Towards Understanding The Design of (Un)Fortunate Superpowers Through A Flytrap-Inspired Hand Augmentation

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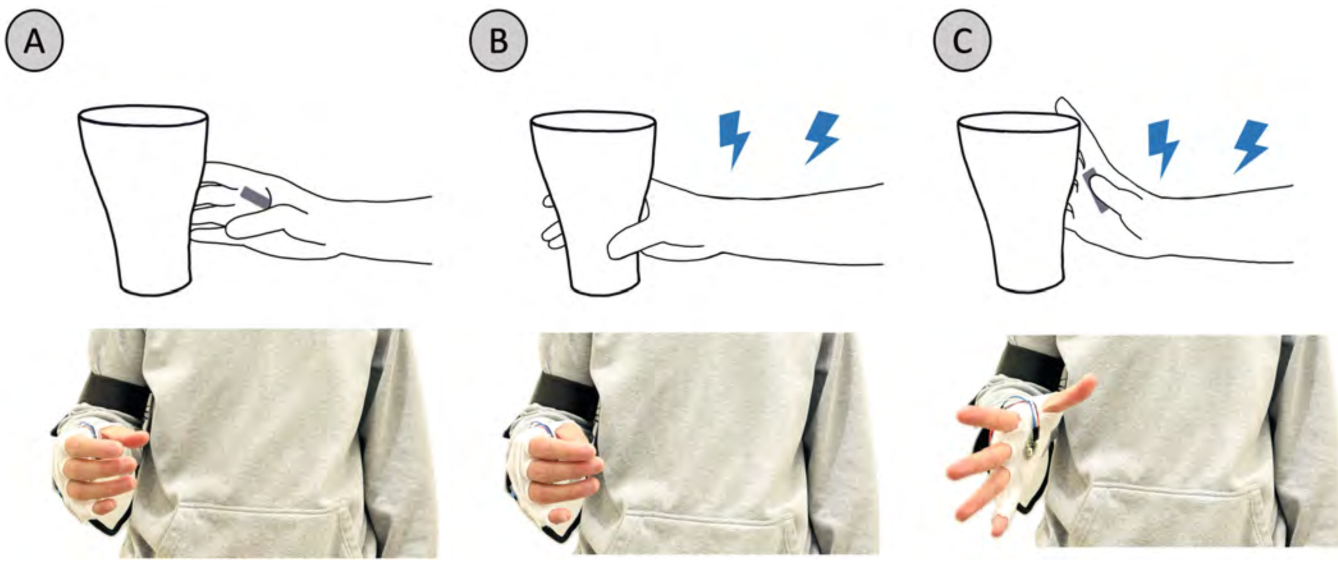

Figure 1: Flytrap Hand: when the user's hand approaches an object (a), the system triggers the user's fingers to contract and grasp the object with increased speed (b), the object is released when the user raises their little finger or after a random amount of time has passed (c).

ABSTRACT

Physical augmentation technologies can extend human abilities beyond biological limitations, creating "superpower" experiences. However, as these technologies integrate with the human body, they can also introduce unfortunate negative effects due to the body's constraints. Inspired by biology, especially the fly-catching mechanism of the flytrap plant, we designed "Flytrap Hand", a provocative artifact that grants users the superpower of accelerated grasping through a distance sensor and electrical muscle stimulation, while resulting in uncertainty. A mixed-method study (N = 12) revealed that participants appreciated the fortunate superpower effects, but also highlighted the unfortunate effects of discomfort, skepticism toward bodily automation, and ethical concerns. Building on these findings, we propose a design framework for designing more thoughtful superpower experiences that account for potential negative effects. Ultimately, with our work, we aim to help designers consider not only superpowers' positive but also negative effects early on as they may be difficult to rectify in hindsight.

CCS CONCEPTS

• **Human-centered computing** → **Interaction paradigms**.

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wearables, human augmentation, physical augmentation, superpower

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1 INTRODUCTION

The pursuit of enhancing human abilities through technology has long been a central theme in human-computer interaction (HCI) [19, 43, 89, 94]. Technologies such as exoskeletons [16, 27] and bodily extensions [93, 110] expand human capabilities, enabling people to act faster, stronger, and more efficiently, creating an experience often described as a "superpower" [62, 68, 71]. For example, *Wi-Fi Twinge* grants a Wi-Fi sensing superpower [72], *VibraHand* grants a remote telekinesis superpower [58]. These technologies have the potential to change everyday activities by overcoming biological limitations. However, prior research suggests that augmenting the human body to create superpower experiences come at a cost [25, 70, 72]: while people may benefit from enhanced abilities such as increased speed, they can also face negative "unfortunate" effects due to the physiological, psychological, and ethical constraints that arise when the boundaries between human and machine begin to blur.

Inspired by speculative design that aims to provoke critical reflection (instead of focusing on practical solutions) [5, 26], we explore the concept of "unfortunate superpower experiences" - physical augmentations that lead to fortunate but also unfortunate negative effects as a result of augmenting the human body - through a provocative artifact as a research probe [11] to reflect on what is gained, lost, or distorted when technologies attempt to augment the human body [37, 91, 109].

Drawing from biological metaphors, especially the fly-catching mechanism of the flytrap plant, we present "Flytrap Hand" (Figure 1), a provocative artifact that grants users the superpower of accelerated grasping through a distance sensor and electrical muscle stimulation (EMS), similar to how the flytrap plant closes its leaves at "super" speed (for a plant) when insects make contact [35, 111]. We designed two distinct release mechanisms to examine how different levels of system control affect user experience, agency, and trust in augmented interaction: (1) Randomized time control: Object release occurs unpredictably within a time range determined by the system, aimed to represent altered muscle fatigue, potentially undermining user agency and (2) Body control: Users actively release objects by lifting their little fingers, regaining control however, this necessitates the introduction of an unfamiliar gesture.

In a mixed-methods study with 12 participants, we found that Flytrap Hand reduced physical exertion, but also increased cognitive load, decreased user trust, and diminished the sense of agency. Participants appreciated the fortunate superpower effects, but also expressed the unfortunate effects of discomfort, skepticism toward bodily automation, and ethical concerns. Building on these findings and our design experience, we propose a design framework to guide the design of future superpower experiences that consider not only fortunate, but also unfortunate effects.

Our research features the following contributions and benefits:

- **System design**: A provocative design artifact offering fast grasping superpower experiences, inspiring designers of superpower systems.
- **Empirical understanding**: A user study investigating the superpower experiences with Flytrap Hand revealed three key themes, offering insights for user experience researchers interested in both the fortunate and unfortunate effects of superpower technologies.
- **Design framework**: A two-dimensional design framework and three design strategies, derived from our study and design process, guiding designers when aiming to create future systems that facilitate superpower experiences.

Ultimately, we expect that our work can deepen our understanding of how to design superpower experiences by explicitly considering both the fortunate and unfortunate effects early on in the design process to rectify in hindsight.

2 RELATED WORK

This section details what we learned from prior work surrounding superpower experiences in physical augmentation research, the discomfort and negative effects in interaction design and how previous research examined such negative effects.

2.1 Augmentation as a superpower

Throughout history, humans have sought ways to enhance the abilities of people with specific needs, from the use of simple tools to the development of complex machinery, such as prosthetics that restore a person's abilities [19]. In contemporary times, technological advances have extended physical augmentation beyond functional restoration, towards improving human physical abilities beyond their biological limits [19]. For example, exoskeletons enabling paralyzed individuals to walk [16, 27], wearable devices providing extra limbs to handle an increasing number of tasks [23, 93] or jet-packs allowing a person to fly [49].

These developments have led to the articulation of the physical augmentation concept, a specific form of human augmentation [89, 92]. Physical augmentation refers to the application of technology to improve a human's ability to perform physical actions, granting individuals capabilities that can be likened to "superpowers" [43, 94, 96]. For example, flying [49] or super-jumping abilities [95, 101]. Therefore, we define a superpower experience as the experience of enhanced action, perception or cognition mediated by a system, where users perceive their capabilities as extended beyond natural limits, drawing on literature in human augmentation [43, 94].

Electrical Muscle Stimulation (EMS) have often been explored as a method for physical augmentation, offering enhanced abilities such as increased movement speed [56, 57, 79, 113]. EMS transmits electrical signals to muscles via surface electrodes, inducing muscle contractions to facilitate movement [76, 86, 90]. EMS applications can be categorized into rehabilitative, assistive, and augmentative/playful contexts, with Flytrap Hand exemplifying the augmentative/playful type, where stimulation enhances a healthy user's capabilities in novel ways [29]. Prior work has shown that EMS can accelerate reaction times, leading users to report experiences akin to having a "superpower" [56, 79]. User acceptance of EMS has been found to depend on comfort, perceived control, and predictability of stimulation, which are key factors influencing trust and engagement [30, 59]. Although EMS can enhance movement and elicit superpower experiences, prior work has highlighted potential risks associated with electrical stimulation. Studies have reported muscle damage and negative motor responses under certain conditions [81, 106], emphasizing the need for careful calibration and monitoring when designing EMS-based augmentation systems.

