Exploring Extended Mind-Wandering Through an Interactive Haptic Fidget Object

Eichenlaub, J.A.; Huisman, G.; Xue, H.

DOI
10.1145/3563657.3596084

Publication date
2023

Document Version
Final published version

Published in
2023 ACM Designing Interactive Systems Conference (DIS '23)

Exploring Extended Mind-Wandering Through an Interactive Haptic Fidget Object

John Anders Eichenlaub
Human-Centered Design
Faculty of Industrial Design
Engineering
Delft University of Technology
Delft, Netherlands
eichenlaubj@sigchi.org

Gijs Huisman
Human-Centered Design
Faculty of Industrial Design
Engineering
Delft University of Technology
Delft, Netherlands
g.huisman@tudelft.nl

Haian Xue
Human-Centered Design
Faculty of Industrial Design
Engineering
Delft University of Technology
Delft, Netherlands
h.xue@tudelft.nl

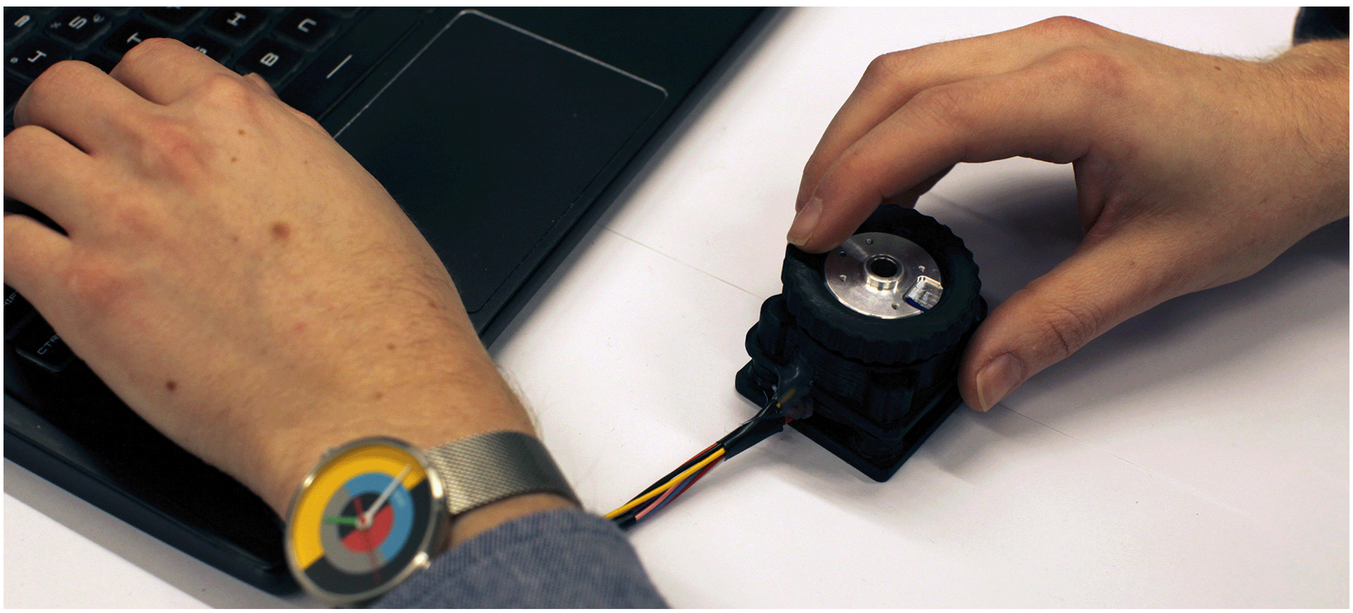

Figure 1: Researcher using the interactive fidget object while working at their desk.

ABSTRACT

Mind-wandering (MW) and fidgeting are both present as pervasive phenomena in everyday life and can positively impact ideation. Importantly, within the MW experience, MW can manifest in bodily behaviors such as physical fidgeting. Here, we use an extended mind framework to consider fidgeting as a case of extended MW, where (part of) a MW episode is mediated by a fidget object. We position extended MW, fidgeting, and cognition as interrelated processes. We present the design of an interactive haptic fidget object that aims to support introspective self-awareness in MW and aid in idea synthesis. We discuss the results of an exploratory user evaluation in which the fidget object was used by designers during a personally relevant work session combining research, synthesis, and creativity. We close this paper by discussing the initial findings of our research, the implications for extended MW, and additional propositions for future research directions.

DIS '23, July 10–14, 2023, Pittsburgh, PA, USA

ACM ISBN 978-1-4503-9893-0/23/07…$15.00
https://doi.org/10.1145/3563657.3596084

CCS CONCEPTS

• **Human-centered computing → Haptic devices**; *User centered design*; *HCI theory, concepts and models.*

KEYWORDS

mind-wandering, fidgeting, extended mind, haptics, creativity, tangible interaction

ACM Reference Format:

John Anders Eichenlaub, Gijs Huisman, and Haian Xue. 2023. Exploring Extended Mind-Wandering Through an Interactive Haptic Fidget Object. In *Designing Interactive Systems Conference (DIS '23), July 10–14, 2023, Pittsburgh, PA, USA.* ACM, New York, NY, USA, 15 pages. https://doi.org/10.1145/3563657.3596084

1 INTRODUCTION

Mind-wandering (MW) is a frequent occurrence in everyday life [35], and research aimed at better understanding MW has increased in recent years [9]. There are various positive effects associated with MW, such as improved management of personal goals [5], creative problem solving [4], and introspective, self-directed thought [20]. Conversely, negative effects of MW are also prominent in literature concerning subjective well-being [35], performance of daily life tasks [40], and attention and retention [22]. The contrasting effects of MW can be partially attributed to variable definitions of MW as a phenomenon.

Currently, there is no consensus on the definition of MW [25, 26, 55]. One approach is to consider MW from a "family resemblance" perspective, where MW is characterised as a natural category with graded membership [55]. Some exemplars of MW may be more or less prototypical than others, which can be determined by the number of shared features of a given definition [55]. The benefit of a family resemblance perspective on MW is that it recognizes MW as a heterogeneous construct that covers various behaviors and subjective experiences, such as day dreaming, tuning out, and zoning out [25]. A family resemblance perspective also opens up conceptualisations of MW that are not purely "mental". Dias da Silva et al. [18] argue that, in some instances, MW manifests itself in bodily behaviors, such as averting one's gaze upwards, bouncing one's leg, or fidgeting with an object. On Dias da Silva et al.'s account, these behaviors should be considered as *symptomatic of* MW [18], with MW proper still being confined to exclusively internal, brain-based processes. The study of bodily behaviors like fidgeting in relation to MW could shed new light on such behaviors, however, the confinement of MW to internal states is problematic in light of recent developments in 4E cognition theories. These theories argue (in various ways) that minds are not purely internal but are best understood as spanning brain, body, and environment; in other words, are embodied, embedded, extended, and enactive [46].

An account of such a 4E perspective on MW is given by Bruineberg and Fabry [7] who present an extended mind approach to MW and discuss how MW can be extended through unintentional smartphone use. The original extended mind thesis argues that cognitive processes and mental states extend into the environment, and are thus not just "in the head" [12]. When using tools, such as notebooks or smartphones, these tools should be considered as an integral part of cognitive processes in the solving of tasks. Bruineberg and Fabry [7] argue that such cognitive extensions are not just relevant to cognitive *tasks*, but also to task-unrelated cognitive processes, such as MW. Habitual, unreflective use of smartphones, where the device mediates MW, should be considered a form of extended MW [see also 26].

From the previous we can gather that MW is at least partially manifested as bodily behaviors [18] and that MW can be extended when it is mediated through the use of tools such as smartphones [7, 26]. Following the proposal of Bruineberg and Fabry [7], we consider task-unrelated bodily behaviors, in particular, fidgeting [18], which often involves specific artifacts such as fidget objects [34], as an interesting exemplar of extended MW. In line with an extended mind approach, we argue that fidgeting is not just a symptom of mind-wandering, but should be considered as an integral part of an extended MW episode in which the fidget object mediates extended MW (see Figure 2). MW itself thus extends through fidgeting with objects. Evidence for this notion is found in experimental research into MW and fidgeting [11, 22, 54, 65].

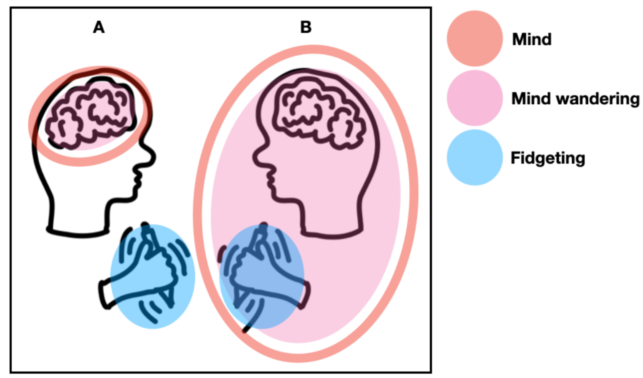

Figure 2: Figure A depicts minds and mind-wandering as being internal, brain-based processes. Here, fidgeting can only ever be a symptom of mind-wandering. Conversely, Figure B represents an extended mind approach. Here, minds extend beyond brains to include bodies and environments. Mind-wandering also extends beyond the brain. Here, fidgeting is not merely a symptom of mind-wandering but an integral part of it.

Approaching fidgeting from this extended MW perspective opens up opportunities to design fidgeting interventions for MW. The design of interactive tools that can adaptively guide fidgeting behavior and thus, considering fidgeting as a central part of an extended MW episode, guide (part of) a MW episode, could be beneficial. This especially holds true when we consider the positive role that (extended) MW can play in creativity [4], self-directed thought [20], and introspection which are central to design work [66]. We propose that interactive fidget objects, by virtue of offering physical extensions of MW, can be useful tools for productive extended MW during creative processes in design work. In addition, interactive fidget objects might also serve as reflective tools that aid designers in developing self-awareness regarding their extended MW behaviors and the felt impact of these behaviors.

The main contributions of this paper are threefold: first, we present a novel theoretical perspective on object-mediated fidgeting as a form of extended MW. Second, to embody this theoretical perspective, we present the design of an interactive fidget object (the Fidget Knob) in the form of a haptic device that enables adaptive fidgeting and recording of fidgeting behaviors. Third, we present an explorative user evaluation in which participants used the Fidget Knob during a personally relevant creative session. The insights of this evaluation are used to reflect on extended MW, fidgeting, and the potential of interactive fidgeting devices.

