Prototyping and Evaluation of Emotionally Resonant Vibrotactile Comfort Objects as a Calming Social Anxiety Intervention

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Fig. 1. Four examples of affective vibrotactile comfort objects produced by socially anxious participants.

Social anxiety is a prevalent mental health concern that impacts quality of life and makes social spaces less accessible. We conducted two studies with socially anxious participants, investigating using affective haptic comfort objects to provide calming support during social exposure. Participatory prototyping informed the design and use of the intervention, which was then evaluated between-groups with a social exposure task. Treatment participants held their preferred vibration-augmented prototype during this task; control participants did not. We observed no change in physiological measures, but treatment participants exhibited a significantly broader distribution of psychological anxiety scores. Participants in both studies found their objects pleasant and calming, made positive emotional associations with resonant stimuli, and used their objects to afford self-soothing tactile experiences. We discuss how future designers can facilitate calming affective haptic interfaces for socially anxious settings.

CCS Concepts: • **Human-centered computing → Human computer interaction (HCI)**; *Haptic devices*; User studies.

Additional Key Words and Phrases: Affective Haptics; Personalisation; Emotion Regulation;

1 INTRODUCTION

Social anxiety, the fear of negative evaluation during social performance [101, 126], is among the most prevalent mental health concerns, as Social Anxiety Disorder has a lifetime prevalence of 12% [62]. During social situations, people with social anxiety are more likely to perceive themselves as receiving social negative from peers and focus

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on their own physical anxiety symptoms, such as elevated heart rate, which can impact their social performance, resulting in continual maintenance of social anxiety [101]. These experiences make social exposure challenging to engage with and encourage avoidance, reducing accessibility to important public or social spaces such as transport, healthcare, and education facilities, as well as shopping or leisure centres [1]. The difficulty of social exposure can also impede participant adherence to Exposure Therapy (ET) [37, 100, 122], a core treatment and component of prominent psychotherapies for social anxiety [15, 33, 77]. An intervention that provides *in situ* support which makes engaging in social exposure easier could, therefore, be beneficial for the quality of life of socially anxious people.

Affective haptics have the potential to promote emotion regulation by facilitating response modulation, attentional redeployment, and cognitive change [73, 82]. In particular, vibrotactile stimuli are ideally placed for use during social exposure. Vibrotactile cues can be experienced during social exposure without interrupting the use of conversational faculties [72], like sight, hearing, or speech, and can discreetly augment devices, like smartphones or smartwatches, reducing the risk of assistive device stigma [120]. Vibrotactile stimuli have enabled emotion regulation via response modulation [8, 22, 82, 142], but interventions that facilitate attentional redeployment or cognitive change, as well as interventions that provide on-the-spot, ongoing support, are under-explored [123, 136]. Recent research has demonstrated the potential for vibrotactile stimuli to elicit a wider range of emotional responses than previously observed [70, 71, 119], providing an opportunity for the novel utilisation of these cues to craft calming and pleasant experiences that facilitate emotion regulation. In addition, prior work has not surveyed or accounted for how the specific needs and wants of socially anxious people may impact such haptic emotion regulation interventions, or evaluated them in social exposure contexts. Thus, it is unclear how the challenges of living with social anxiety impact one's requirements and preferences for an *in situ* affective haptic intervention, how willing they may be to use such an intervention, or how effective it may be. Additionally, what role does the shape or texture of the object which houses the vibrotactile actuator have in creating a holistic calming haptic experience, or influencing the tactile experiences they afford?