2.2 Discomfort and negative effects in interaction design

While physical augmentation can produce seemingly exciting "superpowers," it can also lead to negative effects [24, 69, 72, 78]. For example, continuous sensory stimulation may lead to fatigue [72, 86], while automation of motor functions may reduce the user's sense of agency [80, 87]. Such discomfort caused by negative effects has often been seen as a problem that needs to be minimized. However, Benford et al. [9] introduce the notion of "uncomfortable interactions", showing that discomfort can be used intentionally as a design material to provoke reflection or reveal hidden assumptions.

Similar negative effects can also emerge from "coercive or manipulative behaviors" embedded within a system's operation. For example, interactions that override user control or impose involuntary actions, paralleling "dark patterns" in interface design [40], can be reframed in research contexts as provocative strategies to reveal concerns about empowerment, agency, and consent. Such intentional design choices can prompt deeper investigation into the negative effects of technology, informing the development of ethical and user-centered experiences [40, 42, 74].

Beyond experiential downsides, physical augmentation also raises ethical concerns around privacy and security [66, 78, 82]. For example, systems that rely on sensitive physiological data or actuate the body via EMS can be vulnerable to malicious interference, posing risks of manipulation or harm [3, 10, 15, 63]. Therefore, considering ethical dimensions alongside experiential factors such as discomfort and perceived control can help create augmentation systems that are not only technically safe, but also socially responsible and critically informed.

2.3 Learning from critical and speculative design in HCI

Critical and speculative design have been widely discussed in HCI as approaches for questioning dominant technology narratives and exploring alternative futures [7, 26, 75]. These approaches create artifacts as provocations to stimulate reflection on the social, ethical, and cultural dimensions of technology [99]. Inspired by speculative design principles, particularly the intentional use of discomfort and loss of control as triggers for reflection on the ethics and implications of physical augmentation, we adopt a provocative design approach to drive more efforts to understand the negative effects of physical augmentation. This inspiration informed the creation of an augmentation device that intentionally incorporates negative effects in its design choices, challenging the assumption that technological enhancement is inherently beneficial, revealing deeper insights into agency and trust in superpower experiences. Our adoption of a speculative and provocative design approach is informed by prior work demonstrating the value of design fiction in eliciting ethical, societal, and experiential insights [11]. Such approaches allow researchers to intentionally introduce discomfort or ambiguity in user interactions to probe assumptions, elicit reflection, and study emergent behaviors, thereby situating our work within an established methodological tradition.

Taken together, there appears to be an awareness that emerging technologies come with dangers, and physical augmentation is no exception. However, less attention has been given to the potential negative effects of physical augmentation, in particular, the resulting superpower experience. While prior EMS-based augmentation systems primarily focus on functional enhancement [56, 57, 80], a gap remains in understanding the complex trade-offs involving agency, trust, and negative user experiences. Our work begins to addresses this gap by investigating both the fortunate and unfortunate effects of a novel superpower design provocation to elicit experiential feedback and fostering critical discussion. This approach extends previous EMS research by foregrounding the uncomfortable and conflicting experiences that arise when users partially surrender agency to automated systems. Ultimately, we aim to raise awareness of potential negative side effects of physical augmentation so that the people at the forefront of designing them can consider mitigation strategies early on and pass on lessons to other practitioners to prevent similar issues in the future.

3 FLYTRAP HAND

We designed the Flytrap Hand as a provocative research probe that enables users to automatically grasp and release objects. This design allows exploring how augmenting human action through EMS can simultaneously empower users and introduce complex trade-offs around bodily control. This section details the design motivation, hardware components and interaction mechanisms.

3.1 Design motivation

The Flytrap Hand was designed to investigate how physical augmentation can simultaneously enable and constrain the user. Motivated by the Venus flytrap, a plant whose leaves automatically close when triggered [35, 111], we transformed this reactive mechanism into a wearable augmentation system that closes the user's hand when an object enters a predefined sensing range. In this study, we define "fortunate" superpowers as augmentations that enhance task performance, efficiency, and user comfort, and "unfortunate" superpowers as those that reduce predictability, induce discomfort, or compromise agency. EMS was selected as the augmentation modality because it helps preserve bodily ownership, making the augmented actions feel as if they originate from the user rather than from an external device, as is often experienced in other augmentations such as exoskeletons [65]. Furthermore, its capability for precise temporal control and immediate sensorimotor feedback renders it well-suited for exploring preemptive action, alignment, and the dynamic experience of agency. By intentionally incorporating bodily automation and loss of control, the design treats discomfort and ambiguity as design materials [9] to question the assumption that "superpower" capabilities are inherently beneficial, prompting reflection on control and autonomy in augmentation experiences, following principles from critical and speculative design [7, 26].

3.2 Hardware components

The Flytrap Hand consists of a glove embedded with a time-of-flight distance sensor [1] and a flex sensor [97], connected to a SparkFun RedBoard micro-controller [98], controlling a dual-channel EMS device (Comfy EMS [103]).]). We chose a commercial EMS device controlled via relay switches to produce a safe, adjustable waveform for controlled electrical stimulation (Figure 2), as suggested by prior work [86, 87]. The distance sensor detects the distance between objects and the hand, and the flex sensor measures the bending angle of the little finger.

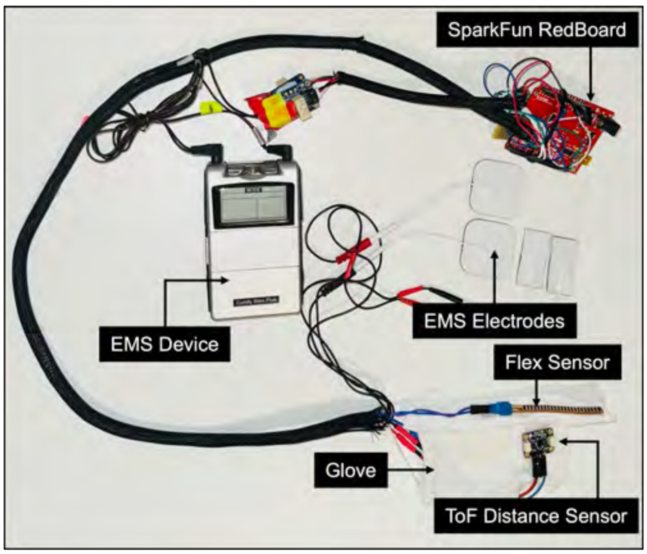

Figure 2: Flytrap Hand system.

Two rectangular EMS electrode pads (4cm x 2cm) are attached to the lumbrical muscles (palmar side) and dorsal interosseous muscle (dorsal side) between the second digit and third digit to flex fingers to generate a tripodal grasp gesture (Figure 3). Another two square EMS electrode pads (4cm x 4cm) are placed around the extensor carpi ulnaris muscle and extensor digitorum muscle to stretch the wrist and fingers to produce an open-hand gesture. When the user's hand becomes near an object but is not yet holding the object, the distance sensor detects proximity (typically within 4–8 cm, corresponding to the reachable space of the participant's fingers) and sends the signal to the micro-controller which immediately triggers the EMS to activate the stimulation of the hand muscles so that the hand would automatically grasps the object. This reduces the delay (below 5 ms) between the user's intention to grip an object and the actual grip. A pilot study (N = 4, M = 28.00, SD = 5.48) demonstrated improved grip reaction times, with faster grip speeds (M = 140 ms) compared to those without the system (180 ms), measured by a slow-motion camera. Although the sample size was small, the pilot provided reliable measurements of reaction dynamics primarily influenced by hardware and neuromuscular response. Despite minor individual variation, the consistent improvement in reaction times and minor delay established a stable temporal profile. These findings align with preemptive action research [56], ensuring the reliable temporal behavior of the Flytrap Hand system.

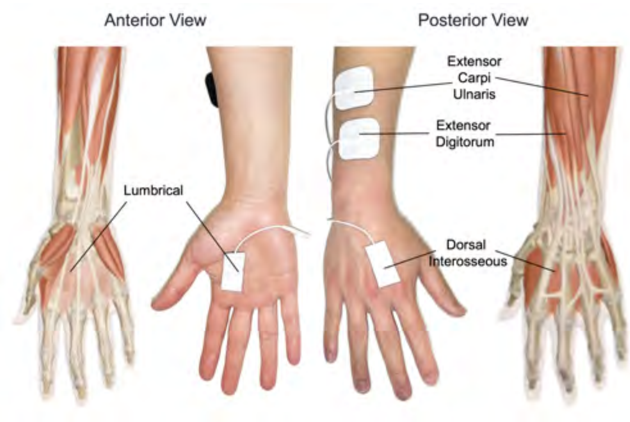

Figure 3: The placement of the EMS electrode pads.

3.3 Grasp gesture selection

A grasping gesture refers to the physical movement or positioning of the fingers and hand to hold or manipulate an object, which is a fundamental action in human-object interaction, relying on both the biomechanics of the hand and the sensory feedback received during the action [18, 32]. In the Flytrap Hand prototype, a grasping gesture is controlled by EMS to induce specific hand movements. Selecting an appropriate grasping gesture is key to providing the user with a fast grasping superpower, which needs to enable the user to manipulate objects naturally at faster speeds, and take into account the biomechanical limitations of the EMS.

