheld mobile robot that could potentially be expanded to a swarm of robots [37], while Kim and Follmer explored the perception of haptic stimuli from swarm robots and user-defined haptic patterns for conveying social touch [24]. In this paper, we study how a swarm of robots can be used for bi-directional haptic interaction in the context of fidgeting. We examine how robots can actively and dynamically facilitate fidgeting and how people perceive and respond to such a concept.

3 DESIGN SPACE OF SWARMFIDGET

Through independent and collaborative rapid ideation sessions, sketches, and discussions, a group of four HCI researchers delved into the concept of fidgeting with swarm robots and explored its unique affordances and design space as compared to commercial fidgeting devices like fidget spinners. The process of rapid ideation generated tens of ideas and sketches for fidgeting with robots that were inspired by the design parameters discussed below. Ideas from the study participants that the researchers did not come up with are also included below. As we use the definition of fidgeting from Carriere et al. [5], repetitive non-goal-directed action, any ideas that involve an explicit purpose or goal (e.g., any game-like interaction), or are non-repetitive (i.e., one-time action) were discarded.

3.1 Programmable Behavior

Conventional fidgeting tools are limited in their behavior, as they rely on passive mechanical components such as springs. In contrast, swarm robot-based fidgeting allows for programmable behaviors, as the robots can be programmed to move in any 2D trajectory and react to user input in arbitrary ways. For example, a robot can be programmed to behave as if it were connected to a specific point by a spring, and when displaced from the equilibrium point, it will return to equilibrium as shown in Figure 2. The spring constant of this virtual spring can also be fixed or variable depending on the situation. The programmability of the robots' behavior adds a new

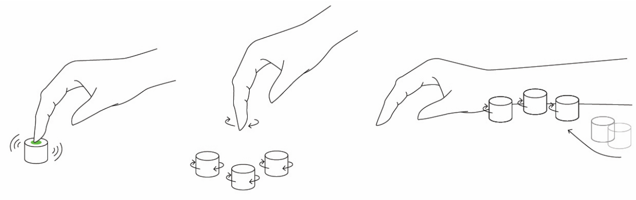

Figure 3: SwarmFidget allows fidgeting through different modalities including touch, gesture, color, and visual motion

dimension to fidgeting, allowing for a diverse range of interactions not limited by the passive mechanical components.

3.2 Interaction Modality

The design space of SwarmFidget extends to the use of diverse modalities for both user input and robot feedback as shown in Figure 3. Users can choose to interact with the robots directly through touch or indirectly through gestures with their hand or other body parts. In terms of robot feedback, the modality options include active or passive haptic feedback, meaning that the robots can initiate the interaction or the person can start it themselves. Additionally, visual feedback can be conveyed through the use of colors and motion of the robots. Audio feedback can be provided both intentionally through external speakers and unintentionally through the sounds of the motors. By offering a range of modalities for input and feedback, SwarmFidget can extend its potential use scenarios for fidgeting with robots, cater to users' different preferences and needs, and provide a more immersive fidgeting experience.

3.3 Leveraging Swarmness

Having a swarm of robots dramatically increases the scale of interaction from a simple dyadic interaction and can enrich fidgeting interaction in various ways. First, instead of being limited to just interaction with one robot, users can interact with multiple robots using both hands as shown in Figure 4. This can be desirable or undesirable depending on whether one hand is already being used for a primary task such as writing or reading. Second, the robots can form complicated shapes or patterns, as demonstrated in prior work [1, 41] and as shown in Figure 4, that users may find more interesting or stimulating to fidget with compared to a single robot. Furthermore, a few participants mentioned that the patterns or shapes could be dynamic meaning that the robots are not only forming different shapes but are also constantly moving while maintaining their shape.

In addition, the swarm can reduce any downtimes that may be experienced when interacting with just one robot, similar to an assembly line. For instance, when repetitively pushing a robot that is programmed to return to its original position, there may be times when the user displaces the robot far away, and it takes a relatively long time for the robot to return, resulting in undesirable downtime for fidgeting. However, with a swarm of robots, when one robot is displaced and is slowly returning, another nearby robot(s) could return instead, allowing users to fidget at a faster pace as shown in Figure 4.

Another commonly known benefit of having a swarm of robots is its robustness, which will be useful for fidgeting as well. When a robot fails (e.g., due to low battery, broken wheels, etc.), the redundancy of the system allows the remaining robots to adapt and replace the vacancy of the failed robot. How the robots adapt can be programmed and will depend on the circumstances. For instance, if eight robots were forming a circle and one of the robots fails, seven of the remaining robots can equally distribute themselves to form the same circle shape as shown in Figure 4. If a robot that was used as a handle to control other robots fails, then one of the remaining robots could become the new handle.

In addition to interaction with users, interaction among robots is a design parameter that can be leveraged for fidgeting. This aspect was brought to our attention by participants during the interview and demo of example fidgeting interactions. For instance, when a few of the robots in a circular formation were displaced, participants were observed interacting with how robots interfere with one another. During the post-demo interview, participants also mentioned how they would like to see the robots optimize assignments in terms of the total distance traveled by all robots, instead of having a fixed position for each robot within a circular format as shown in Figure 4.

3.4 Interaction Metaphors

As the researchers brainstormed different ways robots can be used for fidgeting, ideas were derived from familiar metaphors such as physics, pets, and existing toys or fidgeting devices. As mentioned earlier, the robots can be programmed to behave as if they were a physical system (e.g., mass-spring-damper, magnet, pendulum, etc.) whose behavior mimics the behavior of a spring where the robot will return to its equilibrium point upon disturbance as further explained in the "Flicking" example fidgeting interaction and shown in Figure 1A. Another example is magnetism where each robot could have a virtual polarity and be attracted or repelled to one another as described in the "Magnet" example fidgeting interaction and shown in Figure 1B. Another commonly used metaphor is our interaction with pets (e.g., dog, cat, ant, etc.). For instance, "Fetch" is an interaction where the robots would bring an object repetitively back to the user, similar to dogs. Another example is "Circle Me," where robot(s) circle around the user's finger or a pen held by the user, similar to a dog circling its owner. The last metaphor is toys/existing fidgeting devices. An example of it is the "Spring-loaded Car" example fidgeting application, where the user will pull back the robot and the robot will propel forward in the opposite direction it was pulled, similar to spring-loaded toy cars. Utilizing these common metaphors allows users to quickly grasp how to fidget with the robots without dedicated learning.