In this work, we addressed these questions by adopting a user-centred approach, working with socially anxious participants to understand how their lived experiences, requirements, and concerns inform the design and personalisation of an affective haptic intervention, emotionally resonant vibrotactile comfort objects, which aimed to provide ongoing support during social exposure. We theorised this intervention could interrupt the maintenance of social anxiety during social exposure, making social spaces more accessible and comfortable, by facilitating emotion regulation in two ways (see Figure 2). First, by redirecting attention from elevated physical symptoms of stress and anxiety to calmer and non-threatening external cues [23, 60, 113]. Second, interrupting negative rumination on perceived social performance by cueing up positive thoughts or associations with specific haptic stimuli [49, 66, 82]. Informed by the breadth of vibrotactile preferences observed by Macdonald et al. [72] and the co-design approach of Simm et al. [121], we first conducted a participatory prototyping study with socially anxious participants (n=20) who created personalised handheld comfort objects based varied by form-factor and texture. They then augmented their object with their choice of calming emotionally resonant vibrotactile stimuli, affective cues which evoke real-world phenomena to elicit associated emotional responses [70]. Participants discussed their personal experiences with social anxiety and affective touch, their goals when personalising their prototypes, their preferences for different emotionally resonant vibrations, and how effective they found their prototype as a calming social intervention. This informed the design of higher fidelity vibrotactile comfort objects, which were then evaluated as a calming intervention for social anxiety in a between-groups study (n=28), where socially anxious participants held their personalised comfort object during a social exposure task.

Physiological anxiety measures were not impacted by the use of comfort objects during social exposure, although a significant difference was observed in the distribution of psychological measures between groups which may suggest the intervention was effective and soothing for some participants, while unhelpful for others. Across both studies we observed a wide variety of preferences for emotionally resonant vibrations and the

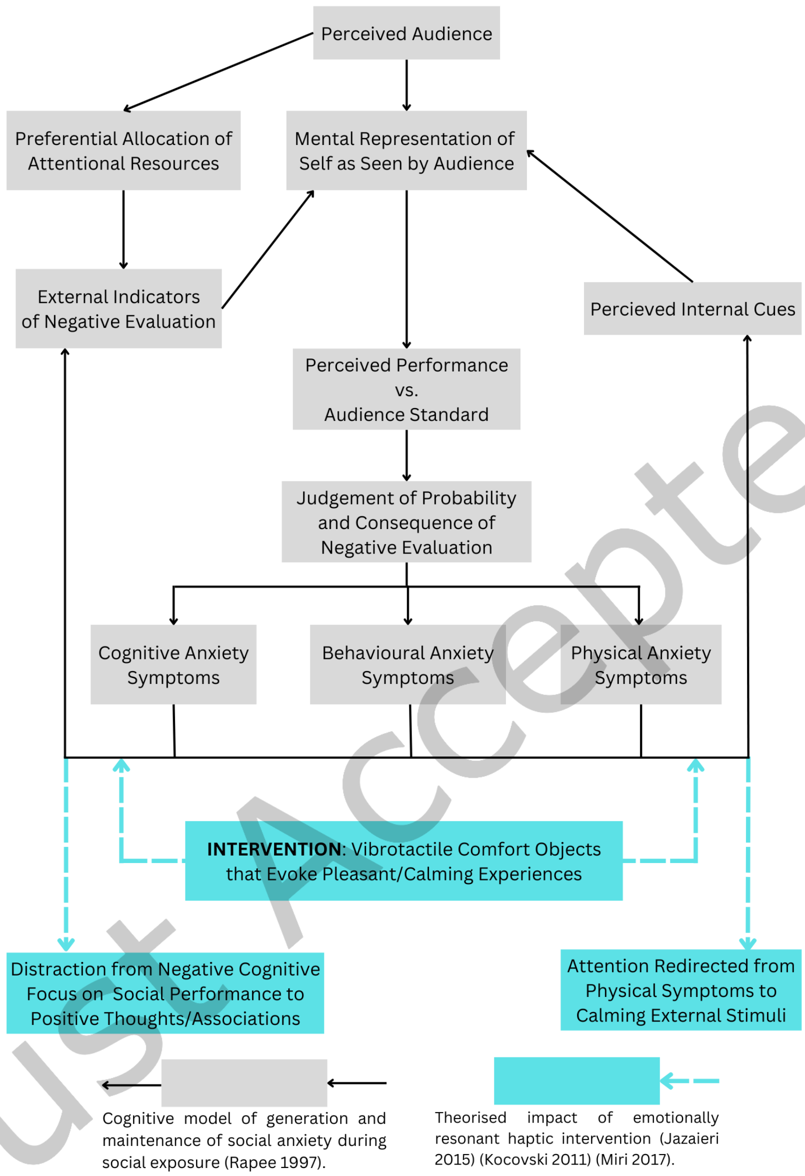

Fig. 2. Visual representation of how the proposed haptic intervention of emotionally resonant vibrotactile comfort objects could intervene in the maintenance of social anxiety, based on the Cognitive-Behavioural Model of Social Phobia by Rapee et al. [101].