Grasp types can be broadly categorized into precision grasps (e.g., pinch grasp, tripod grasp) and power grasps (e.g., cylindrical grasp, hook grasp) [18, 32, 112]. Power grasps primarily engage large extrinsic muscles, making them easier for EMS activation but less suitable for precise object manipulation [79]. Conversely, precision grasps rely on intrinsic hand muscles, enabling finer control for handling small objects. For the Flytrap Hand, we selected the tripodal grasp as the primary gesture after evaluating four grasp types (Figure 4). The tripodal grasp is characterized by the opposition of the thumb with the index and middle fingers. This grasp offers a balance between stability and dexterity, making it suitable for manipulating a variety of everyday objects while preserving a natural hand posture [33].

3.4 Releasing mechanisms

A key design challenge was enabling users to release their grasp reliably, as EMS can sustain muscle contraction indefinitely when active. We implemented two contrasting release mechanism that embody different trade-offs between user agency and system automation.

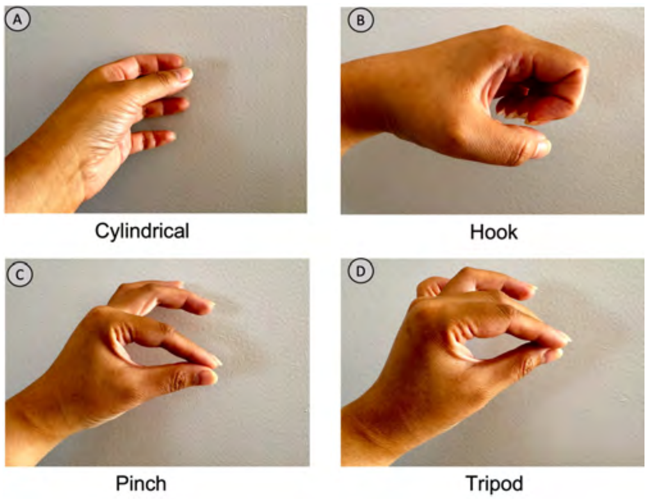

Figure 4: Types of grasp gestures considered and experimented in this study.

The first mechanism we call "randomized time control", where the system deactivates EMS on the hand and activates the EMS on the forearm to forcibly release the grasped object after a randomly determined duration (which is determined by the task requirement). Users have no control over when the release occurs. This design deliberately reduces user agency to explore the emotional and cognitive effects of involuntary movement, simulating an adversarial superpower experience where the system overrides the user's bodily control. The unpredictable, involuntary release can cause discomfort, distrust, and a sense of bodily alienation, thus probing the "dark side" of augmentation and the unintended negative effects of superpowers.

We call the second mechanism "body control", where the system senses through the flex sensor if the user lifts their little finger, and turns off the EMS on the hand and turns on the EMS on the forearm, thereby forcing the palm to open. This design restores partial user agency by allowing the release to be initiated by the user's action, yet it introduces an unfamiliar gesture that may require a learning curve. This mechanism shifts the challenge toward motor adaptation and cognitive load, offering a contrasting lens on the trade-offs between agency, usability, and bodily comfort.

4 STUDY

We conducted a within-subjects, counter-balanced mixed-method study to understand the user experience. The primary goal of this study was to investigate how variations in EMS-driven control influence user experience, including task performance, sense of agency, bodily ownership, cognitive workload, intention alignment and experiential perception of superpower-like augmentation.

We examined three conditions:

- **Randomized Time Control:** Grasping and release occur at randomized intervals. Hypothesis: Participants will experience lower agency, occasional misalignment, increased cognitive load, and mixed emotional responses.
- **Body Control:** Grasping is triggered when participants perform a specific gesture (lifting the little finger). Hypothesis: Participants will experience high temporal alignment, faster grip times, higher agency, and more positive responses.
- **Baseline:** No EMS stimulation where the system remains turned off during both the grasping and releasing actions. Hypothesis: Standard grip performance and agency, serving as a reference for comparison.

4.1 Participants

Twelve participants (5 male, 6 female, 1 non-binary, not providing other descriptions) were recruited, aged between 18 to 45 years (M = 25.67, SD = 7.70). Participants were recruited through advertisements on our lab's mailing list and social media accounts. Participants were screened to exclude any history of muscle disorders, prior injuries affecting the upper limb, or negative experiences with EMS to prevent confounding effects. Four participants had used EMS before. Nine participants were right-handed. The study was approved by our institution's ethics committee. All participants volunteered for the study with written informed consent.

4.2 Tasks

Participants performed each task twice in each condition. The first task was an object relocation task (Figure 5a). This task simulates everyday object manipulation to explore how the system's automatic grasping influences user control. Participants were asked to relocate eight everyday objects including pens, plastic containers, boxing gloves, sponges, paper cups, squeeze balls, charging cables and tissue boxes, between designated points on a table and the floor, three meters away, as quickly as possible. These objects were chosen to represent a range of common shapes and grasp challenges, enhancing ecological validity. Participants could choose their own order, reflecting natural prioritization strategies. The time taken and accuracy of the relocation were recorded. The accuracy was measured by counting the number of times an object was placed in a marked location and not dropped in the process.

To further probe the tension between augmentation and user agency under cognitive load, participants also performed a dual-task (Figure 5b). This combined a cognitive task with a movement task. The cognitive task, taken from prior work, was the *n-back task*, which is commonly used to measure working memory [52, 55, 77]. The participant was presented with a sequence of letters on a screen (randomly chosen from A, B, C, D, E, H, I, K) one by one, and they needed to click the mouse if the current letter was the same as two letters ago (left of Figure 5b). A total of 25 letters were presented for 760 ms each at 2000 ms intervals. The movement task was a repetitive object manipulation task often used to analyze cognitive load under split attention [73, 80]. The participant was asked to pick up and put down a plastic coffee cup with an audio cue at 10-second intervals played over a speaker (right of Figure 5b), simulating repetitive manual tasks like clearing a table or packing a bag. This dual-task is designed to capture how augmented control interacts with attention and coordination by simulating real-world challenges such as managing devices or tools while thinking or conversing. The accuracy of the n-back task (proportion of letters clicked correctly) and the error rate of the movement task (proportion of times the

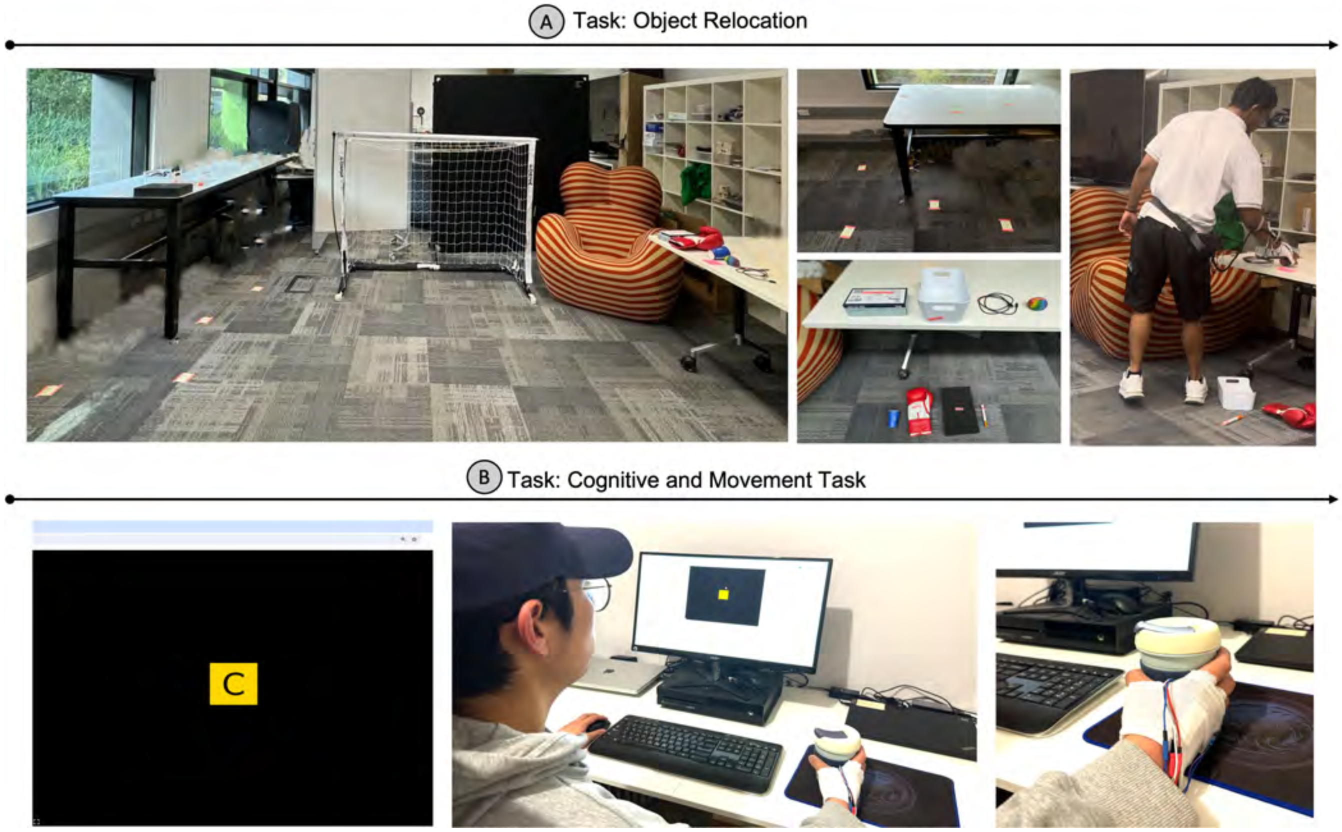

Figure 5: The process of tasks for each condition and results of task performance. A: object relocation task; B: cognitive and movement task simultaneously.

participant missed or forgot to grasp or release the coffee cup) were recorded by the experimenter.