3.5 Involvement of External Objects

The design space of SwarmFidget also includes the involvement of external objects during the fidgeting interaction. In terms of input, users can leverage external objects such as a pen or a ruler to indirectly exert physical force on the robots or draw desired trajectory as shown in Figure 5. In terms of feedback, the robots themselves could be integrated with existing fidgeting devices such as magnets, buttons, and stress balls. This integration can mobilize

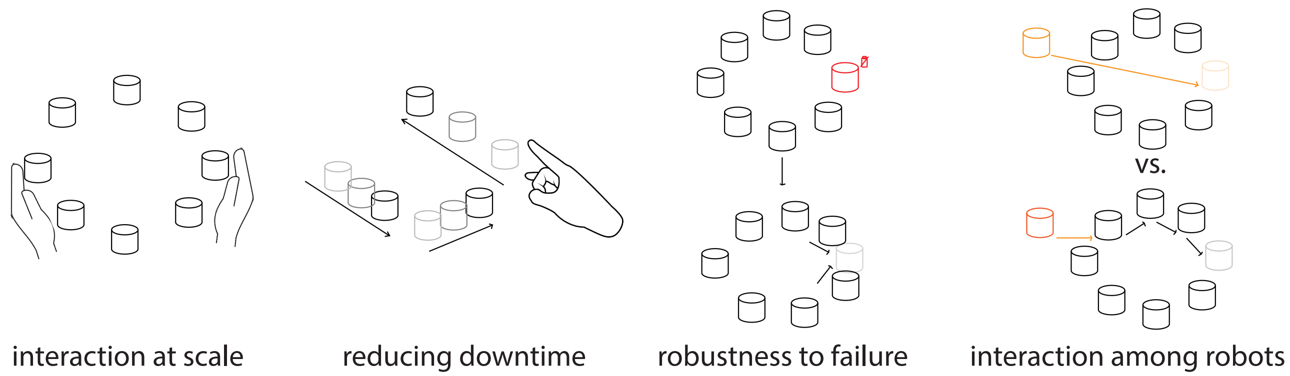

Figure 4: Leveraging Swarmness: having a swarm of robots enable interaction not possible with a robot alone such as interaction at scale, reducing downtime, robustness to failure, and interaction among robots.

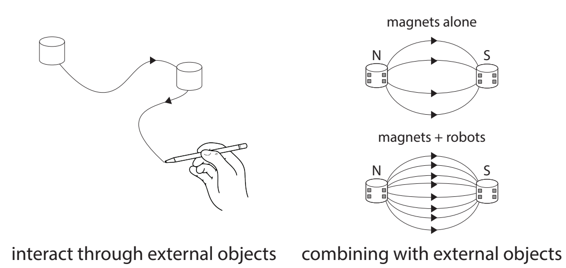

Figure 5: robots could be integrated with external objects such as magnets to not only mobilize magnets but also augment the interaction to simulate stronger or weaker magnetic fields.

static fidgeting devices which may be used to initiate fidgeting with users and augment the fidgeting interaction. For instance, robots integrated with magnets can simulate stronger or weaker magnetic fields than magnets alone as shown in Figure 5. A similar concept of enhancing robots with add-ons was introduced in prior literature but not for fidgeting purposes [32, 33, 54]. This flexibility to interact with external objects can enrich the type of fidgeting possible with SwarmFidget.

3.6 React vs. Proact

Interacting with conventional fidgeting devices involves individuals performing an action on the device and receiving feedback in the form of haptic and/or aural responses. For example, pressing one end of a pen can provide tactile and auditory satisfaction through a click sound. Unlike these traditional fidgeting devices, robots can be both reactive and proactive. In situations where a person is feeling stressed or bored and could benefit from a fidgeting break, robots can initiate the interaction instead of waiting for the person to initiate it. There can also be multiple levels of autonomy for the robots similar to different options in the case of automated standing desks [26]. Prior literature on smart interactive devices [53] and automated standing desks [26] has shown that people generally

Figure 6: Robots are able to be *proactive* and initiate fidgeting interactions when needed such as when users are under stress

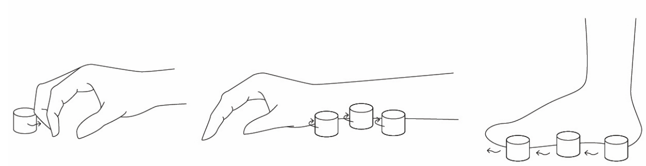

Figure 7: Users can fidget with the robots via different body parts including fingers, hand, and feet.

prefer to retain some level of control over their environment. Therefore, it may be best to seek permission from users regularly, but not too frequently as to cause annoyance, to ensure that the users are comfortable with the level of control they have over the system.

3.7 Body Parts

Some participants brought up that they would like to fidget with the robots using other parts of their bodies rather than just their hands as shown in Figure 7. This was suggested because they are often completing tasks that involve the use of their hands such as typing on a keyboard and would be unable to concurrently fidget with

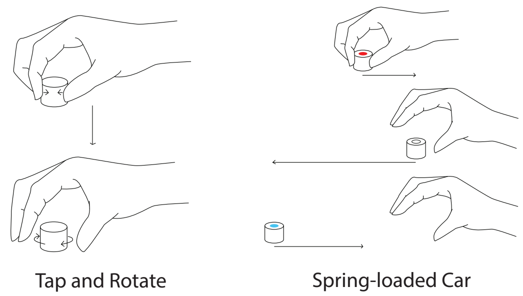

Figure 8: Left: Tap & Rotate interaction where the robot will rotate after being grabbed by the user. Right: Spring-loaded car interaction where the robot will propel forward after being pulled back similar to a spring-loaded car toy.

the robots. Body parts that were mentioned include their feet and arms. Other body parts could also be leveraged such as your legs or head if appropriate. Depending on which body part is used and the amount of motion involved, users can exercise micro-fidgeting or macro-fidgeting [12].

4 EXAMPLE FIDGETING INTERACTIONS

Drawing from the design space of SwarmFidget, we programmed a variety of fidgeting interactions, the first six of which were implemented and used for the subsequent study, as described in detail below.

4.1 Flicking

The flicking interaction requires users to physically disturb the robot, such as by flicking or pushing it, in order to move it out of its position as shown in Figure 1A. The robot can be programmed to either react immediately or with a delay, and move back to its original position at a desired speed. The flicking interaction can be modeled as a mass-spring-damper system, in which a robot with a specified mass is connected to a particular position via a virtual spring and damper. The elasticity and damping coefficients of the virtual spring and damper can be adjusted via programming, unlike with a physical spring and damper.

4.2 Tap & Rotate

The tap & rotate interaction requires the user to grab the robot and release it, causing the robot to rotate, as shown in Figure ??. The duration and speed of the rotation can be programmed to meet the desired specifications. In our study, we programmed the robot to rotate for the same duration as the user held it. For instance, if the user held the robot for 1 second, the robot would rotate for 1 second before coming to a stop.

4.3 Spring-loaded Car

The spring-loaded car interaction is akin to the action of a pull-back toy car, where a user grabs and pulls the car to wind up the torsion spring. Upon release, the toy car will move forward, utilizing the energy stored in the torsion spring as shown in Figure ??. Similarly, the spring-loaded robot interaction entails the user pulling the robot

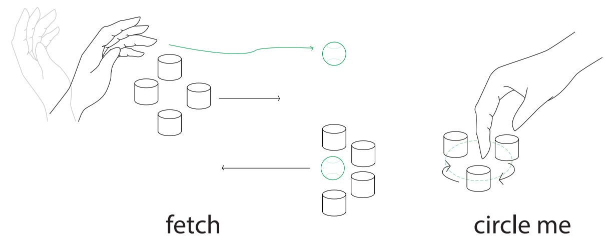

Figure 9: Left: fetch interaction involves a robot "fetching" a ball back to user. Right: circle me interaction involves robot(s) circling around the user's finger or other body parts.

back from its initial position, and the robot moves forward once released. The distance traveled by the robot can be regulated, but in our study, we programmed the robot to travel twice the distance it was pulled.