2 BACKGROUND

2.1 Mind-wandering

MW is conventionally treated as an unwanted state that hinders focused work [10, 43]. However, much recent research has shifted to explore positive consequences of MW [49]. Researchers have suggested various potential benefits that MW may offer [58], among which, creativity or promoting the generation of novel and valuable thoughts, ideas, and insights, has attracted significant attention. Smallwood and Schooler [58] argue that MW facilitates creative incubation, and therefore should be seen as a mode of creative problem solving, rather than simply an unwanted state of distraction [57]. Sawyer suggests that "brief episodes of mind-wandering may provide the mind with moments of 'mini incubation' that contribute to creative thought, by temporarily taking conscious attention away from the problem at hand and providing a brief opportunity for insight to occur" [51, p.146]. A recent study found that daily ideas, as reported by the participating writers and physicists, that occurred in the moments of spontaneous task-independent MW were more likely to be impasse-overcoming (i.e., experiencing a "eureka moment"), in comparison with those generated during focused work [23]. A study by Baird et al. [4] showed significant evidence for the facilitating effect of mind-wandering on creative incubation. The authors claimed that conditions that favor MW (i.e., taking a break involving an undemanding task compared with simply rest, doing demanding task, and taking no break) enhance creativity [4]. However, later studies failed to replicate these results [59] and Steindorf et al. [60] challenged "the idea of mind-wandering states contributing to a creative-incubation process in divergent-thinking tasks" [60, p.584].

Murray et al. [44] offer two potential reasons for the low replicability of MW-related creativity experiments. First, "task-unrelated thought", the widely used definition and measure of MW, does not describe the kind of MW that benefits creativity, because thoughts being task-unrelated is not necessarily equal to being exploratory and unconstrained and vice versa. Thus, an updated definition and measure of MW is needed to allow us to better explore the relationship between MW and creativity. Here, taking a family resemblance approach to MW [55] opens up possibilities for studying MW phenomena in relation to creativity. Second, applying methods that measure a single type of creativity in an experimental setup may not be a fruitful approach to understanding the positive relationship between MW and creativity that has been observed mostly in everyday life. Thus, one important methodological improvement is to engage participants in creatively solving problems with personal relevance [44]. We take this point into account in the setup of our fidgeting and MW study (see Section 4).

Finally, work by Agnoli et al. [2] holds a nuanced position as the authors find that distinguishable types of MW (classified as "deliberate" and "spontaneous," or meta-aware and meta-unaware, respectively) correlated oppositely with creative performance, with deliberate MW predicting increased performance. This potential influence of meta-awareness is echoed by Zedelius and Schooler [67], who demonstrate the value of and call for "constructive," meta-aware, and purposeful MW to facilitate creative thinking. These fine-grained distinctions in MW suggest that, to support creativity, a guided and intentional approach to MW may be fruitful. We see potential here for interactive fidget devices to provide such deliberate guidance, specifically when we view MW from an extended mind perspective.

2.2 Extended mind-wandering

The original extended mind thesis, as formulated by Clark and Chalmers [12], holds that, simply put, cognition is not "all in the head". Instead, we should consider resources in the environment as integral to cognition: "If, as we confront some task, part of the world functions as a process which, *were it done in the head*, we would have no hesitation in recognizing as part of the cognitive process, then that part of the world *is* (so we claim) part of the cognitive process." [12, p.8, emphasis in original]. The quintessential example is of a person using a notebook to navigate towards some destination, where the notebook replaces remembering directional instructions (i.e., biological memory [7]). Other examples include modern-day technologies, such as smartphones, which can serve as cognitive extensions for a range of different tasks, such as interpersonal communication, spatial navigation, and remembering. Importantly, this "first wave" extended mind thinking is based on the parity principle; functional equality between internal and external cognitive processes (e.g., a notebook functionally replacing biological memory) [7, 24, 26]. Second wave extended mind theory [7, 24, 62], on the other hand, considers complementarity, rather than parity. On this second wave account, external components (e.g., notebooks, smartphones) need not functionally replace internal cognitive processes, but can complement them. The second wave perspective is important for fidgeting as a case of extended MW, as it allows fidgeting to not necessarily be a replacement for internal MW. In other words, fidgeting may be an important part of a MW episode and serve a functionally complementary role to internal MW processes. Our approach in this paper follows the second wave extended mind approach.

Most work on the extended mind thesis (both first and second wave approaches) primarily concerns *cognitive tasks*. In contrast, Bruineberg and Fabry [7] build on second wave extended mind approaches and provide a conceptual framework that focuses on *task-unrelated* cognition, specifically MW. The authors argue that habitual, diversionary smartphone use, also conceptualised as absent-minded smartphone use [38] and smartphone-related inattentiveness [37], are "canonical cases of *extended mind-wandering*" [7, p.4, emphasis in original]. In such cases, a person may find themselves using their smartphone without there necessarily being a task-specific reason to do so. MW is mediated by the smartphone and thus qualifies as a case of extended cognition [7]. Whether or not smartphone mediated, extended MW offers some of the same benefits as non-extended MW is still an open question. Gozli [26] does speculate that smartphones may serve as a tools for specific forms of MW; social networking sites, for example, might help one to mind wander about social relationships. More generally, Gozli [26] suggests that "[w]e might also be able to control MW with the help of technologies designed for regulation of our attention" (p.118). Inspired by the work of Bruineberg and Fabry [7] and Gozli [26], we suggest that fidgeting, when viewed as a member of the extended MW family, offers a potentially interesting route for guiding MW episodes.

2.3 Fidgeting as extended mind-wandering

Fidgeting is a common behavior with close to 50% of adults fidgeting regularly [27], though individual differences in the frequency and style of fidgeting also exist [11, 54]. An agreed upon definition of fidgeting is currently lacking, but it is typically described as physical movements that are nonessential to some ongoing focus task. Frequently, fidgeting involves small external objects like rocks, pens, and rings, but it is also common to use one's own body (twirling hair, scratching one's face, etc.) [34]. These types of fidgeting can be described as either "micro" or "macro" fidgeting [22], where the former refers to small movements often made with the hands while interacting with an objects and the latter refers to whole body movements, or movements with larger body parts [54], such as squirming in a seat. Farley et al. [22] demonstrated negative effects on lecture material retention for macro, but not micro, fidgeting. Thus, there is evidence for distinguishable types of fidgeting which can differ in impact effect. Little research has focused on differentiating effects of fidgeting with a "self-touch" component from object-based fidgeting, though self-touch itself is a popular research topic. As Karlesky and Isbister [32, 34] have established, fidgeting exhibits a lot of potential "in the margins" of the workplace, a physical and mental environment that does not readily support whole-body, macro fidgeting and movement. In order to provide a clear scope for our research, as well as address an understudied subcategory of fidgeting, we focus exclusively on object-mediated, micro scale fidgeting, excluding both fidgeting in a "self-touch" style and macro-scale movements.

There are many proposed reasons why people fidget, primarily grouped in a few categories. First, multiple authors suggest fidgeting for arousal self-regulation (a component of affect) or as a response to boredom [22, 50, 64, 68]. Others suggest fidgeting is a form of embodied self-regulation that can bound and encourage focus and attention [21, 32]. Another prevailing theory is that bodily fidgeting is a biological process to optimize calorie burn called 'non-exercise activity thermogenesis' [36].

As previously discussed, second wave extended mind theories enable the understanding of fidgeting as both complementary to internal cognition and as an exemplar of extended MW. Therefore, no matter its effects, fidgeting can be clearly positioned as a member of the "mind-wandering family" as discussed by Seli et al. [55] and Bruineberg and Fabry [7]. The dimensions of task relatedness, perceptual coupling, intentionality, and meta-awareness are used to situate fidgeting within and establish the boundaries of this MW family.

Fidgeting has previously been classified as "non instrumental movement" [64] that by definition does not pertain to the primary task [41]. We wish to further draw a distinction between task-relatedness and purpose. Fidgeting may lack the clear, desired outcome that underpins instrumental movements, but this does not render it purposeless. We propose that fidgeting may have an implicit, unconscious purpose as a critical component of extended MW. Recently, a study of neural activity in mice reveals significant cognitive influence of task-unrelated movement while solving a primary task [45], which could be equated to a form of extended MW. This movement in mice has already been compared to human fidgeting behaviors [39]. Other authors, such as Mittner et al. [42], have proposed finer distinctions between being on-task and MW, suggesting fidgeting is indicative of a "light MW" state of exploratory off-focus thought. This middle ground occupied by fidgeting challenges the instrumental (goal-directed and purposeful) classification of technology use as applied to extended mind-wandering by Bruineberg and Fabry [7] (adapted from Hiniker et al. [30]).

Fidgeting is also perceptually coupled (e.g., through sensorimotor coupling with a fidget spinner or other object). This goes against many conventional conceptions of MW as being perceptually decoupled, but note that Gozli [26] argues that "characterizing MW in terms of perceptual decoupling, or in terms of attention to 'internal' and private events, neglects instances where MW is enabled, triggered, and guided by perception of external events" [26, p.117]. We therefore situate fidgeting as a clear "style" of extended MW that integrates perceptual coupling and uses external events to influence and shape a MW episode [see also 7, 55].

Previous MW research has shown fidgeting to increase during unintentional mind-wandering [11], with Seli et al. [54] finding a particular correlation between depth of MW and total amount of fidgeting movement. People often engage in fidgeting without the intention to do so [47]. However, there are also cases in which people may deliberately fidget, indeed, people purchase fidgeting devices for the intended use of fidgeting with them [34]. We recognize fidgeting as spanning this intentionality spectrum, presenting a design opportunity to modulate intentionality for selective benefit.

Fidgeting is unguided and meandering, and can wax and wane during a mind-wandering episode [55]. This not only applies to the intention behind the fidgeting, but also its related attribute of meta-awareness. Just as intention changes, so can meta-awareness, so it is not a required component of fidgeting behavior [47]. Anecdotally, fidgeting on the active side of the "active engagement-passive experience" spectrum (or meta-aware/unaware spectrum) utilizes dynamic stimuli to support daydreaming, surmount mental blocks, and broaden experience to encourage and inspire creativity [34]. We anticipate meta-awareness to contribute to intentionality in fidgeting and vice-versa.

Clarifying and explicating these dimensions of extended MW allows us to clearly situate fidgeting as a proper, distinguishable member of the MW family. When viewed from the extended mind perspective, the argument for including fidgeting is only further strengthened.

2.4 Existing fidgeting devices

Existing research on fidgeting largely concerns analysis of "off-the-shelf" objects and devices, such as stress balls, fidget cubes, and fidget spinners. Given the immense popularity of these devices, such a choice is highly pragmatic. However, purpose-built research artifacts for triggering, modulating, and recording fidgeting interactions would also provide access to a deeper level of insight in research [see, for example, 16].