This design balances ecological relevance (everyday objects, real-world multitasking) with experimental control, allowing us to systematically analyze how superpowered grasping affects agency and task performance.

4.3 Procedure

After signing a consent form, participants were introduced to the system. The experimenter then helped participants attach the electrodes to the dominant hand and forearm. We prepared a pair of gloves to fit both hands. Calibration for EMS was performed for each pair of electrodes. Participants were guided to slowly increase the intensity of the stimulus until the desired intensity was reached to observe hand movement. A constant EMS with a pulse width of 200 µs and a pulse rate of 100 Hz was adopted based on repeated pilot testing. Next, the experimenter helped participants put on and calibrate the distance sensor and flex sensor. This calibration ensured that the tripod grasping gesture was triggered within the reach of the participant's finger in order to grasp the object at the appropriate time. Additionally, participants were asked to move their little fingers to calibrate the flex sensor to open their hands and release objects. Participants were given at least three minutes to familiarize themselves with the system. In the randomized time control condition, each grasp lasted 300–700 ms, with releases occurring at randomized intervals, whereas in the body control condition, grasp onset was contingent on the participant lifting the little finger. Stimulation intensity was controlled by the participants themselves, allowing them to stop EMS at any time to prevent prolonged stimulation or accidental grasps. Participant-specific offsets were calibrated to account for individual differences in hand size and muscle activation thresholds, ensuring consistent stimulation intensity and timing accuracy across participants.

Participants performed two tasks and each task twice under three conditions in a counter-balanced order to reduce order effects. At the end of each condition, we administered the "Sense of Agency Scale" [50, 102], the "Sense of Bodily Ownership Questionnaire" [41] and the "Unweighted NASA-TLX Questionnaire" [46, 47]. Afterwards, participants were asked to fill out the overall preferences questionnaire. We then conducted a semi-structured interview [2, 54] that lasted approximately 30 minutes. The interview included 14 questions about participants' interactions with the system, potential physical and psychological effects, and their reflections on control, agency, and overall perceptions of each release mode. For example, participants were asked: "How did each of the two modes make you feel?", "Did you experience any discomfort or loss of control?", and "In what situations, if any, would you find such a system useful?"

5 FINDINGS

We used repeated measures analysis of variance (RM ANOVA) to analyze normally distributed data with generalized eta squared for effect sizes. The post-hoc analysis was conducted by a paired t-test to identify significant differences. We used a Friedman test to analyze data from the questionnaire and non-normal distributed data in our within-subjects design. The post-hoc analysis was conducted by a paired Wilcoxon signed-rank test. To address multiple pairwise comparisons, the significance threshold for both parametric and non-parametric tests was adjusted using the Bonferroni correction [4]. Qualitative interview data were audio-recorded and transcribed for qualitative analysis. Inductive thematic analysis was used to analyze the interview data and identify themes by distilling and articulating meaning from the data [13, 34].

5.1 Task performance

Figure 6 shows the performance data of the relocation task. An RM ANOVA on task completion time (TCT) revealed a significant difference ($F(2, 22) = 13.55$, $p < 0.001$, $\eta_G^2 = 0.355$). Post-hoc Bonferroni-corrected t-tests [4] revealed that the baseline ($M = 53.30s$, $SD = 6.34$) was significantly faster than randomized time control ($M = 72.10s, SD = 16.70, p < 0.05$) and body control ($M = 72.30s$, $SD = 12.30$, $p < 0.01$). However, there was no significant difference between randomized time control and body control. For object placement accuracy, a Friedman test found no significant differences ($W = 0.05$, $\chi^2(2, N = 36) = 3.16$, $p = 0.21$) across the randomized time control ($M = 95.83\%, SD = 3.08$), body control ($M = 96.88\%, SD = 4.21$) and the baseline ($M = 98.43\%, SD = 2.83$).

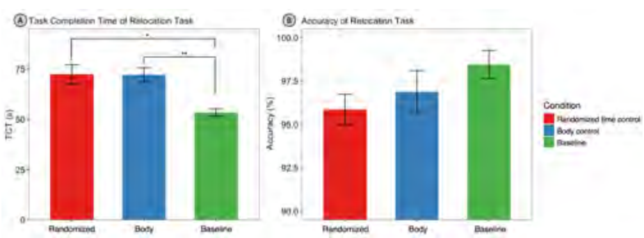

Figure 6: Results of participants' performance for the relocation task, including (a) task completion time and (b) accuracy (Error bars: one standard error of the mean/ $*$: $p <= 0.05$ / $**$: $p <= 0.01$).

Figure 7 shows the performance data of the dual (cognitive and movement) task. We measured the movement task error rates using a Friedman test, revealing a significant difference ($\chi^2(2, N = 36) = 7.48$, $p = 0.024$, $W = 0.11$). Post-hoc Bonferroni-corrected pairwise Wilcoxon signed rank test showed a significant difference ($W = 4.5$, $p = 0.007$) between the baseline ($M = 21.53\%, SD = 9.70$) and randomized time control ($M = 13.19\%, SD = 10.33$), but no significant difference was found for body control ($M = 18.75\%, SD = 11.85$). Cognitive task accuracy, analyzed via RM ANOVA, showed no significant differences ($F(2, 22) = 1.85$, $p = 0.18$, $\eta_G^2 = 0.027$) across the randomized time control ($M = 46.79\%, SD = 31.94$), body control ($M = 37.42\%, SD = 29.86$) and the baseline ($M = 48.75\%, SD = 31.39$).

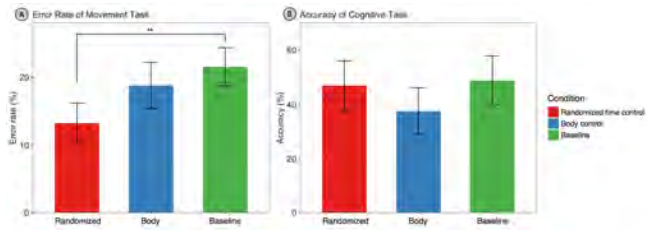

Figure 7: Results of participants' performance for the dual task, including (a) error rate of the movement task and (b) accuracy of the cognitive task (Error bars: one standard error of the mean / $**$: $p <= 0.01$).

5.2 Sense of agency

We measured the sense of agency using the 7-point Likert scale Sense of Agency Scale (SoAS) [102], comprising Sense of Positive Agency (SoPA) and Sense of Negative Agency (SoNA) factors (Figure 8). Higher SoPA indicates stronger body control, while higher SoNA reflects greater helplessness. A Friedman test revealed significant differences in overall SoA ($\chi^2(2, N = 36) = 17.17$, $p = 0.0002$, $W = 0.26$). Post-hoc Wilcoxon signed rank tests revealed that the baseline ($M = 77.00$, $SD = 12.01$) was significantly different from randomized time control ($W = 0$, $p = 0.008$, $M = 43.50$, $SD = 9.31$) and body control ($W = 1$, $p = 0.009$, $M = 51.50$, $SD = 7.83$). Similar results were observed for SoPA ($\chi^2(2, N = 36) = 18.67$, $p = 0.00008$, $W = 0.28$) and SoNA ($\chi^2(2, N = 36) = 14.91$, $p = 0.0006$, $W = 0.23$), with both time (SoPA:$W = 0$, $p = 0.008$, $M = 21.08$, $SD = 6.49$; SoNA:$W = 4.5$, $p = 0.012$, $M = 16.42$, $SD = 9.29$) and body control (SoPA: $W = 0$, $p = 0.008$, $M = 24.00$, $SD = 6.34$; SoNA:$W = 4.5$, $p = 0.023$, $M = 28.50$, $SD = 6.11$) conditions showing significantly lower SoPA and higher SoNA compared to the baseline (SoPA: $M = 37.42$, $SD = 5.55$; SoNA: $M = 16.42$, $SD = 9.29$).

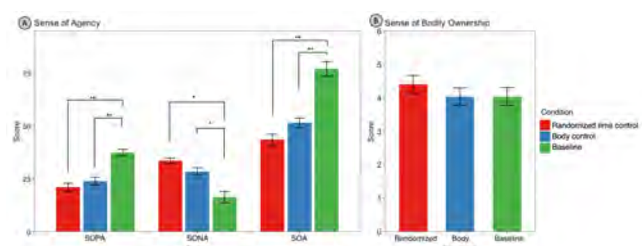

Figure 8: Results of participants' responses to (a) sense of agency and (b) sense of bodily ownership questions (Error bars: one standard error of the mean / $*$: $p <= 0.05$ / $**$: $p <= 0.01$).

5.3 Workload

The NASA-TLX Questionnaire results showed no significant difference in overall workload across conditions (Figure 9). However, the *frustration-level* was significantly different ($\chi^2(2, N = 36) = 6.69$, $p = 0.03$, $W = 0.10$) across three conditions. A Post-hoc analysis showed a significant increase ($W = 52$, $p = 0.013$) in randomized time control ($M = 48.30, SD = 23.30$) compared to the baseline ($M = 27.90, SD = 24.10$).