4.4 Magnet

The magnet interaction, similar to the spring-loaded car interaction, is based on a physical phenomenon, namely magnetism. As shown in Figure 1B, robots with opposite programmed polarity will be attracted to each other once they are within a threshold, while those with the same programmed polarity will be repelled from one another. Unlike real magnets, we can program any relevant magnetic properties such as the strength of the attraction or repulsion, activation distance threshold, and magnetic polarity as desired.

4.5 Circle

The circle interaction is similar to the flicking interaction in that the robots are programmed to stay in a specified position as shown in Figure 1C. However, the difference lies in the number of robots and their relative positions, which is in a circular formation for this interaction. In addition to properties relevant to the flicking interaction, such as desired speed and timing of movement, we can modify additional properties for this interaction, such as the size and shape of the formation as well as the interaction among the robots. For instance, the robots can either return to a specific position every time or return to a position that optimizes the distance traveled by all robots.

4.6 Remote Control

The remote control interaction, like the circle interaction, also involves multiple robots. As shown in Figure 1D, the user controls the robots indirectly by manipulating a single robot designated as the control knob. Once the user grabs the control robot, the remote control mode is activated, indicated by a red light. In this activation mode, the rest of the robots will mimic the movement of the control robot. The mapping between the movement of the control robot and the other robots can be programmed as desired. While we use one of the robots as the control knob as a quick prototype, we can also enable gesture control where the position of the user's hand is tracked using a sensor such as Leap Motion Controller [51] and controls the position of the robots.

4.7 Fetch

As shown in Figure 9, fetch interaction implemented in SwarmFidget draws inspiration from the common game of fetch played with dogs and other animals. In this interaction, the robots take on the role of the pet, bringing an object back to the user after it has been thrown. Unlike pets that may be distracted or bored after a few throws, the robots will continue to fetch the object. This can provide a repetitive yet playful and interactive experience for the user involving an external object.

4.8 Circle Me

Similar to the fetch interaction, the circle me interaction is also inspired by the playful behavior of pets, such as dogs, that love to run and circle around their owners. In this interaction, the robot(s) circles around the user's finger or hand, mimicking the behavior of a pet as shown in Figure 9. Users can also move their finger or hand to another location, and the robot(s) will follow and continue to circle around. The robot(s) could be programmed to provide physical touch as they circle around the user or to stay at a distance and provide only visual feedback, depending on the user's preferences and the intended use of the interaction.

5 METHODOLOGY

To investigate the potential of fidgeting with robots, we conducted an exploratory study in which we introduced the concept of using robots for fidgeting to the 12 participants and collected their feedback on both the general idea and specific pre-programmed fidgeting interactions with the robots.

5.1 Participants

Initially, 16 participants were recruited from a public Canadian institution but the first three participants (P1-P3) were used as pilot subjects to refine the study procedure such as having the participants wear noise-cancelling headphones to reduce the impact of robots' noise. For P9, there were technical issues during the study and thus the data was discarded. The data from the remaining 12 participants (4 Women, 8 Men) were used for analysis. Age ranged from 18 to 44 (average: 26.9, std: 9.1). Their educational backgrounds ranged from computer science (9), engineering (1), psychology (1), and business (1). In terms of race, participants identified themselves as white (3), East/Southeast Asian or Asian American (3), South Asian or Asian American (2), Middle Eastern (2), mixed (1) and preferred not to identify (1). Their affiliations were either student (10) or staff (2). One participant noted they are taking medications for ADHD. They were compensated CAD $20 for their participation.

5.2 Apparatus

During the initial part of the interview, participants had access to various fidgeting tools such as a fidget spinner, fidget cube, pop-it fidget toy, stress ball, and a pen to discuss their general fidgeting experience as shown in Figure 10. To showcase the fidgeting interactions, we employed the Zooids, a multi-robot platform on wheels [28]. Figure 10 illustrates the setup, where participants sat facing the robots while being recorded by a camera and a microphone. To preserve their privacy, their faces were not included in the recording. In order to minimize the impact of sounds from the robots, participants were provided with noise-cancelling headphones that played white noise.

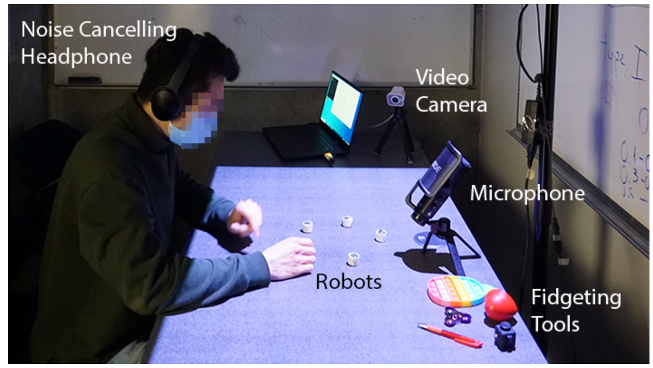

Figure 10: Setup for the study: participants interacted with the robots on a table while wearing noise-cancelling headphones. A video camera and a microphone recorded the interviews and their interaction with the robots.

5.3 Procedure

After providing consent, participants received an introduction to fidgeting, which included its definition (i.e., a non-goal-directed action that involves repetitive patterns [39]) and examples of fidgeting (e.g., shaking leg, playing with hair, clicking pen, etc). Once participants were familiar with the concept, they completed the Spontaneous Activity Questionnaire (SAQ) which measures one's fidgeting behavior [5], and answered questions about their general experience with fidgeting and fidgeting devices, including when, where, and how often they engage in it. Several common fidgeting tools (a fidget spinner, a fidget cube, a pen, and a pop-it) were available to experience during the study if not already familiar as shown in Figure 10. Afterwards, participants were shown physical robots and videos of them and were asked about how they envisioned the robots being used for fidgeting. Next, participants were introduced to six different fidgeting interactions (flicking, circle formation, virtual magnets, spring-loaded car, remote control, and tap & rotate). These interactions were experienced in a randomized order, with each lasting a few minutes. After each interaction, participants filled out a survey rating it based on ease, pleasantness, intuitiveness, usefulness, and likelihood of future usage using a 7-point Likert scale. They also indicated whether they considered each interaction as fidgeting or not, and provided a written explanation. Participants provided suggestions for improvements if any. Once they experienced all the fidgeting interactions, they ranked them in order of preference and provided their reasoning. Finally, a post-demo interview was conducted to gather participants' overall experience, perception of the robots, areas for improvement, and concerns about using robots for fidgeting.