physical haptic properties of comfort objects, which in turn afforded varied affective tactile interactions suited to individuals' personal experiences, reinforcing the value of personalisation. Participants in both studies also reported that holding their comfort objects and experiencing the emotionally resonant vibrations was calming and pleasant, and felt their comfort object could be helpful in future anxious situations, showing a desire and willingness for such an intervention. Our research demonstrates how personalisable comfort objects, augmented with emotionally resonant vibrations, can allow socially anxious users to craft evocative, soothing, or grounding tactile experiences. We reflect on the lack of a consistent impact on anxiety measures and participant experiences with the intervention, then provide design recommendations for how future haptic interventions could best accommodate the requirements and preferences of anxious users in real-world settings.

2 CONTRIBUTION STATEMENT

We make three contributions:
(1) Documentation of how socially anxious people design and perceive comfort objects through participatory design, new understanding of key design challenges, such as breadth of haptic preferences and the need for discretion, and identification of preferred trends in form factor, texture and intent between prototypes;
(2) We establish participant willingness toward personalising and using haptic comfort objects in social exposure scenarios, driving further exploration of *in situ* affective haptic emotion regulation;
(3) Evaluation of emotionally resonant vibrotactile comfort objects as a calming social exposure intervention via physiological and psychological measures, accompanied by design recommendations to accommodate key implementation challenges such as social acceptability, technical barriers and facilitating personalisation.

3 RELATED WORK

This work is grounded in several research areas. First, we introduce social anxiety, its impact, how it is cognitively modelled, and traditional interventions. We will then discuss emotion regulation and its applicability in socially anxious settings. This will lead to how HCI has attempted to facilitate emotion regulation and provide support for social anxiety and other anxiety disorders. Finally, we will discuss the fields of affective haptics and vibrotactile stimuli, how they can facilitate calming emotion regulation, and what makes these modalities well-suited for use during social exposure.

3.1 Social Anxiety and Established Interventions

Social anxiety, defined as the fear of negative evaluation during social interaction [101, 126], is one of the most prominent mental health issues. Social Anxiety Disorder (SAD), a condition reached when the symptoms of social anxiety cause “clinically significant distress or impairment in social, occupational, or other important areas of functioning” [1], has a lifetime prevalence of 12% [63]. In addition, social anxiety is also a symptom of other prominent conditions including Depression, Attention Deficit Hyperactivity Disorder (ADHD), and Obsessive Compulsive Disorder (OCD) [126]. Rapee and Heimberg’s Cognitive-Behavioural Model of Social Phobia describes how socially anxious individuals tend to focus excessively on their own anxiety symptoms and over-scrutinize potential negative evaluation from social peers, resulting in worsening perception of their outwardly presenting social self [25, 101]. Thus, social anxiety during social exposure can be a vicious cycle, as anxiety symptoms lead to a worse perception of self, which results in worsening symptoms [86]. Social anxiety and SAD can have a significant negative impact on quality of life. People with social anxiety can face stigma [126], inhibit social functioning [25, 74, 101] (which in turn feeds future social anxiety) and co-morbidity with depression and social isolation is common [1, 68, 74, 101].