Existing design work on fidgeting occupies a broader focus than MW alone, primarily within the space of "embodied self-regulation." These works are in turn inspired by devices like the *Mind spheres* speculative interactive meditation aid and the *Relax!* pen, a prototype device leveraging implicit interaction for affect modification [8, 19]. Karlesky and Isbister [33] created two "Fidget Widget" prototypes using the Sifteo platform of connected, sensor- and touch display-enabled blocks to enable "mindless" interactions to selectively influence cognitive and affective states. A thematically-related in-process work leverages an AR system and fidgeting motions to support emotion regulation [31].

Two connected papers describe the construction and testing, respectively, of soft-bodied interactive fidget objects [13, 15]. The devices, in the forms of animals, embody multiple desirable fidgeting interactions such as squeezing, stroking, clicking, and more. Further, these interactions were captured by embedded sensors and fed back to provide limited dynamic interaction through "LED eyes" on each animal. This idea of an instrumented fidget object was further evolved in da Câmara's PhD thesis [14] through the "Fidgetato" prototype. This potato-shaped device logs the state of buttons, a tilt switch, and a pressure sensor with a timestamp to later enable data analysis. The Fidgetato lacks user-customizable options in feedback sensation or interaction mode, but is still an important example of an instrumented fidget object.

Contemporary work in design-centered fidget research reveals a few key underexplored opportunities: first, existing research only tangentially considers the interplay of fidgeting and MW, if at all, and thus our theoretical proposal broadens the range of potential applications for fidgeting. Second, providing user customizable interactions in fidget devices, especially if that device is centered in the physical (not digital) world, would be relatively novel. Third, the data logging of an instrumented fidget object can be leveraged not only for immediate feedback modulation but also for retrospective behavioral self-awareness. No one research fidget device has yet combined haptic feedback, personalization, and instrumentation in a robust manner.

3 DESIGN OF AN INTERACTIVE FIDGET DEVICE

3.1 Goals

Our approach takes fidgeting to be an integral part of an extended MW episode. As we argued previously, this opens up opportunities for examining extended MW through interactive fidgeting devices. Such devices can adapt to users' fidgeting preferences and can provide measurements of fidgeting behavior, where both of these traits are unique in comparison with traditional fidgeting devices, which are often 'dead' objects repurposed for fidgeting use [34]. The Fidget Knob may not immediately supplant other existing (repurposed) fidget objects for every user, but rather exemplifies a new class of technologically-enabled and responsive fidget devices. With the connection between extended MW, fidgeting, and creativity as evidenced by the literature, interactive fidgeting devices have the potential to provide new insights into fidgeting as extended MW by offering recording of fidgeting behaviors, to provide personal retrospective insights into MW, and to guide a person's extended MW by providing adaptive haptic feedback. With these aims in mind we set out to create the *Fidget Knob*.

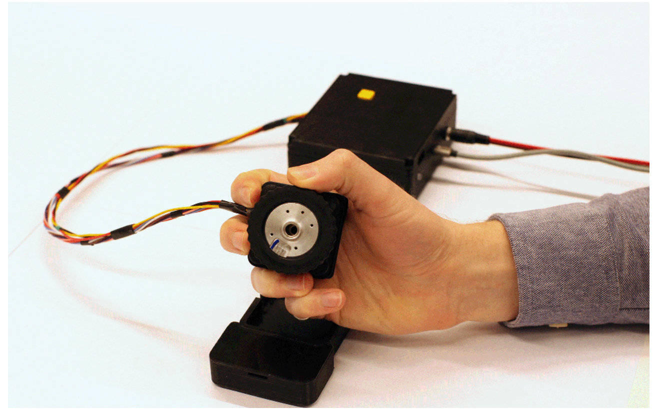

Figure 3: The Fidget Knob removed from its base and held securely in one hand by the user.

3.2 Research Device: Fidget Knob

While elements of fidgeting interactions are classifiable and recurring [15, 21], each individual still exhibits clear (and often narrow) fidgeting preferences. Accordingly, there will be no one fidget object or device that suits all users, so the Fidget Knob seeks to cover the widest base possible through it's implementation of interactive, "digital" haptic feedback. We sought to isolate a single type of movement for measurement, so we selected rotating a circular object axially due to it's relative popularity for fidgeting [21]. The Knob's design allows a user to select specific fidgeting modes, with different types of haptic feedback to suit their personal preferences. In the current implementation, the Fidget Knob features nine preset modes of feedback meant to a cover the general range of possibilities, from very fine to coarse detents, light to heavy forces, and more. Figure 4 visualises the haptic feedback sensations currently produced by the Knob. Utilizing software-controlled "digital detents" (instead of traditional mechanical detents) supports a range of haptic feedback vastly more diverse than offered by existing fidget objects, and theoretically unlimited distinguishable patterns of haptic feedback can be created. The Fidget Knob also enables data logging and analysis of fidgeting interactions within a single device, which can aid a user's self-awareness with regards to fidgeting as a part of an extended MW episode.

The Fidget Knob is a derivative design of a recent open-source project called the Haptic Knob by Scott Bezek [6], which is itself based on the open-source SimpleFOC platform [56]. The device consists of a brushless DC motor, magnet, and radial magnetic position sensor precisely aligned within a 3D-printed assembly, as well as a secondary box housing the control electronics, mode switch, indicator LED, and I/O ports. The knob and sensor assembly is tethered to the control box through an umbilical wire bundle. The knob's motion and haptic feedback is generated with a vector control (or *field-oriented control*) algorithm, capable of simulating different patterns and forces of "digital detents" within the rotation of the knob. To enable flexible modes of working in line with the adaptable feedback offered by the device, the Fidget Knob is magnetically secured in a weighted tabletop base and can also be easily removed to become handheld. The general form factor of

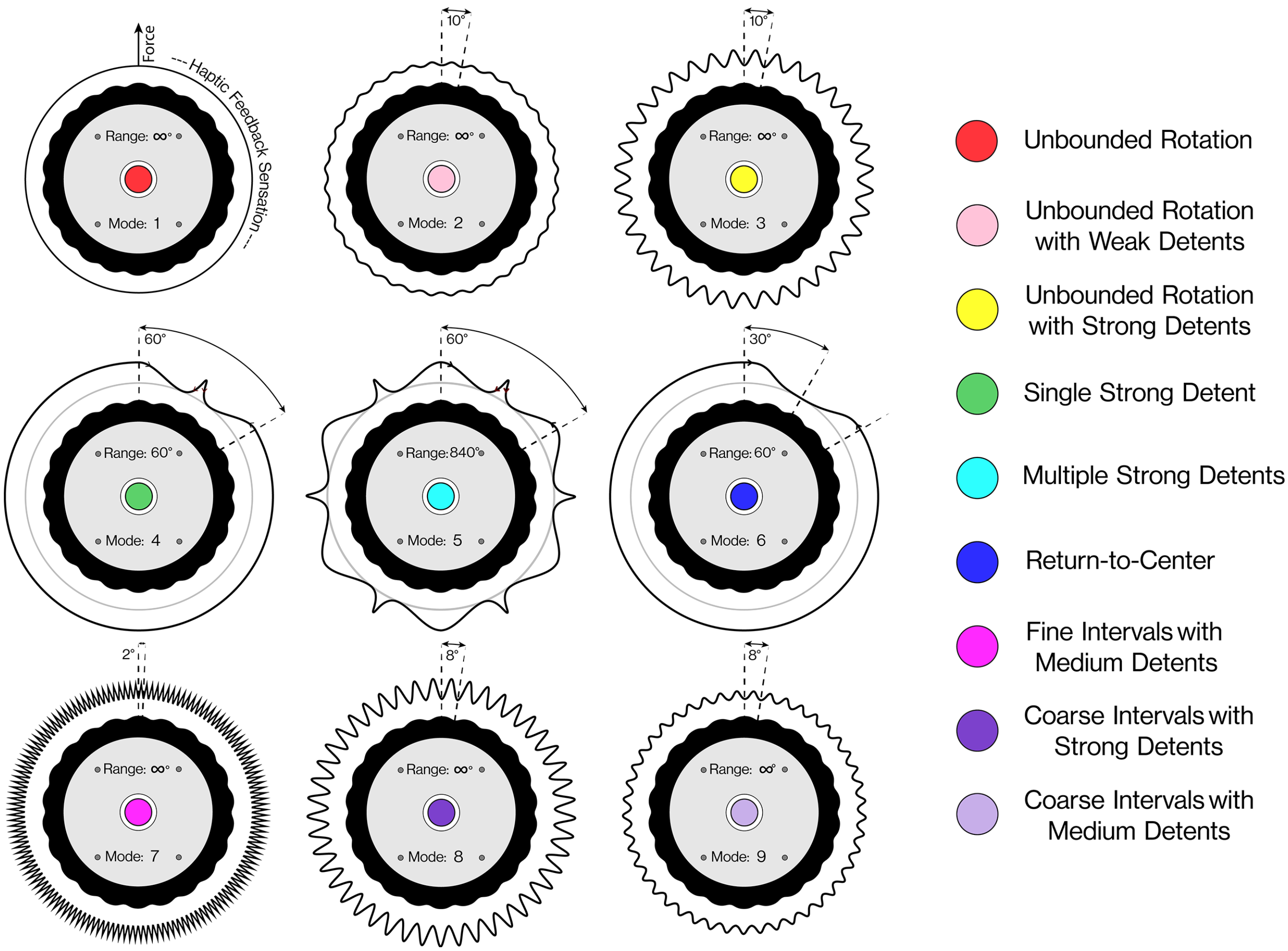

Figure 4: A graphical depiction of the Fidget Knob with 9 feedback modes. Th outermost shape on each knob represents the perceived sensation of the haptic feedback.

the device is constrained by the shape and size of the DC motor, as selecting a smaller size would render the haptic feedback too weak. Material selection (3D printed PLA) was driven by ease of manufacturing and widespread availability. Further, chosen micro-electronic components were selected for ease-of-use over reduced size or cost. As the device is intended as an open source research tool, it's design was largely influenced by the aim of consciously lowering the knowledge barrier for it's construction and operation.

The Fidget Knob runs firmware, written in C++, on an ESP32 microcontroller and controls motor phases with a TMC6300 motor driver and a 10 volt, 1.5amp DC power supply. The Fidget Knob logs timestamped data for the knob's absolute position, angular velocity, and applied phase voltages, through USB serial connection and a Processing script. These data function as proxies for overall amount of use (position/distance), engagement frequency and urgency (velocity), and resistive force (applied voltage and position).

The specifications, software, CAD files, and instructions for the Fidget Knob are covered under the Apache 2.0 and CC BY 4.0 "Attribution" licenses. All documentation and files can be found here: https://github.com/jeichenlaub/fidgetknob. It is a goal of this research to provide the Fidget Knob as a platform for further instrumented fidgeting research with a variety of populations and purposes (see Discussion), and to that aim, one could reconstruct this Fidget Knob in its entirety from the open-source files.