5.4 Analysis

This study involved both qualitative and quantitative responses from the participants. To analyze the qualitative responses from the participants, three researchers performed a basic thematic analysis, where each researcher was assigned questions to analyze and develop common themes that emerged from the 12 participants. The results are summarized with quotes from the participants in the following results section.

While we collected quantitative measures such as ratings and rankings of the example fidgeting interactions that the participants experienced, our main objective was not to necessarily determine statistically significant results but rather to gather high-level insights through these numerical evaluations. Nonetheless, we conducted a few statistical analyses.

To analyze the differences in the ratings of the different fidgeting interactions, we conducted a 1-way repeated measures ANOVA and Mauchly's Test of Sphericity. If the sphericity assumption was violated, we applied a Greenhouse-Geisser correction for F and p values, denoted as F^* and p^*. In case any independent variable or their combinations had a statistically significant effect ($p < 0.05$), we performed Bonferroni-corrected post-hoc tests to identify which pairs were significantly different.

To analyze the ranking of the different fidgeting interactions, we conducted a Friedman Test and if a statistically significant effect is observed ($p < 0.05$), a post hoc analysis with Wilcoxon signed-rank tests and a Bonferroni correction is conducted.

6 RESULTS

Here we summarize the study results including qualitative responses during the interview portions before and after the demo and quantitative feedback on the example fidgeting interactions experienced. Note that P# indicates participant ID.

6.1 Pre-demo Interview

Before experiencing the example fidgeting interactions, participants were given definitions and examples of fidgeting and were introduced to the swarm robots (i.e., Zooids [28]). Here, we summarize the response when asked about how they envision fidgeting with the robots would look like and what are some desirable ways of interaction and features.

6.1.1 Initial Thoughts on Fidgeting with Robots. Five participants (P4, P5, P6, P7, P8) pointed out that interacting with robots was a novel idea that they barely thought about before. Most participants described that the robots would move around. In particular, five participants (P5, P6, P7, P12, P14) expected the robots to return after moving away. Four participants (P5, P6, P7, P10) would control the robots' movement with hands or fingers, expecting them to follow their gestures, for instance, P7 expected the robots to follow their finger: *"if I tap it, then whatever my finger does, it should do the same movement, e.g., [if I] draw a circle, it should move in a circle"*. P8 wanted the robots to create soothing patterns *"that are just pleasing to watch"*.

6.1.2 Desired Interactions and Features. Three participants (P5, P6, P12) considered motion as the most important feature for fidgeting with robots, for instance, *"repetitiveness of the motion"* [P5] and *"moving around in a circle, following my finger"* [P6]. Three participants (P4, P8, P14) expected immediate responses from robots. As P4 pointed out, *"it is distracting if it is very slow"*.

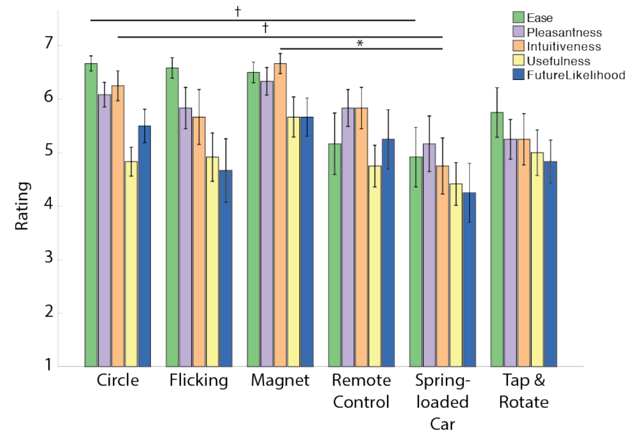

Figure 11: Ratings of the fidgeting interactions. The magnet interaction has the highest average ratings while the spring-load car interaction has the lowest.

Eleven participants (P4-P8, P10-P16) would change their interaction with the robots depending on the context or their emotional state. Four participants preferred to fidget with robots for concentration (P7, P8, P10, P14). P8 wanted slower movements to allow better concentration because *"if I have to pay attention to it, then it will become more like a game"*. Five participants (P6, P7, P10, P14, P16) preferred interacting with the robots at home or in a private setting. P6 mentioned it *"would be more comfortable to use them at home than in public"*. Because of the physical space that the robots took up, P7 and P16 thought it would be easier to fidget in a private setting than in public. P14 said they would not fidget with robots in front of friends feeling obligated to explain the novel experience to others, *"...if it's like an inanimate object that doesn't move at all, doesn't have any semblance of intelligence, then I don't really care about the other person knows about the object, but if it has a little bit of smartness, then it'd be an experience I would want to share with someone else. But I think the main reason for that would be because it's so new. If it became common ground, it's so common that it becomes as ordinary as a pen"*.

6.2 Perception of Example Fidgeting Interactions

Here, we report the quantitative measures taken regarding participants' perception of the example fidgeting interactions. The mean values and standard errors are presented in Figures 11-13, with statistical significance indicated by asterisks ($\dagger : 0.05 < p < 0.1, * : 0.01 < p < 0.05$).

6.2.1 User Experience Ratings. Figure 11 shows the ratings of the six fidgeting interactions that the participants experienced in terms of ease, pleasantness, intuitiveness, usefulness, and the likelihood of future usage. ANOVA analysis with a Greenhouse-Geisser correction reveals statistically overall significant differences among fidgeting interactions in terms of their ratings on ease ($F^*(5, 55) = 4.6, p^* = 0.015, \eta^2 = 0.30$) and intuitiveness ($F^*(5, 55) = 4.6, p^* =$

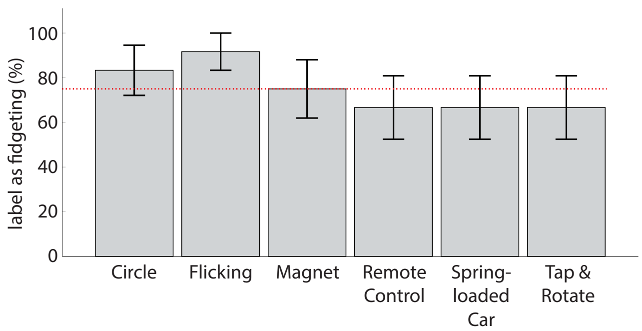

Figure 12: Percentage of participants who labeled the interactions as fidgeting. Red dashed line indicates the average percentage.

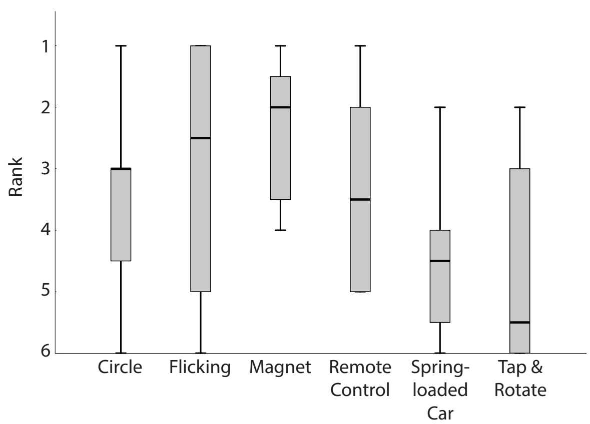

Figure 13: Ranking of the fidgeting interactions. The magnet interaction is the most preferred whereas the tap & rotate is the least preferred interaction.