There are several prominent psychotherapy treatments for SAD; Cognitive Behavioural Therapy (CBT) [33, 68, 126], Dialectical Behavioural Therapy (DBT) [89, 127], and Acceptance and Commitment Therapy (ACT) [58, 90] each utilise different approaches to overcome deeply held beliefs or fears and effect long-term cognitive change in patients. A core element used by these therapies is Exposure Therapy (ET), the structured repetition of facing one’s fears, followed by therapist discussion [15, 33, 77]. ET is a first-line intervention with proven efficacy, being core to many other prominent psychotherapies, and will be encountered by the majority of socially anxious people seeking treatment. Adherence to ET is a limitation, however, as the act of repeatedly facing one's fears, in this case, social exposure, is understandably challenging for patients [37, 100, 122]. Difficulty in engaging in social settings also makes areas like schools, shops, work and leisure spaces less accessible for socially anxious people [1, 114]. Given this, the value of an intervention which can reduce the difficulty of engaging in social exposure for socially anxious people is clear.

3.2 Emotion Regulation

In order to manage their emotional state and anxiety symptoms in response to social exposure, socially anxious people may employ a variety of emotion regulation strategies. Emotion regulation "refers to how we try to influence which emotions we have, when we have them, and how we experience and express these emotions" [43]. Gross describes five broad emotion regulation strategies: Situation Selection, Situation Modification, Attentional Redeployment, Cognitive Change and Response Modulation [41–43]. For example, in the specific context of social anxiety, redeploying attention from the perceived threat of external negative evaluation, or internal anxiety symptoms, towards non-threatening cues can lead to positive behavioural and anxiety outcomes [60, 113]. Providing such a distraction at the moment where negative rumination would begin can also facilitate positive thoughts, interrupting the negative cycle of social anxiety [66] and prior work has hypothesised or explored how haptic cues could facilitate emotion regulation in this way by evoking pleasant and calming experiences [49, 72, 73] or by cueing specific reappraising thought patterns [82].

A key category of emotion regulation strategy used by socially anxious people is safety behaviours [15], defined as an "overt or covert avoidance of feared outcomes that is carried out within a specific situation" [111]. In the context of social anxiety, these behaviours may range from overt actions, like exiting a conversation (Situation Selection) [99, 100], to more covert actions, like avoiding eye contact and focusing on one's phone (Attentional Redeployment) [15]. Reliance upon safety behaviours can be maladaptive and research has linked their use to worse therapy outcomes [15, 84, 106], with Wells et al. finding that socially anxious patients who underwent exposure experienced better outcomes when decreasing their use of varied safety behaviours [139]. It has, however, also been proposed that "judicious use" of safety behaviours could be used to improve early ET adherence [100]. It must be clear from the outset that any intervention which could constitute a safety behaviour should be used carefully, with the aim to slowly phase out their use to avoid dependence or maladativity. There is, however, value in understanding how such an intervention, if judiciously used, could best suit the specific use case of *in situ* socially anxious settings, a space less explored by prior HCI emotion regulation work [123]. There is also a distinction between the various safety behaviours undertaken by patients and interventions specifically designed to facilitate emotion regulation without directly obstructing exposure.

Emotion regulation can occur in the context of human-computer interaction without specifically designed interventions. Smith et al. have documented how digital interfaces are beginning to be used to facilitate emotion regulation by people in everyday life [124]. Their participants described using digitally delivered media, such as music, audiobooks or TV shows, to distract from negative feelings, trigger positive cognitive change or engage in catharsis with negative feelings. However, HCI has also sought to actively facilitate this effect. A framework proposed by Slovak et al. describes HCI emotion regulation interventions in three aspects: (1) the *theoretical psychological basis* of the intervention, (2) its *strategic basis* (i.e. how, when and where it can intervene) and (3) its *practical basis*, how the intervention is implemented. Grounding the intervention described in this paper, emotionally resonant vibrotactile comfort objects, in this framework, it would be described as an explicit, experiential, ongoing and on-the-spot method of exploring how attentional redeployment toward calming physical cues and positive thoughts can be "scaffolded through innovative intervention delivery mechanisms" [123]. The following sections will explore HCI interventions that aim to positively intervene with anxiety disorders or facilitate beneficial emotion regulation with both non-haptic and haptic interfaces, before then identifying the gap specifically addressed by this work.

3.3 HCI Interventions for Social Anxiety and Emotion Regulation

HCI researchers and designers have explored if technology could enable new interventions and therapy variants for social anxiety, which will be overviewed in this section.