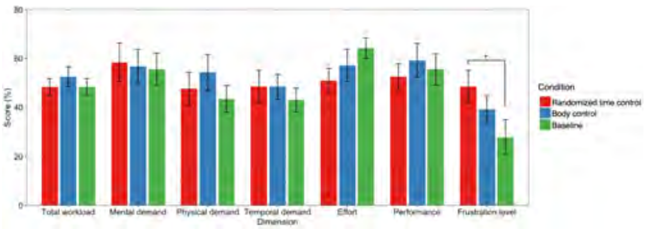

Figure 9: The NASA Task Load Index score for each condition (Error bars: one standard error of the mean / $*$: $p <= 0.05$).

5.4 Sense of ownership

The "Sense of Bodily Ownership Questionnaire" was revised based on Grechuta et al. [41] with ordinal 7-point Likert scale (1 = strongly disagree, 7 = strongly agree). We calculated the average score and conducted a Friedman test (Figure 8). The test did not reveal a statistically significant difference ($\chi^2(2, N = 36) = 3.27$, $p = 0.20$, $W = 0.06$) between the randomized time control ($M = 4.05, SD = 0.85$), body control ($M = 4.41, SD = 0.89$) and the baseline ($M = 4.05, SD = 0.88$).

5.5 User preferences

Two-thirds of participants (N = 8) preferred body control over randomized time control . Overall system performance was considered satisfactory. Seven participants rated their overall experience as positive, while three remained neutral. Six participants reported that they believed the system improved their reaction time. Eleven participants expressed appreciation for the system's ability to automatically grasp and securely hold objects, indicating general satisfaction with its functionality.

5.6 Interviews

Our analysis identified three themes that demonstrate the complexities of experiencing a superpower with Flytrap Hand: (1) perceived benefits and challenges of superpower, (2) changes in agency and system acceptance and (3) psychological and behavioral adaptations. Participant quotes are labeled according to our coding scheme. "Qx.y" denotes the y-th illustrative quote under Theme x (e.g., Q1.1 is the first quote under Theme 1). Each quote is further labeled with participant ID and condition: P# (R/B), R for Randomized time control and B for body control.

5.6.1 Perceived benefits and challenges of superpower.

Flytrap Hand introduced a complex mix of benefits and challenges, with participants appreciating the efficiency and reduced physical exertion, while they also experienced difficulties in task execution, control, and adaptability.

Experiencing the superpower of increased speed. While the Flytrap Hand system did not consistently boost raw task performance, users reported qualitative improvements such as feeling faster and more confident, and perceiving tasks as easier to execute. These subjective experiences illustrate that superpower experiences encompass more than measurable outcomes, including cognitive and perceptual enhancements. Eight participants reported that they experienced a superpower with the system. P6 (R) said: *"It felt like something out of a sci-fi movie. It made my hands close and open on their own. It was crazy. I felt like I had superpowers"* (Q1.1). One of the most often reported benefits of Flytrap Hand was the speed enhancement in object interaction. Many participants found that Flytrap Hand enabled them to grasp objects more quickly than they would manually, allowing them to act with greater efficiency. P2 (R) shared: *"It helped me pick up objects quicker than I usually would"* (Q1.2). This ability to automatically initiate a grip as soon as an object was detected reduced the need for conscious decision-making, which some participants perceived as *"saving them time"*(P4 (B), Q1.3). For example, P1 (R) reflected:*"For grabbing things in a hurry, it worked very well"* (Q1.4). Participants highlighted that this enhanced speed could be particularly beneficial for sports or activities requiring quick reflexes, such as catching or dribbling a ball. P8 (B) noted: *"I think it's very useful in sports if you need to catch or grab something quickly"*(Q1.5). This quick response could also be seen as a benefit in unexpected situations, such as reacting to falling objects or intercepting moving objects. P11 (R) described: *"This system helped me react quicker, perhaps allowing me to pick up the dropped item directly"* (Q1.6).

Reducing physical exertion. Participants appreciated being able to grasp objects without fully engaging their hand muscles, which they found helpful in scenarios involving repetitive grasping. For example, P3 (R) said: *"The system made gripping objects very easy, and I didn't have to think about it, which was great"* (Q1.7). Five participants *"felt relieved"* (P4 (B), Q1.8) by this reduction in effort. Furthermore, by minimizing the need for fine motor control, participants could focus on other aspects of the task. For example, P5 (R) stated: *"When I was doing the dual task [cognitive and movement together], I could focus more on the task of memorizing the letters"* (Q1.9). In addition, seven participants suggested that such a system might be useful for people with limited hand strength or conditions such as arthritis, as it could assist with grasping. For example, P10 (B) speculated: *"I thought it would help people with weak hands. It does the grasping for you, which is very helpful for people with diseases that affect hand function, and it can even help practice grasping"* (Q1.10).

Complicating task execution. Participants reported that the system's automation also introduced new difficulties when it comes to task execution. Five participants reported that while the system sped up the grasping process, it sometimes acted prematurely, leading to disruptions. For example, P7 (R) said: *"Sometimes it grabbed too early [...] so I had to adjust my hand gesture later"* (Q1.11). Seven participants noted that unintended grasping could lead to dropped objects and excessive force, which required additional effort to compensate for these errors. P5 (R) described this experience: *"I had to deal with items falling out or waiting for the hand to open, which slowed things down"* (Q1.12). For some participants, these disruptions outweighed the anticipated efficiency gains, as they had to spend more time correcting unintended actions, which led to longer task completion time and complicated the task. For example, P9 (B) said: *"The hand action was fast, but if it reacted at the wrong time, it actually made things harder instead of easier"* (Q1.13).

5.6.2 Changes in agency and system acceptance. Flytrap Hand introduced an unconventional form of control that may lead to an unexpected misalignment between thought and action, thus challenging the user's sense of agency and affecting their overall acceptance of and trust in the system.

Feeling of external control over actions. Two-thirds of participants expressed discomfort with the system acting beyond their control. This feeling arose because the system automatically activated grasping based on proximity sensing rather than conscious active engagement. Five participants described this as a loss of control or forced control by the system, as their hands moved without their explicit authorization. P12 (R) reflected: *"It wasn't me making the decision to grab. It just happened"* (Q2.1). Furthermore, the EMS-driven automation could trigger actions before users consciously decide to act, leading to a sense of cognitive lag. For example, P6 (B) described: *"My brain was still thinking... but my hand had already started closing around it"* (Q2.2). This phenomenon of external control had mixed effects. Some participants felt that it facilitated quick responses, while others expressed unease about the loss of bodily control. P3 (R) noted: *"I wasn't sure whether it was me controlling my hand or if the system was acting on its own"* (Q2.3). It appeared that this effect could make users perceive themselves as passive observers rather than active agents of their own actions.

Conflict between intentions and actions. Participants also experienced moments where their intentions and the system's actions were misaligned, even within the same condition. Three participants described a cognitive disconnect in which the system initiated action before they fully formulated their intentions, thus disrupting their action-perception loop, rather than simply feeling like the system was taking over in the body control condition. P5 (B) explained: *"Even if sometimes I know I want to pick something up, my thoughts are interrupted when my hands move faster than my brain commands"* (Q2.4). This misalignment also led to hesitation in performing tasks. Some participants reported a newfound uncertainty in their interactions with objects, as they were unsure when the system would engage in the randomized time condition. P9 (R) reflected: *"I had to pause before reaching for things because I wasn't sure if the system would start at the right moment"* (Q2.5). This hesitation was not only a reaction to external control but an adjustment strategy where users had to actively change their actions to cope with the system. Furthermore, three participants reported that once they became familiar with the system, they could *"anticipate the system activation"* (P7 (B), Q2.6) and adjust their hands accordingly. For example, P2 (R) said: *"After a few rounds, I started to time my movements to match the system's stimulation, and it felt more natural"* (Q2.7).

Fluctuating trust in the system. Participants reported that their trust in the system fluctuated depending on predictability. Unpredictable actions, such as grasping or failing to release objects at unintended moments, caused four participants to doubt whether they could trust the system. P4 (B) illustrated this trust difference by contrasting different control mechanisms: *"In the body control mechanism, I can control the release action with my finger, which is predictable, so I have relatively more trust in the system compared to the randomized time control mechanism"* (Q2.8). For some participants, the system's inconsistency was an occasional inconvenience, while for others, it fundamentally influenced their willingness to engage with the system. For instance, P1 (B) remarked: *"The system is impressive, but I would not fully trust it and rely on it in everyday life"* (Q2.9). P9 (R) expressed frustration over its unpredictability: *"If you're trying to get something done, you'll get frustrated with how it sometimes messes up"* (Q2.10). Despite these concerns, not all participants considered unpredictability as inherently negative. For example, P5 (R) found it a novel and playful experience: *"It felt like a game sometimes. I need to figure out when it would grip and when it would release. It wasn't always bad, just different"* (Q2.11).

5.6.3 Psychological and behavioral adaptations. The Flytrap Hand prototype influenced not only how participants performed tasks but also how they adjusted their behaviors, perceived their own actions, and considered the long-term consequences of augmentation.