4 USER EVALUATION

In order to explore our conception of extended MW and the potential of the Fidget Knob to help users reflect on their extended MW behaviors, we conducted an exploratory user evaluation. This evaluation focused on the relation between extended MW, fidgeting, and behavioral expression. In the evaluation we sought to both record (using the knob) and observe moments of extended MW. We were particularly interested in situations where participants' self-reported MW co-occurred with fidgeting behavior, something

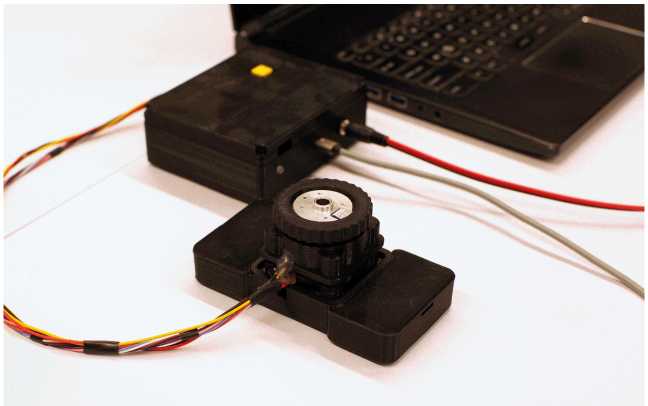

Figure 5: The Fidget Knob full assembly shown next to a laptop in an empty workspace.

which we take as an indication of extended MW. We created an isolated context with a physically stationary participant and one specific focus task, where that task was both personally relevant and involved elements of synthesis and creativity. Our aim was to take a first step towards better understanding object-mediated fidgeting as a form of extended MW.

4.1 Methods

The present evaluation is structured to gather qualitative and quantitative data on fidgeting tendencies and effects in a small group of participants. This data collection is accompanied by an interview for explanation and clarification of the captured events and other experiences during the evaluation. Through this evaluation, we immersed participants in a design-adjacent work task with elements of research, synthesis, and creativity and observed their behavior with the Fidget Knob. The intent of this evaluation is not to prove any single generalizable theory, but rather to start from the individual. We explore the possibilities for the Fidget Knob to support meta-awareness of extended MW within object-mediated fidgeting interactions and uncover whether self-reported MW (or data-captured MW) co-occur with fidgeting. The study was approved by the Human Research Ethics Committee of the Delft University of Technology, application #2643.

4.2 Participants

We felt it important to constrain the scope of the primary work task for our participants, even as we sought to allow freedom to fidget and work in a personally optimized way. For this, we gathered all participants from a specific subgroup of masters' degree students at the Faculty of Industrial Design Engineering at the Delft University of Technology. Each participant was in the middle-to-late stages of formulating their "project brief" (PB), a critical document for structuring and commencing the individual final thesis project. This brief is made outside the scope of formal coursework, requiring personal agency and self-sufficiency to complete. Importantly for this research, the PB requires academic literature research, creative synthesis and "connecting the dots" between abstract concepts, personal reflection, future planning, and more. Selecting the PB as the task for this study follows methodological improvement advice for studies on MW and creativity given by Murray et al. [44] by providing a task with strong personal relevance that requires complex creativity.

Our six participants were distributed five female and one male, spanning an age range of 23 to 31. Four of the six participants described themselves as fidgeters, with two of these four expressing a deeper interest in analyzing their own fidgeting behaviors on a regular basis. Two participants (#1 and 3) considered fidgeting "unnecessary" and not valuable or desirable. Importantly, these participants were still known to fidget, suggesting that fidgeting is not so much a choice as a latent characteristic. This variety in participant disposition towards fidgeting is later represented and visible in the results of the evaluation.

4.3 Procedure

Each of the six participants joined a session that lasted between 100 and 120 minutes, which included:

- A briefing and informed consent
- A short (2-3 minute) exploration period for using the Fidget Knob
- 60-70 minutes "immersion period" for utilizing the Fidget Knob alongside working on the PB.
- A 30-minute semi-structured interview at the conclusion of the immersion period.

The evaluation was conducted in a quiet and isolated study room in the StudioLab on TU Delft campus (Figure 6). The worktable surface and Fidget Knob were video recorded to later compare physical fidgeting movements to logged data from the device.

Participants were instructed that their primary task during the evaluation was to work on their PB in as natural a manner as possible. The use of the Fidget Knob was *not* required in any form for the evaluation, and one was to use the Fidget Knob only if they felt like doing so. An observing researcher (first author) was present during the entire session with the primary aims of conducting the probes and taking notes on the participants' behavior. These observations focused on recording moments of fidgeting (with or without the Fidget Knob), key changes in the participants' body language and apparent focus, and environmental circumstances that could influence the participants behavior. The researcher also monitored the Fidget Knob for proper functioning and data logging.

4.4 Probes and Interviews

To detect instances of MW during the evaluation and provide a basis for interview questions, participants were made to complete "categorical" type probes at semi-random moments. Review work conducted by Weinstein [63] found 69 methodological probe variants over 145 MW studies in five general categories that vary in comprehensiveness and analysis workload. We selected the categorical probe structure for an appropriate balance between the effort required to complete the probe (and therefore distraction from the primary task) and quality of data returned. We also chose an extended probe interval (target of 12 minutes, and a minimum and maximum of 8 and 16 minutes between probes, respectively) as Seli et al. [53] report that MW is more likely to be caught and reported in a probe as a function of increased time between probes.

Figure 6: A view of the study location and experimental setup.

The probes used were two-part: first, participants were asked "which of the following categories best describes your thoughts in the last 5 seconds?" and chose from the following categories:

(1) *The project brief (PB) itself*
(2) *Some topical information related to your work*
(3) A memory from the past
(4) Something in the future
(5) Current state of being (ex. I'm feeling hungry)
(6) Thinking about using another technology or device (ex. texting, checking Facebook, etc.)
(7) Other:

From the above categorization, items 1 and 2 (italicized) represent on-task states, with 3-7 denoting MW. After the appropriate number(s) were selected, the researcher asked participants to further describe the contents of their thoughts to understand the nuance of responses, overlap between reported categories, and, importantly, whether a participant was able to introspectively understand if their mind had been wandering.

The user evaluation session was followed by a semi-structured interview that asked both general questions on the participant experience and Fidget Knob perception as well as specific questions over events that transpired during the evaluation session. Interview recordings were retroactively reviewed for specific quotations and general notes were taken on key findings concurrent with the interviews. The hands-on sessions, probes, and interviews together demonstrate some clear patterns in use and perception of fidgeting and its interplay with (extended) MW.

5 RESULTS

Since the data for this explorative evaluation include a diversity of interconnected sources (observation, probes, interview, and data recorded from the device), it is logical that the study results are themselves a synthesis of these sources. There is no specific prescribed qualitative analysis method applied to this study (like grounded theory or thematic analysis) and instead we use a holistic evaluation of all the data available. A few elements drove the selection of the results presented here: first, we paid particular attention to participant fidgeting behavior and Fidget Knob usage during and around probe-caught instances of mind wandering. These moments became key points of questioning during the interviews. While the restricted scope of six participants does not give much opportunity for statistical significance in data, opinions and perceptions that reoccurred across multiple participant interviews were flagged as important and included in the results, often with representative quotations. During the course of the device evaluation session, the observing researcher noted key moments of individually "out of the ordinary" fidgeting and work behaviors. These moments were later compared to the video recordings and timestamped fidgeting data to show how device use data was clearly linked to real-world occurrences. As with all researcher-centered analyses, the results as presented thus contain an element of subjective conclusion, and therefore already build towards the later discussion section.

5.1 Fidgeting Cause and Effect

As expected, any one individual exhibits vastly different tendencies towards fidgeting than another, supporting prior research investigating trait fidgeting [11]. These differences are clearly visible in comparing traces of fidgeting activity over time for low and high-activity participants (#2 and 3, respectively). Participant 3 only engaged with the device sparingly, and for a very short time at each instance. In our interview, the participant admitted most of the engagement was intentional to "fit the study," and they would have done less naturally. In contrast, participant 2 is hands-on and engaged frequently (Figure 7). The interviews of participants 2 and 3 revealed different opinions on the value of fidgeting as well as social stigmas that further contributed to the observed engagement disparity. Participant 3 was frequently reminded of their facial touch-based fidgeting by their friends in a somewhat shameful manner, where participant 2 experienced no such feedback.

Device data reveals that different work activities produce divergent interaction characteristics in fidgeting. Participant 1 remained relatively inactive while typing and writing in their project brief. The moment they switched to reading an academic paper, however, their fidget device use spiked (visible at the dotted line and shaded area in Figure 8). This suggests that micro, object-mediated fidgeting has strong situational, not global, benefits. In their own words, Participant 1 felt "…for some reason when I started reading, [fidgeting] kind of made me focus more."