0.023, $\eta^2 = 0.25$). The post hoc analysis with a Bonferroni adjustment revealed intuitiveness ratings of magnet interaction are statistically significantly higher than those of the spring-loaded car interaction ($p = 0.033$). The ratings for both ease ($p = 0.099$) and intuitiveness ($p = 0.063$) of the circle interaction were marginally higher than those of the spring-loaded car interaction.

6.2.2 Labelling as Fidgeting. As depicted in Figure 12, the majority of the participants (>66%) labeled all 6 example interactions as fidgeting. In particular, all but one participant labeled the flicking interaction as fidgeting, while all but two participants labeled the circle interaction as fidgeting. Four participants did not label the remote control, spring-loaded car, and tap & rotate interactions as fidgeting.

The participants provided various reasons for labeling the interaction as fidgeting. The most common reasons included repetitive actions, movement without a goal, predictable patterns, and simple activities. Participants found the repetitive nature of the interaction satisfying and engaging, and it helped them concentrate. They also enjoyed the predictability of the movement, which allowed them to carry out the action without paying much attention. One participant noted that the interaction was almost like fidgeting because the action was easy to carry out, but they had to worry about how to place their fingers to activate the touch sensors.

The participants' reasons for not labeling the interaction as fidgeting centered around the idea that the activity required too much attention and conscious effort to be considered a mindless, small action. Many participants likened the interaction to playing with a toy rather than fidgeting, with some noting that the movements were too large in scale or required too much focus on grabbing. Others pointed out that the repetitiveness was not consistent or not noticeable enough, and some found the interaction to be monotonous or lacking in activity. Overall, the participants perceived some interactions as more closely resembling playing rather than fidgeting.

6.2.3 Ranking. Figure 13 shows the ranking among the six fidgeting interactions. The magnet interaction has the highest median rank of 2 followed by the flicking (2.5), circle (3), remote control (3.5), spring-loaded car (4.5), and tap & rotate (5.5). There was a statistically significant difference among the rankings of the fidgeting interactions ($\chi^2(5) = 12.3, p = 0.03$). Post hoc analysis with Wilcoxon signed-rank tests and a Bonferroni correction revealed no pair-wise statistically significant differences between the fidgeting interactions.

In terms of the rationale behind their ranking, the majority of the participants (7/12) mentioned that they ranked the interactions based on *"the ease of use, and the amount of conscious effort being spent"* as described by P13. P11 also explained that *"any interactions where I don't have to focus on activating the movement automatically ranks above the ones that do. Fidgeting needs to be natural, and not need to focus on anything"* while P14 found that higher-ranked interactions were *"easier to repeat. This meant that I could start to do them without paying too much attention to the task. The response of the robot(s) was also easier to understand without me looking at them"*. The next common rationale (3/12) centers around the collective behavior among the robots. P4 explained that they *"preferred the interactions with several robots. Also, the interactions which showed a larger scale of inter-robot interaction were more interesting when compared to the interactions which were simpler, and just responding to myself"*. Additionally, P15 ranked interactions based on how predictable the motion and interactions were, while P10 ranked based on enjoyment.

6.2.4 Impressions. In addition to the ratings and ranking, participants verbally expressed their impression of the fidgeting interactions as described below.

Magnet The magnet interaction was the most preferred interaction both in terms of ratings and ranking as shown in Figures 11-13. Additionally, verbal feedback from many participants (6/12) reinforced their fondness for this interaction, describing it as *"satisfying"* [P6, 12] and *"nostalgic"* [P13]. For instance, P6 found it *"satisfying to see the robots swarm together and follow each other"*, while others referred to their past experiences playing with magnets and noted that they could *"play with it"* [P12, P16].

Flicking The second most preferred interaction was the flicking interaction. However, there were split opinions on how much conscious effort is needed. For instance, P14 described flicking interaction as the most natural and convenient as *"you can "shoo" it then it comes back, "shoo" it and come back. Continue repeating it. And without even thinking about it, you're gonna get it"*, while P12 felt that they *"had to watch it and be mindful about it, keep an eye on it"* as they were afraid they might tip over the robots or make them fall off the table.

Circle For the circle interaction, the majority found it interesting and entertaining to watch the robots organize themselves after being disrupted, with some participants finding it akin to a game. P4, for instance, found it intriguing to *"break the entire formation and reorganize them in a certain way"*, while P16 suggested that the bots could *"interact with each other and maybe even do a dance to make it more interesting"*. However, some participants found the circle formation to be too attention-demanding, without providing any tangible outcome or enjoyment, as stated by P12 and P15. Additionally, P15 expressed dislike towards the *"motor movements"* of the robots, which was intensified by the presence of multiple robots and their ability to draw a lot of attention. Overall, it can be inferred that the circle formation was found to be an engaging task by some participants, while others did not find it particularly useful or enjoyable.

Remote Control The participants had mixed opinions on the remote control interaction. Some found it fun and enjoyable, as they could control the robots and make them move in specific patterns or follow their hand gestures. They found it useful as they did not have to pay too much attention to the robots and could multitask. Others found it to be more of a main task than a fidgeting task, which required more energy and thought to think about what they wanted the robots to do. P4 found it interesting to see the impact of controlling one robot on several others, while another (P4, P10, P14) found it *"visual"* and *"cool"* to see the robots move around while doing something else with their hands. However, P16 found it frustrating that the bots were not behaving the way they expected them to, and they were unable to control them as much. Overall, while some enjoyed the remote control feature of the robots, others found it too much effort to control them and preferred the simpler circle formation.

Spring-loaded Car Participants had varied responses to the spring-loaded car. P10 found it cool and enjoyed making it perform different movements, while P4 liked the unpredictability and found it fun. However, P12 found it confusing and requiring close attention, while P13 found it *"more like playing with a toy rather than performing something subconsciously"*. P14 found it mediocre and required attention, while P15 did not like the unpredictable movements. P16 had high expectations for the car's ability to come back but found it challenging to predict where it would land.

Tap & Rotate Participants had varying opinions about the tap and rotate activity. Some found it satisfying to see the object spin around repeatedly, particularly P6 and P12. However, P8 suggested that the experience could be improved by making the robot more comfortable to grab and hold as it is currently made out of hard plastic. On the other hand, P4 and P10 found the activity boring and repetitive, while P13 felt that it lacked haptic feedback and required too much attention to understand what was happening. P14 also found the activity to be somewhat tedious and not worth the effort put in, while P16 felt that it had potential but needed improvement.