Experiencing mixed emotions from excitement to anxiety. Participants reported a wide range of emotions, from excitement to stress and anxiety. Despite initial fears, participants found the Flytrap Hand's automated actions to be novel and entertaining once they became *"accustomed to the system"* (P8 (B), Q3.1). The experience was *"intuitive"* (P2 (B), Q3.2) and made them feel less uncomfortable after becoming familiar. However, participants also mentioned that they felt anxiety when they realized that the release of the system was unpredictable. P1 (R) expressed it like this: *"I felt like I'm always preparing for my hand movements. It makes me nervous because I didn't know exactly when it would start"* (Q3.3). Furthermore, four participants reported feeling tired at the end of the relocation task as they had been focusing on the system and their own gestures, resulting in negative emotions such as *"overload"* (P10 (R), Q3.4), *"stressful"* (P3 (B), Q3.5) and *"exhausting"* (P11 (B), Q3.6).

Concerns about dependency and loss of bodily ability. While participants enjoyed the benefits of rapid grasping, they also raised concerns about potential reliance on augmentation: They asked whether any long-term use might reduce their innate reflexes over time or weaken their hand's function to perform tasks without technology. For example, P7 (R) expressed: *"If I use this all the time, will my brain stop sending those signals as quickly? Will my reaction speed decrease?"* (Q3.7) Some participants assumed that their bodies might quickly adapt to the change and become dependent on the system. P6 (B) explained: *"I noticed that after using it for a while, I started expecting my hand to move automatically"* (Q3.8). In addition, rapid grasping can also lead to hesitation in hand movements as it might conflict with participants' intentions. P9 (B) reflected: *"I felt hesitant because I didn't know if I should let the system do it or if I should take control"* (Q3.9).

Context-dependent acceptance. Participants reported that their acceptance of their superpower was highly related to the environment. Some participants valued faster hand movements in task-oriented scenarios, while some participants reported that they felt distracted or unnecessary to use this ability in their daily activities. P12 (B) described a moment of frustration: *"I do feel like it's a superpower, but I don't think it would be useful in my daily life. I still want to do things in a natural way rather than using devices to speed things up"*

(Q3.10). Our participants suggested that many daily activities require deliberate and controlled hand movements, while sudden and rapid grasping may feel unnatural and sometimes seem awkward in social situations. P5 (R), in particular, described worries in public: *"If I use it in front of other people, I would worry about the impact on others, whether it would scare them, whether I was overreacting"* (Q3.11). As a result, some participants preferred context-sensitive control, allowing them to selectively activate the augmentation rather than have it automatically work in all situations. P4 (B) suggested: *"I want to turn this on only when I actually need it. In everyday life, I don't think I want my hand to move faster than normal"* (Q3.12).

6 DISCUSSION

This section discusses our findings in relation to prior work, especially regarding how our physical augmentation led to superpower experiences but also revealed insights into negative side effects that significantly influenced user experience, including aspects such as agency, task efficiency, and emotional response. By integrating the quantitative and qualitative findings, we reveal complex trade-offs between performance enhancement and reduced control at play.

6.1 Balancing performance gains and cognitive costs

Our results reveal a trade-off between speed-oriented performance gains and the cognitive costs of reduced agency. Quantitative analysis showed that participants' Sense of Agency (SoAS) scores were significantly lower when using the Flytrap Hand, consistent across both Randomized Time Control and Body Control modes. This reduction aligns with prior HCI research on body-actuated interfaces, where automation can diminish the user's perception of being the author of their actions [60, 86, 88]. The thematic analysis supported these findings where participants described the system as "acting before my brain decided" (Q2.2) and "taking over" (Q2.1), which at times created frustration and hesitation. While such automation improved grasping speed (Q1.2, Q1.5) and reduced physical effort (Q1.7), it also disrupted the alignment between intentions, motor commands, and sensory feedback [84], increasing cognitive load and adversely affecting engagement (Q1.11, Q1.12, Q2.4, Q2.5). Although Flytrap Hand reduced certain task errors, it inadvertently led to a feeling of reduced personal control, highlighting the central challenge of balancing automation with agency in superpower experiences.

Mueller et al. [78] describe such interaction as a mix of *fusion* and *symbiosis*. *Fusion* occurs when human and machine functions blend seamlessly so that the technology feels like an extension of the self. *Symbiosis* preserves a distinction between user and system so that agency can be shared between them. Our results suggest that Flytrap Hand leans toward *fusion*, with users feeling that the system sometimes overrode voluntary action (Q2.1, Q2.2). While this could enhance performance efficiency (Q1.2, Q1.3, Q1.4), it also contributed to frustration when unexpected activations occurred (Q1.11, Q1.12, Q1.13). Unlike traditional assistive devices that operate as tools (e.g., prosthetics), Flytrap Hand actively intervened in users' actions, blurring the boundary between assistance and control (Q2.5, Q2.6) and introducing cognitive ambiguity (Q2.3).

This blending of human and system action sometimes produced a misalignment between user intentions and technological assistance, reflected in higher NASA TLX frustration scores. Such misalignment can generate cognitive dissonance, a psychological state in which one's actions diverge from internal expectations [84]. Involuntary movements that occurred without conscious initiation can further create discrepancies between intention and sensory feedback (Q2.4, Q2.5), leading to confusion about action ownership, as well as hesitation and resistance in initiating actions.

Importantly, participants' experiences within the same condition were not uniform. Several reported alternating moments in which the system's activation felt aligned with their intention to grasp, creating a sense of fluent coordination, followed by episodes when the stimulation preceded or lagged behind their intended movement, producing discomfort and loss of control (Q2.2, Q2.4). This indicates that the subjective user experience was also influenced by the temporal alignment between system response and motor intention, which have been examined in preemptive action research [56]. These findings suggest that agency in superpower experience also depends on the dynamic coupling between human motor planning and technological actuation, rather than on static condition parameters alone.

In summary, our study extends previous theories by demonstrating that while automation can bring performance gains, it also introduces complex cognitive and experiential trade-offs. These findings raise questions about how superpower augmentation reshapes users' perceptions of agency and emphasize the need for future research to explore ways to engage with this, such as adaptive strategies that could mediate the benefits of superpower experiences while preserving user agency. Such trade-offs invite further ethical examination of the boundaries of shared control, especially when user intentions are partially overridden.

6.2 Ethics of shared and ambiguous agency

Interviews revealed that perceptions of reduced agency were neither static nor absolute. Participants described moments where the system's automated action felt seamlessly aligned with their intentions (Q2.7) and others where control was abruptly lost (Q2.1, Q2.3). This fluctuation created a "gray zone" of shared control [17, 21, 51, 67] in which user and system jointly shaped actions, challenging traditional clear distinctions between self and other, voluntary and involuntary action [36, 53, 100]. Such ambiguity complicated responsibility attribution, particularly when the system autonomously acted on behalf of the user and the outcomes diverged from intentions (Q2.3, Q2.5, Q2.9), raising questions over whether the user, the designer, or the system bears responsibility [20, 28, 83].

Our findings also suggest how ambiguity can be intentionally crafted to shape these experiences. The randomized time control mechanism introduced unpredictability in the release timing, which some participants experienced as engaging and playful (Q2.11) and others as discomforting and frustrating (Q2.1, Q2.3, Q3.9). This aligns with Gaver et al.'s concept of ambiguity as a design resource [38, 39]. With the Flytrap Hand, the ambiguity was primarily informational [45], where users received inconsistent cues for when an object would be released, compelling them to interpret the system's behavior and reconsider their relationship with it. By embracing these forms of ambiguity, augmentation systems might engage users more deeply and turn discomfort or uncertainty into catalysts for reflection, prompting users to confront and reflect on their ethical perceptions about physical augmentation, including agency and capability [12].

From the proportionality ethics perspective [14, 104, 105], we believe that ethical question is not whether negative effects should be eliminated, but whether they remain within acceptable limits relative to their reflective value. Our results seem to point to three ethical evaluation criteria, which can be seen as a starting point for future investigations. Firstly, system actions should align with user intentions frequently enough to preserve trust and autonomy. Secondly, discomfort must remain proportionate, reversible, and within safe physical and psychological limits. Thirdly, reflective value should outweigh potential long-term risks such as dependency. These ethical criteria could provide a foundation for understanding (un)fortunate superpowers.

6.3 Contrast between enhancing inherent and introducing new abilities

Superpower experiences can either enhance inherent human abilities, such as with our Flytrap Hand and *SpiderVision* [31] or introduce entirely new ones, such as *Wi-Fi Twinge* [72] and *VibraHand* [58] showed. By contrasting their positive and negative effects, we can begin to understand how each type uniquely impacts the user experience. Flytrap Hand enhanced human inherent grasping ability; however, participants expressed concern that continuous reliance on the Flytrap Hand's grasping might lead to a gradual deterioration of their natural reflexes and motor control (Q3.7, Q3.8, Q3.9). These risks are particularly salient when amplifying a user's inherent ability, as it may erode natural motor skills over time. In contrast, *Wi-Fi Twinge* introduced a novel sensory ability that extends the user's sensory perception to unseen Wi-Fi signals through EMS without threatening existing skills. The authors argued that while it could trigger confusion or negative emotion, participants focused on integrating it into daily life, considering it as a beneficial augmentation that complements their natural senses rather than replacing them.