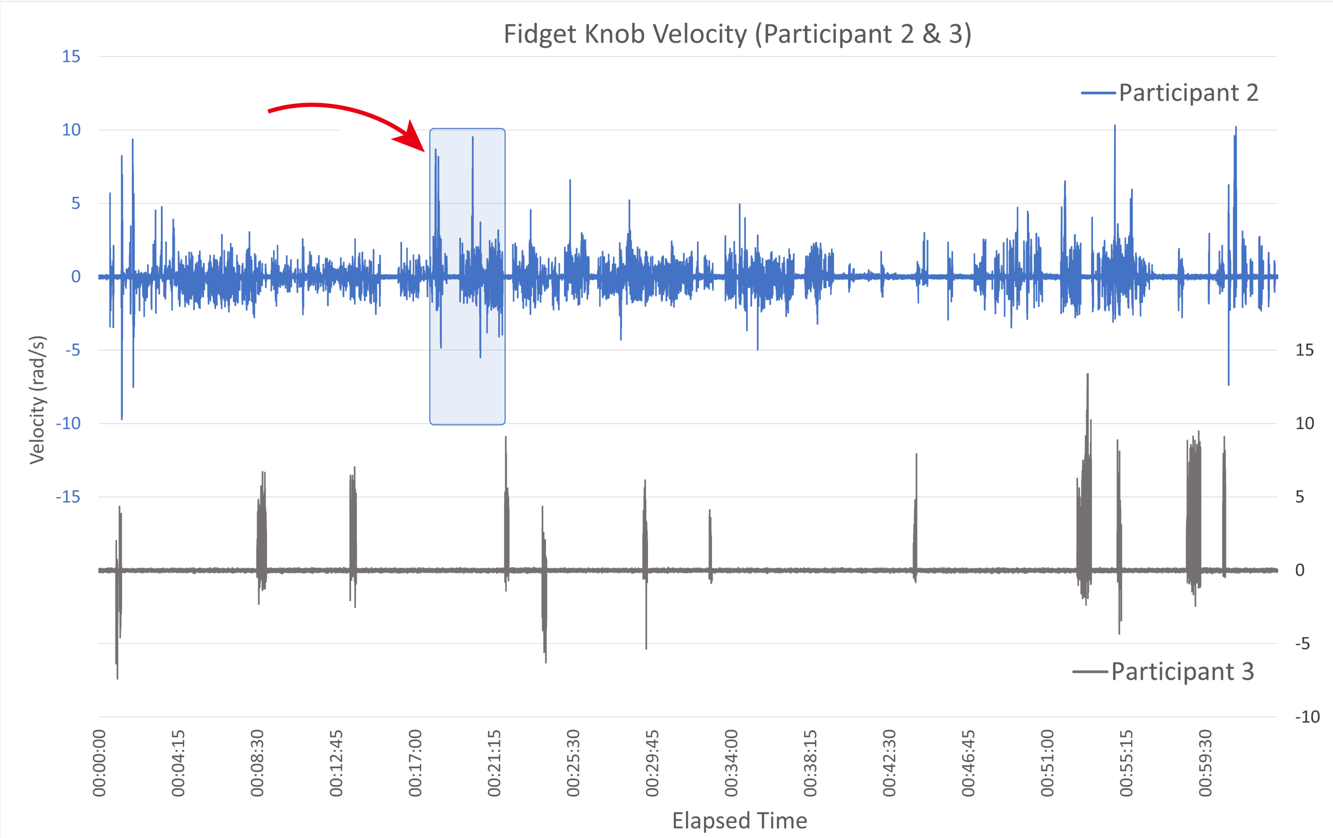

Figure 7: A comparison of the traces of the velocity of the Fidget Knob over time for participants 2 and 3. Velocity acts as a proxy for engagement with the device.

Multiple participants exhibited fidgeting behavior outside of the knob during the study, largely with their own bodies and faces. When asked, many discussed prior awareness of this behavior, and one participant (4) offered a potential explanation:

> *I started touching my hair while I study, and it's actually a problem because then I associate that motion with thinking. So, if I don't do that, I think I'm not able to think! And with this [Fidget Knob] I didn't do it now that I think about it.*

We can see that the Fidget Knob has potential to supplant existing ways of fidgeting that are harmful or distracting. Further, our participant explicitly describes their learned association between a fidgeting behavior and the ability to think. While this is only anecdotal evidence, it strongly aligns with findings from this and past studies in fidgeting.

5.1.1 Activity-Specific Fidgeting. While general patterns of engagement emerged based on focus task, multiple participants also demonstrated different work activities to engender specific fidgeting behaviors. For example, Participant 5 began to fidget when they "need to distract myself, I need to get rid of some thoughts" that are filling their head. The same participant also suggested "when I'm in the good flow and I'm focused, I don't fidget that much. It's the moment of fidgeting when I'm kind of… this switch between the [ongoing] tasks and what I should do now."

A particularly interesting scenario occurred while participant 2 was reading an academic paper. The paper itself ended suddenly with no clear conclusion, in a way that seemed to be in error. This unexpected occurrence triggered an immediate change in bodily posture and in intensity of fidgeting (visible in Figure 7 at the red arrow). This episode could exhibit fidget device usage as a compensatory mechanism for some change in state outside the norm of what was expected in the work environment.

5.2 Mental Representation

Multiple participants expressed that interaction characteristics of each Fidget Knob mode could, in some way, form a representation of mental processes. When discussing the return-to-center mode (#6, blue), participant 4 offered the following insight:

> *I think of my brain, and of something I'm doing, and the two kind of go together in a way. I thought hmmm, maybe this is too… like it makes you feel stuck. Instead, if you keep going with the 'flowy' [modes]… it represents the mental flow."*

Participant 5 also echoed these sentiments about the more resistive feedback modes (#4 to 6), saying the modes would fit a more

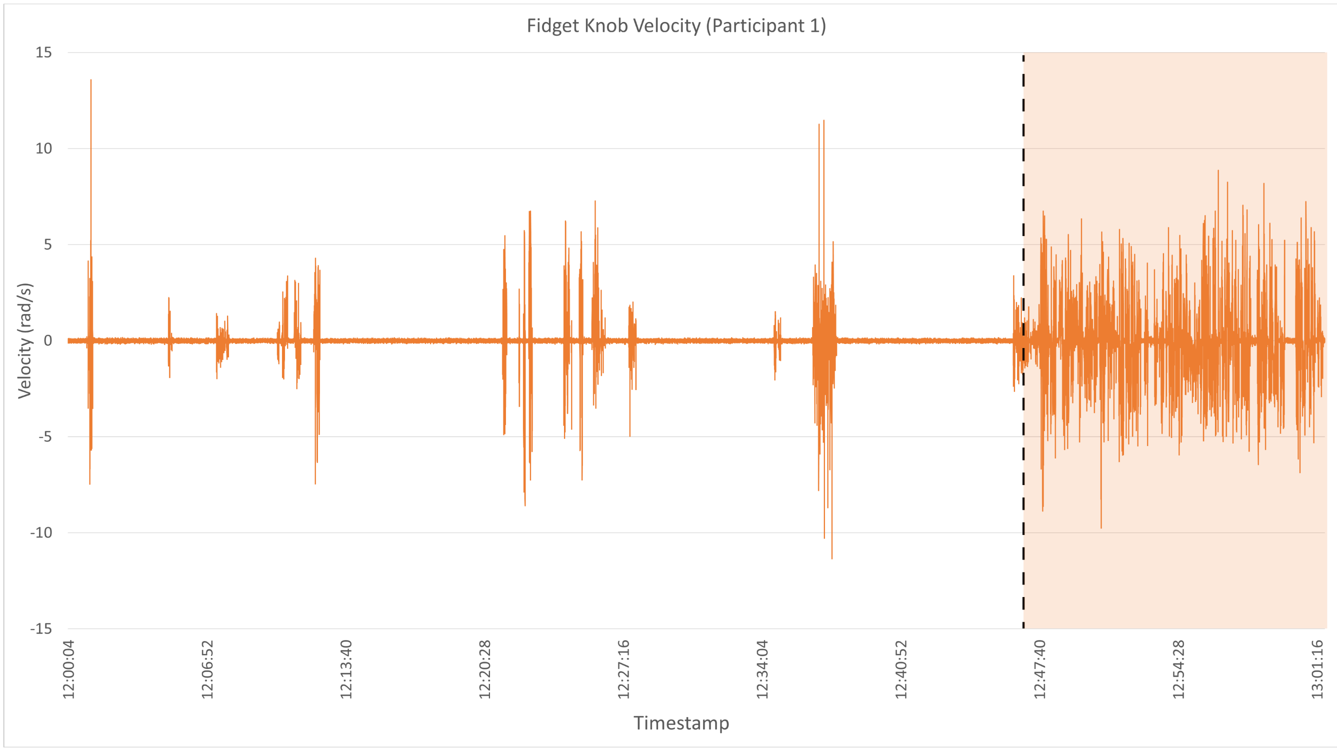

Figure 8: Trace of the velocity of the Fidget Knob over time for participant 1

high-stress work context, with the cycles of tension in the knob allowing for one to "release their stress". Their propensity towards utilizing such modes drove self-awareness and informed them of their own internal stress during fidgeting episodes, yielding greater introspective knowledge than without the device.

Extending this "mental representation," fidgeting can also be seen as a vehicle through which thought is conducted (or inhibited). Participant 4 believed the resistance of the return-to-center mode would cause annoyance and they "could go crazy" as the knob "blocks you." Participant 5 used the haptic and auditory clicks of the device as a physical signifier of mental movement from one idea to the next. Participant 2 also stated "it's correlated with what I was reading. If I'm done with a sentence, I switched a click." Not only does this embodied behavior represent the content of one's thoughts, but also forms an integral component of executing those thoughts through a physical cognitive extension (i.e., the Fidget Knob). These results open up possibilities for situationally variable fidgeting feedback to support constructive extended MW, which we further elaborate in the discussion.

5.3 Pleasurable Fidgeting

Another popular use for the Fidget Knob was simply for pleasure-seeking. Participant 1 enjoyed the prototype as it provided a pleasurable scrolling similar to their mouse wheel, without the negative side effects of moving their display window around. Participant 6 said "it was a good thing to always feel like I have a pet in my hand or something that is reacting to me. I like the little vibration [between detents]." Participant 3 felt the feedback provoked a "desire to play," and participant 4 found the prototype so satisfying that they got distracted by the "instant gratification for the hands" the device offered. While the purpose of this Fidget Knob is not only to provide pleasure, it can also be seen as a necessary component of voluntary engagement, and such engagement and desire is a prerequisite for accomplishing any future fidgeting-mediated goals. We do note, however, that the potential for the Fidget Knob to act as a distractor aligns with potentially negative effects of extended MW mediated through digital devices [7] (see also discussion section 6.1.2).

5.4 Consistent Preference

Users exhibit both clear and enduring preferences for specific modes of the Fidget Knob, with a general trend towards the lighter and finer modes (#2, 7, and 9) with unlimited rotation (see Figure 9) . Each participant verbalized having a specific preferred mode (or two) for use while working and showed little to no interest in utilizing other modes. Our most consistent participant (3) used their favorite mode for 98.2% of the study duration, and the least consistent (4) used theirs for 38% of the time (and top 2 modes for 73% of the time). This is in direct accordance with the observed principles of "individual consistency in collective variety" [21] and ritual interaction from prior fidgeting research [34].

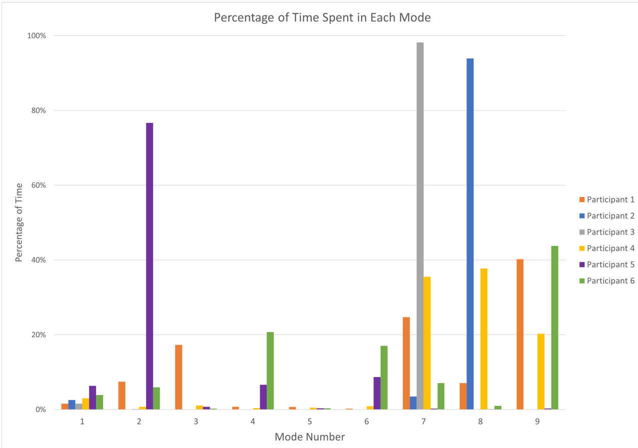

Figure 9: Distribution of participants’ selections of device mode during the study

5.5 MW Probes

Of the total of 29 probes, 6 probes captured a moment of MW as reported by participants. This amounts to 20.7%, which is on the low end of MW frequency given established frequency of mind-wandering in work tasks is 20-50% [52]. Of these six MW-capturing probes, three showed the Fidget Knob itself was the key focus of the MW episode (always when set to a strong force mode; probe category 7). Participant 3 was seen to increase their fidgeting behavior immediately before the fourth probe (the large spike in movement after 51 minutes elapsed in Figure 7). This probe demonstrated they were reflecting on past memories of time with friends (probe category 3), a clear instance of mind-wandering within the work context. Probes also captured that fidgeting was more likely when performing a task *related* to the project brief like reading, instead of writing the brief itself, with participants 1, 5, and 6 fidgeting more when responding with category 2 than category 1 on the probes.