6.3 Post-demo Interview

6.3.1 Overall Experience. To describe their experience fidgeting with robots, eleven out of twelve participants used positive expressions, for example, *"it was fun"* [P12, P16, P6], *"very, very cool. I enjoyed it."* [P4], *"pretty cool"* [P10], *"it is fine"* [P13], *"it was good"* [P15], *"I like it"* [P14]. Five participants unconditionally liked fidgeting with robots. Three of them (P16, P12, P10) were particularly surprised that fidgeting with robots was possible. For example, P16 said that *"before playing with the bots, I couldn't imagine what they gonna do and also fidgeting"*; P12 expressed: *"I definitely haven't seen anything like this before, so it was interesting to see the possibilities of how fidgeting could be different with small robots instead of static objects"*; P10 shared: *"I was kind of amazed how such technology was compacted in such a small robot. And then how it was able to do such fascinating things. [...] Now I can see I can do different tasks with them"*. Five participants (P7, P8, P13, P14, P15) were positive about the robots but had some concerns or requests. In particular, P14 and P7 would appreciate robots of a smaller size. P15, P13, and P8 were satisfied with some aspects of the robots while finding others annoying, or technically imperfect: P13 enjoyed some interactions, such as flicking and the remote control, while considered some as *"quite annoying or boring"*; P15 did not like some features of the robots and would prefer if the robots were softer and made sounds like music; P8 had many suggestions for design improvements: *"it would have been more fun if the robot was a bigger thing, and maybe the geometry - it is just a cylinder - maybe a sphere would be cooler. [...] If it was made of glass, and it had different colors and layers, so you can see through the glass, and it rotates so you can get some nice visualization out of it"*. Two participants (P11, P5) were least optimistic about their fidgeting experience with robots: they were concerned that fidgeting with robots required paying too much attention and would prevent them from doing the main task. For this reason, P5 did not consider the interaction with robots as fidgeting, while P11 perceived the robots more like a toy.

6.3.2 Perception of Swarm Robots. With respect to the perception of the robots, eight participants compared them to living creatures - pets, insects, rodents - mainly because of a) their manner of moving, b) their responsiveness and playfulness, and c) their size and look. In particular, participants P6, P8, P14, P15, and P16 perceived the robots as pets: to P15 this comparison was concerning, because in their opinion *"the first time when you have pets, you're not familiar with them, which is stressful"*; P14 perceived the robots as *"consistent pets"* that *"you don't have to pay attention to"*; P8 admired the robots' fetch-like behavior (leaving but returning back) that is often demonstrated by pets; to P6 the robots looked like cats because of their appearance. P11 and P4 perceived the robots as bugs because of their jittery movements, and P12 perceived the robots as small rodents because of their manner to work together and because of their small size. Four participants (P5, P7, P10, P13), although perceived the robots as non-living objects (toys, robots), emphasized that they seemed interactive and intelligent. In contrast, all the participants perceived the conventional fidgeting toys as non-living objects.

6.3.3 Perception of Swarm Robots as a Group or Individual. Seven participants preferred interacting with many robots rather than with one because they enjoyed multiple robots moving together (P6, P7, P8, P12, P4, P11) or interacting with each other (P10). P7 liked that *"there will be a lot of movement instead of a single movement of the thing. If they come all at once it is satisfying, they can work together for one goal"*. P10 commented that robots *"reply each other, it's just cool to watch"*. Three participants felt that many robots were a *"double sword"* (P5) as they were *"more exciting, but then at the same time, more stimulation"*. P14 pointed out that *"the more you add, the more it becomes a game, instead of fidgeting. So it gets the more attention it requires whilst we just want it's simpler... fidgeting with one requires so much less effort, so less effort, less barrier for fidgeting"*. Two participants called out that many robots were too distracting for fidgeting, e.g., P15 disliked *"the busy thing and lots of things"*.

Seven out of twelve participants perceived interacting with swarm robots as interacting with one group instead of individuals.

6.3.4 Comparison of Fidget Robots with Conventional Fidget Toys. When comparing fidgeting with conventional fidget toys and fidgeting with robots, all participants agreed that fidgeting with robots was interactive, provided more options for fidgeting, and incorporated feedback. The participants characterized fidgeting with robots using such words as *"lively"*, *"interactive"*, and *"exciting"*. All the participants were in unison that conventional fidgeting tools are restricted to one well-defined fidgeting interaction and they lack interactivity and feedback. The participants characterized fidgeting with conventional fidget toys using such words as *"static"*, *"predictable"*, *"boring"*, *"motionless"*, *"simple"*, *"replaceable"*, *"subconscious"*, *"not exciting"*. Although fidgeting with robots was described in more exciting terms compared to fidgeting with conventional fidget toys, some of the participants had concerns about the robots and saw benefits in the boring nature of the conventional fidget toys. One common robot-related concern (P5, P7, P11, P12, P13) was that the robots seemed more high maintenance compared to the conventional fidget toys. In particular, P7 mentioned the need to periodically charge the robots, while P11, P12, and P13 were worried about damaging the robots because they looked fragile. P15 was concerned with noises originating from fidget robots, while conventional fidget toys are, according to them, rather silent. P16 explained that although robots provide many interaction possibilities they are not straightforward about how to interact with them; on the contrary, the benefit of conventional fidget toys is that the user knows what action to do with them: the toys are *"inviting to that particular action"*. P8 expressed that the lack of interactivity in conventional toys might be beneficial when one wants to take a break from stimulation; on the other hand, if one prefers to be stimulated, get excited, and be emotional, fidgeting with robots would be the right thing to do.

6.3.5 Using the Fidget Robots in the Future. Eight participants were unconditionally positive about using the robots for fidgeting (P4, P6, P7, P15, P16) or leaning toward it if certain issues were improved (P12, P13, P14). The unconditional willingness to use the robots was mostly motivated by the fact that fidgeting with the robots helped regulate emotions and was fun/joyful, and also because the robots were moving in a pleasant way. For example, P6 expressed that the way the robots were moving was satisfying, pleasant to observe, and calming emotions. P16 appreciated that the robots would come back to them; they could not imagine other fidget toys that would be able to do that. P16 also appreciated the size of robots, as for them it was hard to imagine playing with larger robots. With respect to concerning issues that must be fixed the participants mostly named technical issues, such that the robots will not come back to their start position after, e.g., flicking. In addition, P12 expressed concern about the robots' cost and concluded that *"it would be ok to have them if they are free and with no technical issues"*. P14 expressed that the swarm robots should have another primary goal; they compared the robots with a favorite pen that you enjoy writing with, but also you fidgeting with it the most. Four participants (P5, P8, P10, P11) did not express a wish to use the swarm robots for fidgeting. The main reason was that the interaction with the robots felt peculiar to them. For example, P11 said that it was too much effort to fidget with the robots because the interaction was not natural for fidgeting; P10 expressed that the experience was different compared to the conventional fidget toys; for P8 the interaction was rather stimulating whereas they prefer more soothing fidgeting; for P5 the interaction was too conscious while they consider fidgeting as a subconscious activity.