These contrasts suggest that design priorities differ by superpower type. Inherent-ability enhancements demand safeguards against dependency and loss of agency, while new-ability designs should prioritize adaptation and comfort. Recognizing these differences might strengthen our understanding of user experiences in superpower design.

6.4 Trust, dependency, and long-term use

Participants expressed concerns that prolonged use of Flytrap Hand might lead to dependency (Q3.7, Q3.8). This concern is consistent with previous findings that trust in automated systems is dynamic and context-dependent [22, 64, 85]. Trust develops through repeated interactions and perceptions of system performance [64], and our results suggest that trust is also influenced by the user's experiences and familiarity with the technology. For example, in our study, participants with prior EMS experience expressed confidence and adapted more smoothly to the system.

Perceived reliability and predictability were central to maintaining trust [44, 48, 108]. Inconsistent automation, such as unexpected grasp or release, reduced willingness to rely on the system (Q2.9, Q2.10), while consistent performance sometimes inflated trust to the point of over-reliance (Q3.7, Q3.8). This also mirrors placebo effects in human augmentation [107] that the belief in possessing a "superpower" can amplify perceived performance gains beyond the system's actual contribution. In our study, the misplaced beliefs sometimes led participants to credit the system for successes that were partly their own, potentially undervaluing their own abilities.

These findings highlight that trust evolves through a dynamic interaction of performance outcomes, perceived control, and prior experience. To maintain user trust over time, system behaviors should be easy to understand and align with user expectations. Clear cues and predictable patterns could support a stable sense of control, ensuring that superpower experiences enhance rather than diminish user autonomy.

7 DESIGN FRAMEWORK

To discuss the multi-faceted challenges revealed in our study, including the trade-offs between performance and agency, the ethical implications of ambiguous control and the evolving dynamics of trust, we propose a design framework (Figure 10). This framework situates users' interactions with superpower systems along two intersecting axes, highlighting how different levels of automation and control interact with users' physical and emotional states. While the Flytrap Hand implements EMS-based augmentation, we hope that this framework can be generalized in regard to a broad range of physical augmentation systems. This is because the framework emphasizes experiential dimensions, including agency, awareness, and emotional response, which apply to various augmentation modalities, such as exoskeletons, robotic prostheses, or haptic actuators. This framework is intended as a conceptual guide that provides researchers and designers with a structured lens for exploring and critically reflecting on these complex trade-offs. By explicitly acknowledging both the fortunate and unfortunate effects of superpower experiences, the framework could help to ensure that human values such as agency, trust, and user well-being are considered alongside technical performance. We use interaction trajectory mapping [8], visualizing how our participants' experiences with Flytrap Hand evolved over time. We hope that this approach offers insights into how automation and control dynamics change user adaptation, emotional response, and long-term acceptance.

7.1 Dimensions

This framework integrates two key dimensions: body state (ranging from embodied empowerment to embodied strain) and control (ranging from system automation to user control).

7.1.1 Body state (X-axis). This dimension is concerned with the physical state of the body, ranging from *empowerment*, where the user can experience that the system enhances their physical abilities, to *strain*, where the user's body feels discomfort and/or overload. With Flytrap Hand, empowerment occurred when the system optimally facilitated hand actions, providing users with enhanced speed. Strain arose when the system imposed unnatural hand movements,

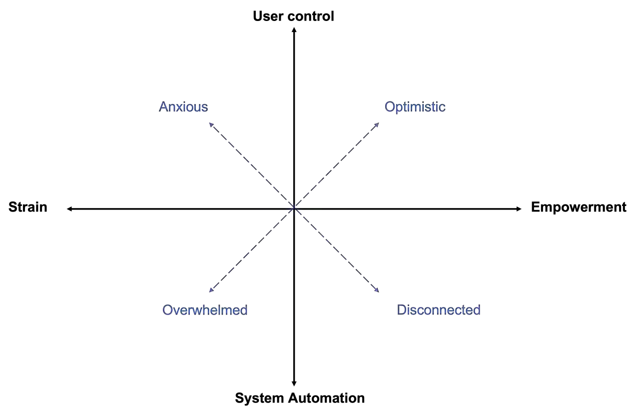

Figure 10: The design space for superpower systems.

discomfort or cognitive overload, such as when the hand felt rigid or difficult to use.

7.1.2 Control (Y-axis). This dimension is concerned with the user's level of agency over the system's actions, ranging from *system automation*, where the system controls actions without user intervention, to *user control*, where the user has full agency of initiating, modifying, or terminating actions. With Flytrap Hand, system automation occurred when the device automatically performed hand actions such as grasping and releasing without explicit user authority. In contrast, user control occurred when the system required conscious user input, such as lifting the little finger, providing a greater sense of agency, but often increased cognitive load.

7.2 Framework quadrants and corresponding emotions

The framework highlights four quadrants, each reflecting a distinct emotional state based on the combination of body state and system control.

Quadrant 1 (top right): User control and embodied empowerment. In this quadrant, users experience embodied empowerment combined with user control, which means they are both physically enhanced and able to control the system's actions. This represents the ideal interaction, where the user feels in control of the augmentation system, and the system is responsive to their intentions. Users have the autonomy to guide the system's behavior while enjoying the benefits of enhanced physical abilities and therefore may experience a sense of optimism.

Quadrant 2 (top left): User control and embodied strain. In this quadrant, users have more control over the system, and they can decide when and how the system will act. However, the system's actions still result in physical strain, making the user feel the burden of the augmentation. While the user might have the ability to control the hand's grasp, they could still experience muscle fatigue or discomfort from the system's demands. Physical burdens and the need to constantly manage the system's actions may create a sense of anxiety.

Quadrant 3 (bottom left): System automation and embodied strain. In this quadrant, users experience high system automation but also embodied strain, which means the system takes control of the actions, but those actions result in discomfort or physical overload. The system might execute tasks in a way that forces the user's body into unnatural or strenuous movements. The user might feel that they are unable to manage the physical discomfort caused by the system, and the lack of control amplifies the emotional burden, therefore they may feel that the system is too demanding and may experience a sense of overwhelm.

Quadrant 4 (bottom right): System automation and embodied empowerment. In this quadrant, users experience a high level of embodied empowerment as the system enhances their physical abilities, but the enhanced abilities are controlled by the system, not the user. Users may feel empowered when the system performs a task, however, as they do not have direct control over the actions taken, there may be a separation between the user's bodily sensations and the system's behaviors, leading to a sense of disconnection.

7.3 Interaction trajectories of Flytrap Hand

We apply the framework to visualizing interaction trajectories across two release mechanisms of the Flytrap Hand system. These trajectories aim to depict the emotional, cognitive, and physical states experienced by users as they transition through different levels of body state and control. Although phase-specific quantitative measures were not available, each trajectory phase is empirically grounded in participants' qualitative reports and reflections collected during interviews. To make the link explicit, representative participant quotes are mapped to each trajectory phase, providing concrete evidence for the experiential patterns identified.

7.3.1 Trajectory 1: Randomized time control mechanism. We believe that participants' journey through the randomized time control mechanism can be understood through four phases, as they moved across distinct body-system dynamics within the framework (Figure 11; Table 1).

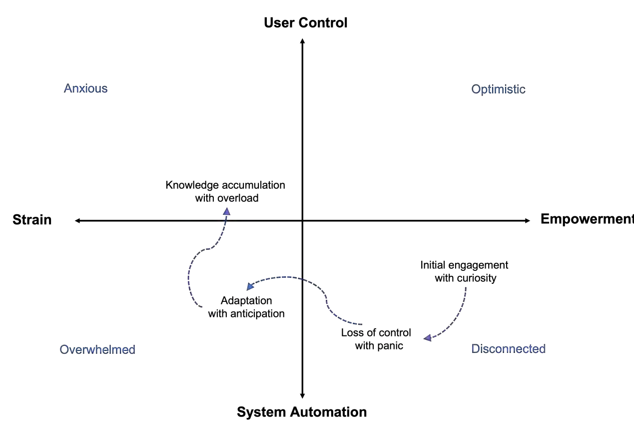

Figure 11: The trajectory of user experiences with the randomized time control mechanism.

Initially (initial engagement with curiosity, quadrant 4), participants encountered an unfamiliar but interesting system: the EMS was automatically triggered when the hand approached the object, but the release time was randomized. This novelty sparked the participants' curiosity and they tried to use the system to understand its logic (Q1.1, Q1.2). Over time (loss of control with panic, quadrant 4), the unpredictability of EMS began to elicit panic. Participants were unable to predict when their bodies would be hijacked, leading to a heightened sense of vulnerability (Q2.1, Q2.3). This randomness pushed their physical limits and led to a disconnection between body and intention (Q1.11, Q3.3). To manage the system's automation, participants began adapting their bodily actions (adaptation with anticipation, quadrant 3). Although they still had no control over when the hand release was activated, they developed anticipatory strategies (Q2.7), such as slowing down their movements or mentally preparing for stimulation, but this also resulted in longer task completion time. This adaptation signals a shift toward user control, despite the constant embodied strain. Finally (knowledge accumulation with overload, quadrant 2), while participants had adapted to the automation of the system, the constant strain of using and managing their embodied responses led to overload (Q3.4). This may be a culmination of stress or an experience of endurance for participants. As such, this phase has the potential to transition into a more empowered state (quadrant 1), where participants could regain some agency through adaptation and emotional resilience, but need to use and familiarize themselves more with the system and their own body.