Participant 6 took it upon themselves to provide self-caught (not probe-caught) open-ended reports of their MW when aware of it, demonstrating that participants were MW much more frequently than was caught with the probes. While the probes themselves did not link MW and fidgeting with as much clarity or frequency as anticipated, the responses did provide a clear basis for the interview discussion that underpins much of the presented results.

5.6 Fidget Knob Itself

Participants had much feedback to offer on the Fidget Knob prototype, specifically in terms of ways it could be made more suitable for varied fidgeting modes. Most participants used the Fidget Knob at very slow rotational speed with their hand in a “claw grip” form that resembled the posture of using a laptop trackpad. Most commonly, participants used their index and/or middle finger on the edge of the knob wheel to rotate it. Some participants used their thumb infrequently, and a number placed the point of their index finger on the top surface of the knob (see Figure 10).

While all participants used the Fidget Knob for the study, two participants declared they were not spinning-type fidgeters, instead preferring to squish or knead something. As expected, we can verify that the choice of rotation as the primary interaction will inherently limit the scope of the device.

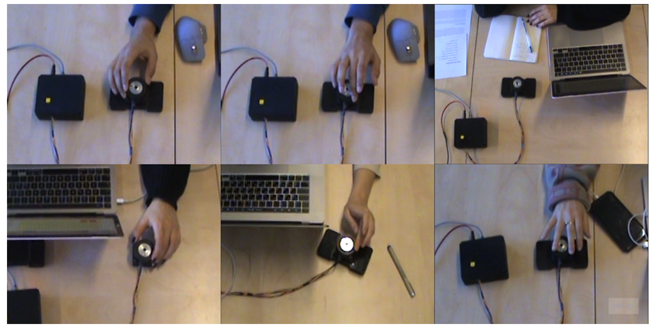

Figure 10: Views of participant interaction with the Fidget Knob during the evaluation

Most participants expressed a desire for the knob itself to become more handheld through a slight reduction in size and an improvement in the ergonomics. Currently, the square base does not fit comfortably in one’s hand. Participants also would have preferred the base to be made of softer and warmer materials. Two participants wished that the textured knob grip was made into a more organic shape. Another three participants suggested softer touch materials like silicone, video game joysticks, and soft fur for the outer ring of the knob, so long as the grip remained.

5.6.1 Software Haptics and Control Systems. Certain feedback modes, especially the stronger and coarser modes, provided a “pulsing” or “jittering” feedback when turned towards the end of a detent or range of motion. This feedback, an artifact of the PID control loop in the firmware, was seen almost universally as displeasurable and distracting. Participants also disliked the separate box with the mode switch button, preferring it to be integrated in the knob stand or even the knob itself. One participant suggested a switch, rotating dial, or multiple buttons would be a better user interface as the current method of clicking through modes sequentially was inordinately demanding and unintuitive.

The above results represent an analysis of the six conducted user study sessions, bringing together quantitative data on fidgeting with in-context behavioral observation and personal interviews. These results are largely in accordance with the limited prior research on fidgeting from a design perspective. We discuss these results, as well as our theoretical connections from the background sections, to propose updated current knowledge and directions for future research.

6 DISCUSSION, LIMITATIONS AND CONCLUSIONS

Mind-wandering research is laced with contradiction and opposing conclusions as it relates to MW efficacy, purpose, origin, and more. Our aim is not to resolve these inherent conflicts, but simply to “create space” for design within this complex field. We present this discussion as evidence-supported provocations, ideas, and exploratory avenues, rather than as strict, factual claims. In discussing our findings, we consider the "inspiration approach" from Stolterman [61] and their proposal that the design process can be improved through clear definition of a design space and provision of tools and methods for study (such as the Fidget Knob), given such tools and knowledge are not strict and prescriptive.

6.1 Findings from Research

6.1.1 Personal Knowledge of Fidgeting. We find the data generated through interaction with the Fidget Knob to be suitable both for internal (personal) and external analysis. The data will allow users to evaluate on their own fidgeting behaviors and effects, generating "self-awareness" as to the situational benefit and applicability of fidgeting. This could be both "in action" or retrospective and data driven. Indeed, some of our participants in the study used the Fidget Knob to reflect on their fidgeting behaviors. Participant 4, for example, related the use of the device to their fidgeting habit of touching their own hair, and came to understand how those actions had become an integral part of their "thinking process." Such self-tracking is known to generate expertise and practical self-knowledge [29] and has already been applied in the HCI and wellness domain [17]. Participant 5 discussed their force and pattern of use of the Fidget Knob as cluing them into their internal stressed state. While not explicitly requested by the users, such self-awareness can be seen as critical to utilizing fidgeting in a manner that supplements their primary goals instead of simply providing distraction.

Further, researchers may use this device to engage a large number of users in citizen science projects (generating large data sets) to create personas or characterizations to classify types of fidgeting behavior and identify subgroups for further study. The data obtained from the Fidget Knob, as illustrated by Figures 7 and 8, highlight individual differences in fidgeting behaviors. While empirical evidence already demonstrates potential groupings for fidgeting behaviors [15, 21], this data-driven approach offers clear input and parameters for classification.

6.1.2 Fidgeting as Extended MW. Our present findings both challenge and extend Bruineberg and Fabry's proposal that extended MW "shares the costs of MW, but does not share the benefits" [7, p.18], as our interviews on participant perception of fidgeting provide empirical evidence for both these costs and benefits. Their claim of extended MW inutility might be driven by the scope and the complexity of ICT devices, with the infinite possibility they offer for extended MW. Distraction with an ICT device can be cognitively consuming, occur over a long time, and is often not ritualistically repetitive in its physical movement in the same way as fidgeting. While Bruineberg and Fabry suggest that their framework may also apply to "other cases of habitual engagements with digital technologies" [7, p.24], they may not have anticipated extended MW occurring through comparatively "dumb" interactive fidget objects when defining their proposal. As such, the claim that fidget objects are providing both costs and benefits during extended MW is not wholly in opposition to Bruineberg and Fabry, but rather extends the manifestation of extended MW with a different "class" of interaction. Indeed, as related to the costs of extended MW, some of our participants (participant 3 and 4), found the Fidget Knob evoked a desire to play, and for one participant, served as a distraction from their primary task due to the satisfaction the device offered. Even the use of relatively simple interactive fidgeting devices could thus potentially result in negative effects of extended MW. Therefore, care has to be taken in the design of these devices, for example, by monitoring ongoing fidgeting behavior and provide feedback or limit the device should fidgeting increase above a certain pre-set threshold. In general, levels of interactivity (e.g., mode switching, the device responding or adapting to a user's behavior) would be interesting to investigate as a parameter in relation to distraction through device-mediated extended MW.

In the present explorations we have considered fidgeting as extended MW in accordance with the family resemblances approach to MW [55]. We should further consider MW as a process instead of a discrete event and explore the nuances within the phenomenon. Setting the classification constructs of perceptual (de)coupling, meta-(un)awareness, and (un)intentionality on a continuum [as also discussed by 7, 55] would allow for studying how one's MW experience evolves over the course of an episode. With our proposition that fidgeting is an integral part of an extended MW episode, fidgeting data could be used to investigate the development of such MW episodes and the relative role of cognitive extensions offered by fidgeting throughout such episodes. As our data show, certain moments during a task (e.g., reading, or task switching) may elicit more pronounced moments of fidgeting and thus of extended MW.

6.2 Future Work

6.2.1 Research Platform. We see our proposition to conceptualise fidgeting as extended MW as an invitation to designers to actively explore the concept of MW. Designers could play a central role in designing specific fidgeting interventions that, for example, support constructive extended MW for creative ideation. By providing an open source, customizable, instrumented, and responsive device with the Fidget Knob, we hope to open up the design space for fidgeting and MW research. The use of a singular platform in multiple studies on fidgeting could finally enable direct comparison of fidgeting behaviors on a large scale and across many conditions. Further, we see strong potential for crossover outside of the HCI domains, for example, in research with young people with ADHD or people on the autism spectrum who often employ "stimming" as a coping mechanism. We encourage adaptation and "remixing" of the existing device to fit any particular research scenario, and we can already offer a few ideas on how the device could be adapted to support constructive extended MW.

6.2.2 Affect Regulation (Personal and Social). Based on past research into non-instrumental movement driving affective change, there exists an opportunity to not only provide responsive haptic feedback but also "feedforward," or a predictive and intent-driven "inherent" feedback [8]. This would of course require a precise knowledge of 1) what manifested fidgeting behaviors signify and 2) what stimuli will cause what affective effects (and we already know this to be highly individual). This was proved to be quite difficult 10+ years ago, but the miniaturization and increase in fidelity of sensors and actuators since could re-open this opportunity space. A broader study with Fidget Knobs given to participants over extended time along with a diary/journal elements could help understand how fidgeting manifests situationally, later informing this "feedforward."

We also envision the Fidget Knob to interface with social contexts in and out of the workplace. This would gain further power if the collected fidgeting data is linked to what is occurring on-screen for an individual, or, for example, tied to events listed in their calendar. Then, patterns of fidgeting could be directly matched with real-world events and activities. These use contexts could provide input parameters to the device to modulate its feedback, perhaps to drive engagement in a long meetings or induce useful MW. This again presupposes knowledge of specific interactions that can generate an affective response. As we saw from this present study, certain haptic feedback was seen as more frustrating and combative (affectively "arousing") than others, so this certainly is within the realm of possibility.

It is already known that "intentionality" is an important dimension in defining MW, and existing research has linked fidgeting to the "spontaneous," or unintentional, type of MW [11]. We see an opportunity the Fidget Knob to take over the responsibility for generating and regulating intentionality in MW episodes. This would challenge existing understandings of fidgeting as without intent and without benefit.