When asked about the particular ways how they would use the fidget robots in the future, five participants (P6, P7, P12, P14, P16) would keep them on their working desks and interact with them while working, talking to others or when taking a break. P7 emphasized the need to be very close to a table to be able to use the robots; for example, it would be desirable but not be possible to interact with robots when watching TV because the table is far. P16 shared that they would mostly hold the robots in their hand because they do not have much space on the table. P10 would use the fidget robots during a break or when stressed; according to them, fidgeting with robots could replace the habit of playing with the phone. P4 would use the robots when in deep thought and trying to focus. P15 envisioned interacting with the robots when tired or on a break. P11 expressed interest to use the robots for physical stimulation when studying. P13 foresees using fidget robots for relaxation and for entertainment. P5, who was not planning to fidget with the robots, expressed that they might show the robots to others because they are *"cool"*.

6.3.6 Desired Features, Design, and Appearance. Participants made a variety of suggestions regarding how to improve the fidgeting interactions with the robots. Five participants wished to have better control over the robots and have predictable interactions with them. P14 wanted *"feedback to know that it has come back to its original position... for every one of the magnets, like some sort of visual cue that they've started doing something or they've probably stopped doing something"*.

With respect to new ideas for fidgeting with the robots, five participants wanted the robots to follow their hand or finger gestures. P7 mentioned, *"with finger movement, I could show them to circle around an object and bring the object back"*. P14 described that *"instead of remote control any group, it's remote control them to follow... almost like playing with a cat"*. Two participants were interested in using feet to fidget with the robots, e.g., *"you might rest your leg on the device, it could try to mimic my sole or pad, it could release some pressure mostly for relaxing so that you could fidget, bounce it, but also relax"* [P9].

When asked how to design the robots to make them more conducive for fidgeting, five participants would like the robots to have a friendlier appearance, e.g., a pet-like design. P13 thought the robots *"can be made visually appealing by giving them some sort of a character, like a cat or dog"*. P7 suggested, *"put eyes on them"*. Throughout the study, six participants wished the material of the robots could be soft and squishy to allow smooth fidgeting behaviors or emotional connections. P3 wanted *"a softer material, a squishy material that is easy to grip on"*. P5 suggested *"making the geometry or the texture of the material a little bit more friendly, because right now it looks very roboty"*. P16 pointed out that *"I just imagine them being little pets. I cannot relate emotionally to robots… I would want to make it so that I can actually call them cute. They're cute because of the size, but also the sensation of it is also important, because in fidgeting, I'm primarily not looking at it, I really care about how it feels on my skin"*.

6.3.7 Concerns about Fidgeting with Robots. When asked about concerns related to fidgeting with robots, only two persons (P10, P15) saw the robots as absolutely harmless and concern-free. Three participants (P5, P4, P12) were concerned about the distraction the robots might cause - by their motion or by the sound they make. Four participants (P8, P11, P12, P13) were worried about the need to control the robots and their delicacy, namely, that they might easily get damaged if they are not kept an eye on. Two participants (P14, P16) expressed concerns about personal data safety, for example, if the robots would track the user's activity or state of mind/emotions, leakage of such personal data is unacceptable. P6 was concerned about the safety of the robot because its circuit at the top is exposed and can be easily touched.

6.3.8 The Attitude toward Robot-Initiated Fidgeting. The participants demonstrated rather cautious attitudes toward robot-initiated fidgeting: three participants (P4, P13, P16) were positive, while three (P8, P10, P15) were against and seven (P5, P6, P7, P11, P12, P14) were debating. The participants, who did not like the idea, explained that such behavior would be uncomfortable and that encouraging for fidgeting does not match the subconscious nature of fidgeting. All the debating participants agreed that such technology would be appropriate only in certain contexts: people could accept being disturbed by the robots only when they actually need fidgeting, e.g., when they are bored, stressed, or need a break. On the contrary, P16, who was supporting the idea, explained that even if the robots appear at a bad time, it would not be a problem to put them away. In addition, another supportive participant (P4) expressed that such behavior would make the robots look more alive and caring. When asked about preferred ways to be approached by robots, the majority of participants (P4-P8, P10-P11, P15-P16) agreed that the robots should sense their state/emotions and not cross the boundaries/be annoying. However, P8 and P10 were particularly concerned about privacy: P10 expressed that tracking the mood and stress level almost feels like the robots are violating privacy while P8 was concerned about the potential leakage of such data. P14 proposed to introduce *"some sort of scale [...] on the level of how annoying people want the robots to be"*. P13 suggested having a timetable, where there are predefined hours when the robots could approach the user (e.g., during work hours, or every half an hour when the user is trying to relax/take a break). P12 preferred that robots would approach them when it is appropriate to take a break.

7 DISCUSSION

From this exploratory study, we gathered preliminary user impressions of the concept of programmable actuated fidgeting through SwarmFidget. The overall experience was generally positive, with all but one participant expressing positivity. The ranking and rating data indicate that a few interactions (i.e., magnet, flicking, and circle) are generally preferred over others. However, qualitative analysis demonstrates that user preferences vary widely with polarized inclinations on interacting with one versus many robots and how much attention they are willing to dedicate to fidgeting with the robots. This finding aligns well with the affordances of programmable actuated fidgeting devices, as we can program different fidgeting interactions tailored to each individual's needs and preferences.

The participants' initial thoughts on fidgeting with robots differed vastly from their post-demo thoughts. While most of them had not considered interacting with robots as a way to fidget before the study, many participants found it a novel and fun concept. Their initial thoughts emphasized watching and controlling the robots to move with hand gestures. After interacting with the robots, some participants mentioned wanting the robots to react to disturbances and interact with each other. Others mentioned that they would fidget with the robots using different body parts, such as their hand, finger, and feet. Overall, the participants' thoughts on fidgeting with robots evolved from simple movements to more complex and dynamic interactions with the robots and even among the robots after the demo.

While fidgeting is most commonly associated with physical movements like clicking a button or shaking a leg, fidgeting can also be visual, as briefly mentioned by Perrykkadd and Hohwy, where they list doodling and visually tracking a fan as examples of visual fidgeting [39]. Before and after the demo, a few participants brought up this aspect as well. For instance, one participant said that one of their primary fidgeting behaviors was looking at different places with their eyes, while several participants gave feedback that they would want to look at the robots move in *"soothing patterns"* that are *"pleasing to watch"*. P8 compared it to how people *"calm down"* by just looking at the motion of fidget spinners. SwarmFidget has the affordance to provide visual fidgeting as partially evidenced by the Remote Control interaction whereas most commercial fidgeting tools primarily rely on tactile fidgeting.