Table 1: Mapping of trajectory phases to qualitative evidence for randomized time control mechanism.

Phase	Representative Quote	Participant & Label
Initial Engagement	"It felt like something out of a sci-fi movie..."	P6, Q1.1
Loss of Control	"It wasn't me making the decision to grab..."	P12, Q2.1
Anticipation	"After a few rounds, I started to time my movements..."	P2, Q2.7
Cognitive Overload	"I felt overloaded after trying to anticipate..."	P10, Q3.4

7.3.2 Trajectory 2: Body control mechanism. Participants' interactions in bodily control mechanisms can be understood through four phases that traverse a trajectory of increasing user control but are influenced by the complexity of stimulus-driven interactions (Figure 12; Table 2).

Initially (initial familiarization with excitement, quadrant 1), participants expressed excitement at discovering they could release objects through a specific hand gesture (lifting the little finger) to trigger EMS opening the hand (Q3.2). The clear causality between action and effect contrasted with the randomized time control, where such a conscious form of body control allowed participants to feel empowered. As they continued (engagement with hesitation, quadrant 4), this excitement turned into hesitation (Q3.9). Although participants understood the control logic, executing the unfamiliar gesture often felt awkward and abnormal (Q3.5). Some users feared making mistakes or triggering the EMS unintentionally (Q2.9, Q3.9), which caused them to hesitate in performing the task, thus prolonging task completion time. Through repeated interaction (adaptation with confidence, quadrant 1), participants gradually developed confidence in their gestures. They became more fluent in using their little finger to control the system and reported that they began to adapt to this method of manipulation (Q2.6). This adaptation marked an increased user control, even though full autonomous

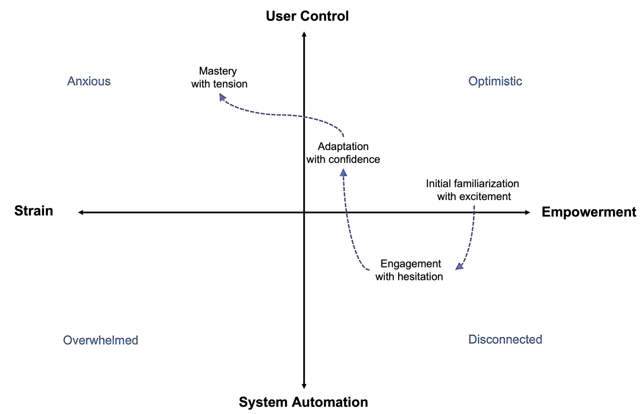

Figure 12: The trajectory of user experiences with the body control mechanism.

grasping remained out of reach. Eventually (mastery with tension, quadrant 2), participants demonstrated a high level of technical mastery (Q3.5, Q3.8), but it was accompanied by remaining tension. Although they were able to coordinate their gestures with the system, this coordination demanded effort, body awareness and thought about the release action. The tension between confidence in mastery and the cost of maintaining that confidence highlights the strain of maintaining a strong sense of agency when using augmentation technologies over time.

Table 2: Mapping of trajectory phases to qualitative evidence for body control mechanism.

Phase	Representative Quote	Participant & Label
Initial Familiarization	"It was intuitive, and I felt like I could control the hand..."	P2, Q3.2
Engagement with Hesitation	"I felt hesitant because I didn't know if I should let the system..."	P9, Q3.9
Adaptation	"...anticipate the system activation"	P7, Q2.6
Mastery with Tension	"I could coordinate my hand later, but it was stressful..."	P3, Q3.5

7.4 Design strategies

Based on our results of the study and combined with our craft knowledge having designed the system, we derived three design strategies to guide future physical augmentation systems

7.4.1 Calibrate control granularity to user mastery. Our research indicates that the user's experience of empowerment or strain is highly dependent on their familiarity and mastery of the augmentation system. Hence, we believe that the control of the system should not be static, but it should rather adapt to a user's growth and familiarity with the technology over time. This requires adaptive control interfaces that dynamically adjust the degree of automation or control granularity based on the user's interaction history, physiological signals, and even emotional states by integrating real-time monitoring from sensors like EMG (electromyography), IMU (inertial measurement units), or motion tracking data. These sensors can provide insight into the user's motor skills, precision, and overall comfort level with the augmentation system. For example, in a robot-assisted system, the interface may initially provide a higher degree of automation to assist novice users, while gradually shifting to user control as the user becomes more experienced, supporting their progression from hesitation to mastery. This adaptability helps prevent early disconnection while maintaining continuous engagement as the user's abilities enhance, offering personalized challenges that cater to the user's ability while reducing physical strain.

7.4.2 Synchronize actuation with predictive body signals. To enhance user experience synchronizing system responses with predictive body signals is required, especially in semi-automated systems where the user still performs some actions. Physical augmentation systems often struggle with a mismatch between intention and action, leading to user frustration and even feelings of panic or tension. To mitigate this, we suggest incorporating intent-aware actuation into physical augmentation interfaces, where the system predicts the user's movement intent using body-based signals like muscle pre-activation, joint velocity, and gaze fixation. For example, EMG sensors can track muscle activity as the user prepares to move, while motion capture systems or gaze tracking can identify when a user is focusing on an object, indicating their intent to grasp or manipulate it. This predictive capability ensures that the system acts synchronized with the user's intent, enhancing the smoothness of the augmented actions, maintaining a sense of agency and reducing embodied strain. Moreover, synchronizing actuation with predictive body signals could be further refined in augmented and virtual reality contexts, enabling more immersive and natural experiences.

7.4.3 Recover from errors through sensory substitution. Our research suggests that as the system enhances the user's physical or sensory abilities, users become aware that their behavior is beyond typical sensorimotor boundaries. However, with this augmentation comes an increased risk of a mismatch between user intent and system action, which can lead to frustration, confusion, or even fear, especially when control errors feel amplified or irreversible. To support users in such superpower experience interactions, we propose a multi-sensory, immersive error recovery mechanism that transforms powerless moments into opportunities for learning and mastery, reinforcing the feeling of having a controllable superpower rather than an unstable superpower. This strategy builds on the principle of sensory substitution [6, 61], which uses one sensory modality to replace or augment another by embedding error recovery into visual, auditory, and haptic channels simultaneously. Rather than suddenly exposing a system failure, designers should consider allowing the system to gently guide the user through corrections with rich sensory cues, so that it feels more like a part of the superpower experience rather than a distraction. By recasting error feedback as a super-sense superpower, users can maintain their sense of augmentation even when things go wrong. For example, a vibration motor on the wrist can be activated in different patterns depending on error type, or directional binaural audio can be gently moved towards the correct trajectory to provide a spatial indication. Providing feedback through substitute sensory channels can help improve users' ability to recover from system errors while reducing cognitive load and guiding them to restore confidence and engagement.

We envision this framework as a tool to inform future research and design explorations in this emerging field. For example, designers developing EMS-based prosthetics can use the framework to map how different levels of automation affect users' sense of agency and comfort, iteratively adjusting control parameters such as timing, intensity, or user override options to balance functionality with experiential quality. Designers can use it as a reflective aid to navigate trade-offs and to create systems that enhance user abilities while respecting their sense of control and comfort.

8 LIMITATIONS AND FUTURE WORK

This work has several limitations. First, the sample size was small (n=12). While the participants provided valuable and diverse perspectives, a larger-scale study involving a broader demographic range could strengthen the applicability of the results, which we encourage for future work. Second, the study was conducted in a controlled laboratory environment, which may not fully capture the complexities and unpredictability of real-world contexts. While the laboratory setting enabled us to isolate and examine specific system behaviors, it may have limited participants' ability to engage with the system as they would during natural, everyday activities. A field study with everyday activities would provide a more comprehensive understanding of the system's user experience. Third, the system's automatic grasping was limited to a tripodal grasp gesture. While this choice allowed for consistency and reliable EMS-induced activation, it may not accommodate the full range of object types and interaction contexts encountered in everyday life. Future iterations of the system could explore alternative grasp types to better align with users' goals and bodily limitations. Fourth, while this study captured users' subjective reports of aligned and misaligned activations, our data did not include event-synchronized recordings to distinguish these occurrences quantitatively. Future studies could incorporate intention detection via EMG onset timing to analyze alignment on an event basis and better understand how momentary synchrony contributes to agency perception. Finally, the proposed framework has not been validated across a broader range of technologies. The applicability of the framework to other types of superpower experiences has not been examined. Future work could evaluate the robustness, generalizability, and practical utility of the framework through comparative studies involving different superpower systems.

9 CONCLUSION

In this research, we explored the superpower experience design through the lens of a provocative (un)fortunate superpower design. We presented Flytrap Hand, a novel artifact that automates grasping and releasing actions through EMS, distance, and flex sensors. Through a mixed-method study with 12 participants, we found that while the system accelerated grasping and reduced physical exertion, it also led to discomfort, skepticism toward bodily automation, and concerns about control, which highlights the ethical and experiential challenges of designing superpower experiences. Based on our work, we provide a framework with three design strategies to guide the creation of future superpower experiences that balance functional gains with sustained user agency and well-being. Ultimately, we hope that our work can deepen our understanding of how to design superpower experiences by explicitly considering both the fortunate and unfortunate effects early in the design process to inform more humanized technologies.

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