6.2.3 Fidgeting, Extended MW, and Creativity. In considering potential benefits of extended MW through the Fidget Knob, we see potential for how the device could support creative ideation. Meta-aware MW has been speculated to enhance (certain kinds of) creativity [2, 28, 48]. Many of the Fidget Knob's modes of interaction are slow, gentle, and calming, rather than fast and activating, and users demonstrated a clear preference for these slower modes during the evaluation. Abtahi et al. [1] argue that slow physical interaction can promote a "mindful state," and thus, the slowness in the physical interaction with Fidget Knob might encourage a form of extended MW that supports creativity.

Baber [3] makes a case for the importance of physical actions in creative problem solving, saying "embodied cognition is playing a role in explicating design thinking (because 'creativity' arises from interactions with materials rather than occurring solely in the head)" (p.2). Participants in our user evaluation repeatedly referenced fidgeting as "needed" to think, and that it is used to guide the progression of one's thoughts as people "think through" or via their fidgeting actions. Based on these findings and our theoretical proposition, we can see fidgeting as an embodied extension that supports creative ideation through non-instrumental movement. One speculation is that fidgeting is a way to "offload" MW onto the environment through use of a cognitive extension such as Fidget Knob. When and where such an extension of MW through fidgeting is somehow restricted, it could be that MW focuses inward exclusively or fails to materialise constructively, which, depending on the specific task, may be detrimental to task completion. Further research into moments where (internal) MW and extended MW through fidgeting align in creative ideation is necessary to substantiate this claim. We envision the Fidget Knob could serve as a way to provide restrictions to extended MW (e.g., by offering limited modes, or "counterproductive" modes as suggested by participants) to test whether restricting fidgeting could restrict constructive MW on the whole.

6.3 Limitations

One of the points of differentiation for this user evaluation is its aim to assess the impact of MW on creativity without an arbitrary task or quantitative evaluation. We consider creativity here in a design context, involving a "connecting of the dots" between abstract concepts, personal reflection, future planning, and more. Participants frequently spoke on the connection between fidgeting and "thinking," but without specific reference to creativity. We found it very hard to trigger organic creativity in the "lab setting," even though the lab mirrored a normal work environment. The chosen task of the PB may have been too developed at the time of the evaluation, requiring only fine tuning and editing rather than early-stage creative ideation as we have targeted. For future study, we recommend a task that is more "hands on" and involves generating some product or deliverable outcome, though not one that is artificial and constrained.

The evaluation was not able to identify the direct impact of extended MW-based fidgeting with as much clarity as hoped. As mentioned in the results, the probes caught MW with less frequency than could be expected. Our probe spacing was larger than other studies [53], so future research should consider increasing the frequency of the probes to match existing research more closely, or train participants in meta-awareness of their MW state to enable effective self-caught reporting (the most effective observed method). These changes would increase the likelihood of capturing significant MW while fidgeting.

The conducted user evaluation was limited in scope, and we see opportunity to extend the scope of future studies both longitudinally and across domains. A user study in which participants "live with" the Fidget Knob for an extended period in their natural work environments could yield deeper insight into stable use patterns and effects. As we discuss "self-awareness" and knowledge as a beneficial effect of the Fidget Knob, we would do well to conduct a study in which participants are given the opportunity to reflect on the gathered data and use it to modulate their fidgeting habits. Further studies comparing the smart Fidget Knob to existing (non-smart) fidget objects could determine how influential users find the haptic feedback of the Knob. Connecting the Fidget Knob with larger scoped research, especially within existing MW study paradigms and groups, could add legitimacy and supportive data to our ideas on extended MW and creativity. Clearly, many opportunities exist for diversified future research.

6.4 Conclusion

We have positioned fidgeting as an example of extended mind-wandering, a second wave extended mind view of the phenomenon of MW. Critical to this fidgeting-mediated extended MW is one's interaction with a fidget object and through this interaction, we consider MW, fidgeting, and creativity to be interrelated processes. This research demonstrates a prototype of the Fidget Knob, an instrumented, interactive, and responsive fidget object with the primary goal of supporting introspective self-knowledge in MW and aiding in cognitive processing and creative ideation.

We conducted an exploratory user study collecting both quantitative and qualitative data as participants utilized the Fidget Knob coincident with a work session on a task that united research, writing, and creative synthesis. Results of this user evaluation demonstrated a connection between fidgeting activity and mental processes as both an influencing factor and a tangible representation. Users had distinguishable fidgeting patterns based on their main focus activity, even if those patterns were not identical across participants. Users also demonstrated clear and consistent preferences for specific haptic sensations. The links to creativity itself were less clear, with some empirical evidence positioning extended MW as beneficial to the reflective and evaluative dimensions of creativity, but with further study necessary to produce conclusive evidence.

Future research can leverage the open-source Fidget Knob platform to further investigate fidgeting as an embodied interactive phenomenon. We believe larger data sets generated with this same research tool could enable novel quantitative identification and classification of fidgeting behaviors that was previously inaccessible. With these presented theoretical connections and platform for fidgeting research, we reengage with fidgeting as a topic of potential benefit in interaction design and establish a new exemplar of extended mind-wandering.

ACKNOWLEDGMENTS

The authors demonstrate no conflicts of interest, financial or otherwise. This research was supported by VICI grant number 453-16-009 of The Netherlands Organization for Scientific Research (NWO), Division for the Social and Behavioural Sciences, awarded to Pieter M. A. Desmet. Special thanks to the 6 participants of the Fidget Knob evaluative study for sharing their insights around fidgeting and dedicating their time to our research. We appreciate you! Credit for the inspiration *SmartKnob* design and code goes to Scott Bezek. Many thanks for your origination of that project and for the community Discord server for offering support and troubleshooting while designing, building, and modifying the Fidget Knob.

REFERENCES

[1] Parastoo Abtahi, Victoria Ding, Anna C. Yang, Tommy Bruzzese, Alyssa B. Romanos, Elizabeth L. Murnane, Sean Follmer, and James A. Landay. 2020. Understanding Physical Practices and the Role of Technology in Manual Self-Tracking. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 4, 4, Article 115 (dec 2020), 24 pages. https://doi.org/10.1145/3432236

[2] Sergio Agnoli, Manila Vanucci, Claudia Pelagatti, and Giovanni Emanuele Corazza. 2018. Exploring the Link Between Mind Wandering, Mindfulness, and Creativity: A Multidimensional Approach. *Creativity Research Journal* 30, 1 (Jan. 2018), 41–53. https://doi.org/10.1080/10400419.2018.1411423

[3] Christopher Baber. 2022. *Embodying Design: An Applied Science of Radical Embodied Cognition.* The MIT Press. https://doi.org/10.7551/mitpress/12419.001.0001

[4] Benjamin Baird, Jonathan Smallwood, Michael D Mrazek, Julia WY Kam, Michael S Franklin, and Jonathan W Schooler. 2012. Inspired by distraction: Mind wandering facilitates creative incubation. *Psychological science* 23, 10 (2012), 1117–1122.

[5] Benjamin Baird, Jonathan Smallwood, and Jonathan W Schooler. 2011. Back to the future: Autobiographical planning and the functionality of mind-wandering. *Consciousness and cognition* 20, 4 (2011), 1604–1611.

[6] Scott Bezek. 2022. Smart Knob. https://github.com/scottbez1/smartknob.

[7] Jelle Bruineberg and Regina Fabry. 2022. Extended mind-wandering. *Philosophy and the Mind Sciences* 3 (2022).

[8] Miguel Bruns Alonso, Caroline C. M. Hummels, David V. Keyson, and Paul P. M. Hekkert. 2013. Measuring and adapting behavior during product interaction to influence affect. *Personal and Ubiquitous Computing* 17, 1 (Jan. 2013), 81–91. https://doi.org/10.1007/s00779-011-0472-3

[9] Felicity Callard, Jonathan Smallwood, Johannes Golchert, and Daniel S Margulies. 2013. The era of the wandering mind? Twenty-first century research on self-generated mental activity. *Frontiers in psychology* 4 (2013), 891.

[10] Jonathan S.A. Carriere, J. Allan Cheyne, and Daniel Smilek. 2008. Everyday attention lapses and memory failures: The affective consequences of mindlessness. *Consciousness and Cognition* 17, 3 (2008), 835–847. https://doi.org/10.1016/j.concog.2007.04.008

[11] Jonathan SA Carriere, Paul Seli, and Daniel Smilek. 2013. Wandering in both mind and body: individual differences in mind wandering and inattention predict fidgeting. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale* 67, 1 (2013), 19.

[12] Andy Clark and David Chalmers. 1998. The extended mind. *analysis* 58, 1 (1998), 7–19.

[13] Peter Cottrell, April Grow, and Katherine Isbister. 2018. Soft-bodied Fidget Toys: A Materials Exploration. In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction.* ACM, Stockholm Sweden, 42–48. https://doi.org/10.1145/3173225.3173266

[14] Suzanne B. da Câmara. 2022. *Developing and Utilizing a Smart, Instrumented Fidget To Better Understand Fidgeting and its Relationship with Cognitively Demanding Activities.* PhD Thesis. UC Santa Cruz. https://escholarship.org/uc/item/82f0w3rkPeer-Reviewed

[15] Suzanne B. da Câmara, Rakshit Agrawal, and Katherine Isbister. 2018. Identifying Children's Fidget Object Preferences: Toward Exploring the Impacts of Fidgeting and Fidget-Friendly Tangibles. In *Proceedings of the 2018 Designing Interactive Systems Conference.* ACM, Hong Kong China, 301–311. https://doi.org/10.1145/3196709.3196790

[16] MR Dias da Silva and Marie Postma. 2020. Wandering minds, wandering mice: Computer mouse tracking as a method to detect mind wandering. *Computers in Human Behavior* 112 (2020), 106453.

[17] Nediyana Daskalova, Jina Yoon, Yibing Wang, Cintia Araujo, Guillermo Beltran, Nicole Nugent, John McGeary, Joseph Jay Williams, and Jeff Huang. 2020. SleepBandits: Guided Flexible Self-Experiments for Sleep. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3313831.3376584

[18] Mariana Rachel Dias da Silva, Myrthe Faber, Diogo António de Andrade Branco, and Marie Postma. 2022. Mind and body: The manifestation of mind wandering in bodily behaviors. In *New Perspectives on Mind-Wandering*. Springer, 59–75.

[19] Tom Djajadiningrat, Luc Geurts, Geert Christiaansen, and Steven Kyffin. 2008. Mindspheres Play your skills, relax your mind. (2008), 5.

[20] Arnaud D'Argembeau. 2018. Mind-wandering and self-referential thought. *The Oxford handbook of spontaneous thought* (2018), 181–191.