While visual fidgeting with robots can be desirable for some, others found it too distracting or requiring too much attention. In such cases, participants found the interaction to be more like *playing* rather than *fidgeting*, because the interaction requires their full visual attention and becomes the primary task, whereas they would prefer fidgeting to be done subconsciously while completing a task. Thus, many participants who voiced this opinion suggested that fidgeting with robots would be more appropriate during a break from the tasks rather than concurrently fidgeting with the robots during a task. All in all, the participants of the study can be roughly divided into two groups: those who liked conscious fidgeting with the robots and those who sought more subconscious fidgeting. This is in line with the two types of fidgeting outlined by Nyqvist [36]: low-focus, i.e., subconscious, fidgeting, and high-focus fidgeting that requires visual focus and attention. In the current form, the fidgeting robots allow for more conscious fidgeting; future work could focus on exploring low-focus fidgeting opportunities with the robots. Another direction for future research is to investigate whether fidgeting with the robots increases mind wandering and benefits divergent thinking as per the observation of Nyqvist [36] with respect to high-focus fidgeting.

Participants expressed a variety of preferences regarding the features and appearance of the robots. Participants wanted better control over the robots, with predictable interactions and clear feedback, though one participant preferred to be surprised by the robots (P8). Furthermore, nearly half of the participants wished for robots with friendlier appearances, such as pet-like designs and softer, squishy textures allowing smooth fidgeting behaviors and emotional connections. For instance, P16 wanted the robots to look "cute" and imagined them "being little pets", otherwise, she "cannot relate emotionally to robots". Many participants preferred interacting with multiple robots rather than one, as it was more satisfying to see them move together and interact with each other. Finally, participants preferred to use the robots in different contexts depending on their emotional state or need for concentration.

The interviews revealed that several participants did not consider fidgeting with robots appealing because the interaction was rather different compared to conventional fidgeting - it involved robot motion and required more attention from the user, also the robots were perceived as fragile and expensive. Similarly, we noticed that with respect to many questions related to the robot acceptance (e.g., the questions asking about robot-initiated fidgeting), the first answer of many participants was a no, but later in the discussion, the participants would change their attitude to more accepting. Arguably, such skepticism originates from the fact that tabletop swarm robots are rather new and not widely spread technology, therefore everything related to it might feel foreign. People tend to fidget with familiar objects that surround them on a daily basis. One such popular fidget device is a click pen. Fidgeting with pens (e.g., clicking, rotating) is so commonplace that we never think about the value of the pen or that we can damage it. However, click pens have been around for at least 70 years, while pens in general for centuries [43]. Notably, click pens' design and popularity changed over time: first patented at the end of the 20th century their design was improved several times until their production became mainstream in the 1950s. Perhaps, if the tabletop swarm robots became a more mainstream technology with error-proof behaviors, user-friendly designs, and uniquely-designated tasks, fidgeting with the robots would also become a natural and commonplace practice. Similar ideas were expressed by several participants: P10 stated that fidgeting with robots *"could be a thing if it's easily accessible [...]. Right now it's just a really different experience. But if it's really common, I can see it replacing fidgeting."*; P14 expressed that the swarm robots should have another primary goal and brought the analogy of the favorite pen with which you write but also fidget a lot. On a related note, recent work explores how to make the robots transition seamlessly from being in our foreground and background by exploring different ways to appear and disappear based on techniques from theatre stages [34].

8 LIMITATIONS & FUTURE WORK

In terms of the study findings, there were technical limitations due to the specific platform used (i.e., Zooids [28]). As mentioned by the participants, the motion of the robots was not always perfect in terms of smoothness or moments where robots were stuck (i.e., not moving temporarily). In addition, the touch sensor on each robot required a particular way of grabbing which some of the participants had trouble activating, and the tracking mechanism relies on an inconvenient combination of a dark room and a high-speed projector. These technical limitations most likely have negatively impacted participants' interaction experience but could be fixed by better tuning of control parameters or by the use of more robust and portable commercial mobile robot platforms such as the Sony Toio platform [46].

However, even with such commercial mobile robot platforms, there are inherent practical limitations of SwarmFidget, especially in comparison with conventional fidgeting tools such as fidget spinners and pens. Many participants commented that while they had a generally positive impression of the experience with SwarmFidget, in reality, they would most likely prefer using conventional fidgeting tools due to their simplicity, portability, affordability, robustness, and lack of need for charging. While these are valid reasons, we envision that fidgeting will not be the primary purpose of the robots. Rather, robots will be a multi-purpose tool similar to a pen, where they will primarily complete more functional tasks but also provide the affordance of being fidgeted with by the users when needed.

Another limitation of this study is that the explored fidgeting with robots incorporated only scarce hand contact with the robots: in the scope of our study we did not include in-hand fidgeting. For this reason, the robots' design was not elaborated with fidgeting features, for example, no fidgeting controls were added, such as buttons. It could be that *"very roboty"* [P5] design made the robots look too foreign for fidgeting. Arguably, incorporating fidgeting-encouraging design features could make a better impression on the participants and pre-dispose them to fidgeting with robots. Some participants were making attempts of in-hand fidgeting with the robots, for example, one participant played with the robots' wheels during the pre-demo session. Similarly, participants were suggesting design-related changes: one participant suggested having a click-button on the robots, six participants wished for a softer texture on the robot's body. Future work could focus on addressing the participants' requests and enhancing the robot's design with fidgeting features.

One aspect we did not study in depth is robot-initiated fidgeting. As discussed in the design space section, swarm robots are mobile, enabling them to approach users and initiate fidgeting with them instead of solely relying on users to grab and initiate. We briefly introduced this idea to the participants at the end of the study to gather their thoughts, but we plan to investigate this further in the future to understand how to design robot initiation for fidgeting as well as how people react and perceive such intervention.

More recent research has demonstrated the benefits of fidgeting in improving focus [2, 21], increasing creativity [36], and reducing stress [39]. While this paper focused on getting first impressions and thoughts around programmable actuated fidgeting and SwarmFidget, we are ultimately interested in studying the effects of SwarmFidget compared to those of traditional fidgeting tools in terms of productivity and mental well-being. After updating the platform and fidgeting interactions based on participants' feedback, we plan to run user studies to better understand the effects of swarm robot-based fidgeting on users' task performance and emotional state.

Although SwarmFidget demonstrates the use of swarm robots for facilitating programmable actuated fidgeting, it is only one example of such a system. In addition to building an entirely new system, other approaches may include retrofitting existing fidgeting devices with motors and sensors. For instance, footfidget devices, as used by Koepp et al. [27], could be equipped with motors and sensors to detect foot movement and automate foot fidgeting. Our paper focuses on swarm robots, but we hope to encourage further exploration of alternative methods for facilitating programmable actuated fidgeting.

9 CONCLUSION

We introduced *programmable actuated fidgeting*, a new type of fidgeting that involves devices integrated with actuators, sensors, and computing to enable a customizable interactive fidgeting experience. In particular, we described and explored the use of tabletop swarm robots to enable programmable actuated fidgeting. We illustrated the design space of *SwarmFidget* and conducted an exploratory study to gather impressions and feedback on the concept and several example fidgeting interactions with the robots. Our study findings demonstrate the potential of SwarmFidget for facilitating fidgeting and provide insights and guidelines for designing effective and engaging fidgeting interactions with swarm robots. We hope this work can inspire future research in the area of programmable actuated fidgeting and open up new opportunities for designing novel swarm robot-based fidgeting systems.

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