[21] John Anders Eichenlaub. 2022. *Constructing Fidgeting: Integrating Extended Cognition, Mind Wandering, and Mindless Interaction in Pursuit of a Productive Mood State.* Master's thesis. Delft University of Technology. http://resolver.tudelft.nl/uuid:d6b4a801-dd06-4624-9ede-831b2d572612

[22] James Farley, Evan F Risko, and Alan Kingstone. 2013. Everyday attention and lecture retention: the effects of time, fidgeting, and mind wandering. *Frontiers in psychology* 4 (2013), 619.

[23] Shelly L Gable, Elizabeth A Hopper, and Jonathan W Schooler. 2019. When the muses strike: Creative ideas of physicists and writers routinely occur during mind wandering. *Psychological science* 30, 3 (2019), 396–404.

[24] Shaun Gallagher. 2023. Technology and the Extended Mind. In *Technology Ethics.* Routledge, 52–60.

[25] Saulius Geniusas. 2022. Prolegomena to a phenomenology of mind-wandering. *Phenomenology and the Cognitive Sciences* (2022), 1–20.

[26] Davood Gozli. 2022. Extended Minds and Tools for Mind-Wandering. In *New Perspectives on Mind-Wandering*. Springer, 103–122.

[27] Gareth Hagger-Johnson, Alan J Gow, Victoria Burley, Darren Greenwood, and Janet E Cade. 2016. Sitting time, fidgeting, and all-cause mortality in the UK women's cohort study. *American journal of preventive medicine* 50, 2 (2016), 154–160.

[28] Danah Henriksen, Carmen Richardson, and Kyle Shack. 2020. Mindfulness and creativity: Implications for thinking and learning. *Thinking Skills and Creativity* 37 (2020), 100689. https://doi.org/10.1016/j.tsc.2020.100689

[29] Nils B. Heyen. 2020. From self-tracking to self-expertise: The production of self-related knowledge by doing personal science. *Public Understanding of Science* 29, 2 (2020), 124–138. https://doi.org/10.1177/0963662519888757 PMID: 31778095.

[30] Alexis Hiniker, Shwetak N Patel, Tadayoshi Kohno, and Julie A Kientz. 2016. Why would you do that? predicting the uses and gratifications behind smartphone-usage behaviors. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. 634–645.

[31] Chen Ji and Katherine Isbister. 2022. AR Fidget: Augmented Reality Experiences that Support Emotion Regulation through Fidgeting. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts.* ACM, New Orleans LA USA, 1–4. https://doi.org/10.1145/3491101.3519874

[32] Michael Karlesky and Katherine Isbister. 2013. Fidget widgets: secondary playful interactions in support of primary serious tasks. In *CHI'13 Extended Abstracts on Human Factors in Computing Systems.* 1149–1154.

[33] Michael Karlesky and Katherine Isbister. 2014. Designing for the physical margins of digital workspaces: fidget widgets in support of productivity and creativity. In *Proceedings of the 8th international conference on tangible, embedded and embodied interaction.* 13–20.

[34] Michael Karlesky and Katherine Isbister. 2016. Understanding fidget widgets: Exploring the design space of embodied self-regulation. In *Proceedings of the 9th Nordic Conference on Human-Computer Interaction*. 1–10.

[35] Matthew A Killingsworth and Daniel T Gilbert. 2010. A wandering mind is an unhappy mind. *Science* 330, 6006 (2010), 932–932.

[36] James A Levine, Sara J Schleusner, and Michael D Jensen. 2000. Energy expenditure of nonexercise activity. *The American journal of clinical nutrition* 72, 6 (2000), 1451–1454.

[37] Magnus Liebherr, Patric Schubert, Stephanie Antons, Christian Montag, and Matthias Brand. 2020. Smartphones and attention, curse or blessing?-A review on the effects of smartphone usage on attention, inhibition, and working memory. *Computers in Human Behavior Reports* 1 (2020), 100005.

[38] Jeremy Marty-Dugas, Brandon CW Ralph, Jonathan M Oakman, and Daniel Smilek. 2018. The relation between smartphone use and everyday inattention. *Psychology of Consciousness: Theory, Research, and Practice* 5, 1 (2018), 46.

[39] Mackenzie Weygandt Mathis. 2019. A new spin on fidgets. *Nature Neuroscience* 22, 10 (2019), 1614–1616.

[40] Jennifer C McVay, Michael J Kane, and Thomas R Kwapil. 2009. Tracking the train of thought from the laboratory into everyday life: An experience-sampling study of mind wandering across controlled and ecological contexts. *Psychonomic bulletin & review* 16, 5 (2009), 857–863.

[41] Albert Mehrabian and Shan L Friedman. 1986. An analysis of fidgeting and associated individual differences. *Journal of Personality* 54, 2 (1986), 406–429.

[42] Matthias Mittner, Guy E Hawkins, Wouter Boekel, and Birte U Forstmann. 2016. A neural model of mind wandering. *Trends in cognitive sciences* 20, 8 (2016), 570–578.

[43] Michael D. Mrazek, Jonathan Smallwood, and Jonathan W. Schooler. 2012. Mindfulness and mind-wandering: Finding convergence through opposing constructs. *Emotion* 12, 3 (June 2012), 442–448. https://doi.org/10.1037/a0026678

[44] Samuel Murray, Nathan Liang, Nicholaus Brosowsky, and Paul Seli. 2021. What are the benefits of mind wandering to creativity? *Psychology of Aesthetics, Creativity, and the Arts* (Sept. 2021). https://doi.org/10.1037/aca0000420

[45] Simon Musall, Matthew T Kaufman, Ashley L Juavinett, Steven Gluf, and Anne K Churchland. 2019. Single-trial neural dynamics are dominated by richly varied movements. *Nature neuroscience* 22, 10 (2019), 1677–1686.

[46] Albert Newen, Shaun Gallagher, and Leon De Bruin. 2018. 4E cognition: Historical roots, key concepts, and central issues. (2018).

[47] Kelsey Perrykkad and Jakob Hohwy. 2020. Fidgeting as self-evidencing: A predictive processing account of non-goal-directed action. *New Ideas in Psychology* 56 (2020), 100750. https://doi.org/10.1016/j.newideapsych.2019.100750

[48] David D. Preiss and Diego Cosmelli. 2017. Chapter 17 - Mind Wandering, Creative Writing, and the Self. In *The Creative Self*, Maciej Karwowski and James C. Kaufman (Eds.). Academic Press, San Diego, 301–313. https://doi.org/10.1016/B978-0-12-809790-8.00017-0

[49] David D Preiss, Diego Cosmelli, and James C Kaufman. 2020. An Introduction to Creativity and the Wandering Mind. , xvii–xxiii pages.

[50] Evan F Risko, Nicola Anderson, Amara Sarwal, Megan Engelhardt, and Alan Kingstone. 2012. Everyday attention: Variation in mind wandering and memory in a lecture. *Applied Cognitive Psychology* 26, 2 (2012), 234–242.

[51] Keith Sawyer. 2011. The cognitive neuroscience of creativity: A critical review. *Creativity research journal* 23, 2 (2011), 137–154.

[52] Paul Seli, Roger E. Beaty, James Allan Cheyne, Daniel Smilek, Jonathan Oakman, and Daniel L. Schacter. 2018. How pervasive is mind wandering, really?,. *Consciousness and Cognition* 66 (2018), 74–78. https://doi.org/10.1016/j.concog.2018.10.002

[53] Paul Seli, Jonathan SA Carriere, Merrick Levene, and Daniel Smilek. 2013. How few and far between? Examining the effects of probe rate on self-reported mind wandering. *Frontiers in psychology* 4 (2013), 430.

[54] Paul Seli, Jonathan SA Carriere, David R Thomson, James Allan Cheyne, Kaylena A Ehgoetz Martens, and Daniel Smilek. 2014. Restless mind, restless body. *Journal of experimental psychology: learning, memory, and cognition* 40, 3 (2014), 660.

[55] Paul Seli, Michael J Kane, Jonathan Smallwood, Daniel L Schacter, David Maillet, Jonathan W Schooler, and Daniel Smilek. 2018. Mind-wandering as a natural kind: A family-resemblances view. *Trends in cognitive sciences* 22, 6 (2018), 479–490.

[56] Antun Skuric, Hasan Bank, Richard Unger, Owen Williams, and David González-Reyes. 2022. SimpleFOC: A Field Oriented Control (FOC) Library for Controlling Brushless Direct Current (BLDC) and Stepper Motors. *Journal of Open Source Software* 7 (06 2022), 4232. https://doi.org/10.21105/joss.04232

[57] Jonathan Smallwood and Jonathan W Schooler. 2006. The restless mind. *Psychological bulletin* 132, 6 (2006), 946.

[58] Jonathan Smallwood and Jonathan W Schooler. 2015. The science of mind wandering: Empirically navigating the stream of consciousness. *Annual review of psychology* 66 (2015), 487–518.

[59] Bridget A Smeekens and Michael J Kane. 2016. Working memory capacity, mind wandering, and creative cognition: An individual-differences investigation into the benefits of controlled versus spontaneous thought. *Psychology of Aesthetics, Creativity, and the Arts* 10, 4 (2016), 389.

[60] Lena Steindorf, Holly A Hammerton, and Jan Rummel. 2021. Mind wandering outside the box—About the role of off-task thoughts and their assessment during creative incubation. *Psychology of Aesthetics, Creativity, and the Arts* 15, 4 (2021), 584.

[61] Erik Stolterman. 2021. The challenge of improving designing. *International Journal of Design* 15, 1 (2021), 65.

[62] John Sutton. 2010. Exograms and interdisciplinarity: History, the extended mind, and the civilizing process. (2010).

[63] Yana Weinstein. 2018. Mind-wandering, how do I measure thee with probes? Let me count the ways. *Behavior research methods* 50, 2 (2018), 642–661.

[64] H Witchel, Carina Westling, Julian Tee, Aoife Healy, Robert Needham, and Nachiappan Chockalingam. 2014. What does not happen: quantifying embodied engagement using NIMI and self-adaptors. *Participations: Journal of Audience and Reception Studies* 11, 1 (2014), 304–331.

[65] HJ Witchel, CE Westling, J Tee, TT Ranji, R Needham, A Healey, et al. 2018. Can fidgeting be used to measure student engagement in online learning tasks. In *Research matters: Articles from the pedagogic research conference*. 39–48.

[66] Haian Xue and Pieter MA Desmet. 2019. Researcher introspection for experience-driven design research. *Design Studies* 63 (2019), 37–64.

[67] Claire M Zedelius and Jonathan W Schooler. 2018. Unraveling what's on our minds: how different types of mind-wandering affect cognition and behavior. *The Oxford handbook of spontaneous thought: Mind-wandering, creativity, and dreaming* (2018), 233–247.

[68] Marvin Zuckerman. 2014. *Sensation seeking (psychology revivals): Beyond the optimal level of arousal*. Psychology Press.