3.3.1 Biofeedback. Prior HCI research has utilised biofeedback training to help users modify their physiological responses with the aid of live feedback of their own physiological state, e.g. using a visual indicator of one's breathing rate and a comparison to a slower rate, encouraging the user to match both rates and thus reduce their anxiety levels [78]. Smith et al. reported a significant reduction in anxiety prevalence for participants using a biofeedback phone app over a four-week period [124]. Hamon et al. explored displaying heart-rate biofeedback using an illuminated environmental object that participants could focus on directly or experience in an ambient way [45], finding that direct attention on the object resulted in higher relaxation. Virtual Reality has also been used with promising effects to present breathing and heart rate biofeedback and can do so inside a calming, immersive environment [105, 135]. Much prior work has also explored the use of haptic interfaces for biofeedback (see Section 3.4).

3.3.2 Lifelogging. HCI research has also worked to aid socially anxious people maintain the practice of lifelogging; removing the cognitive load of remembering to record stressful events and capturing events that the user may not have thought to record, all of which can then be evaluated later on. Lifelogging is a CBT practice of automatically or manually tracking anxiety events so they can then be considered later and unduly negative thoughts re-evaluated [102]. Miranda et al. investigated if using smart glasses that recorded blink rate or a heart rate monitor could effectively detect anxiety events, although only heart rate offered promising results [80]. Berrocal and Wac [14] explored combining the automatic collection of physiological signals with corroborations of observations from family members and friends to give a clearer picture of the mental state of participants in stressful scenarios. The wearable 'FaceIt' camera captured still images of the users' current situation when triggered by the detection of social interaction, elevated heart rate and certain GPS locations [102]. This combination of pictures, heart rate and location can then be viewed holistically later to allow for evidence-based re-considerations. A smartphone prototype by Mohammedali et al. provided calming and instructive aid to users at the point of event recording while simplifying the process of recording an event and contacting a carer or therapist if needed [83]. Ferrario et al. explored an approach dubbed 'intentive computing' whereby the user actively chose when to instigate physiological data capture but through a simple, discrete button press [35], providing a sense of control, relief and closure to those events. Simm et al. explored the role of form factor and personalisation in lifelogging devices, co-designing tactile wristbands alongside participants [121]. Participants highlighted the different kinds of positive and negative events they wished to log and results cited the advantages of allowing users to make assistive devices their own; 'thus reducing abandonment and increasing benefits to users'. In general, efforts to make lifelogging easier and more effective are a valuable way to make a core aspect of CBT, and other therapies, easier for patients to engage with. They do not, however, necessarily make the act of engaging in social exposure easier.

3.3.3 HCI Facilitation of Psychotherapy. Virtual reality has been used to simulate and facilitate Exposure Therapy. Virtual Reality Exposure Therapy (VRET) has numerous advantages over traditional methods: the exposure experienced can be tailored and controlled by a therapist [85, 103, 132] and allows easy access to immersive exposure events in the therapist's office [29, 103]. In multiple meta-analyses, VRET has shown similar efficacy to traditional Exposure Therapy, tackling a large variety of fears and anxiety disorders [76, 85, 132]. Flobak et al. conducted a participatory prototyping workshop with a group of fifteen adolescents to develop immersive virtual reality exposure therapy scenarios informed by their lived experiences for public speaking anxiety [36]. Researchers have also used VRET specifically to tackle social anxiety utilising simulated public speaking scenarios and found it produced a significant reduction in social anxiety when compared to normal Exposure Therapy both immediately after treatment and in a 12-month follow-up [5, 109].

Using digital interfaces to deliver established psychotherapy is another effective tool to improve therapy access by making more people aware of how to get help [21, 50], as research suggests only 25% seek treatment [21]. Online therapy allows access while forgoing the need for socially anxious users to enter physical social spaces to begin face-to-face sessions [50]. These implementations either replace the role of the therapist or allow a therapist to communicate with the user via computer-mediated communication. Internet-delivered CBT (ICBT) has shown efficacy in treating social anxiety and SAD when hosted online [21, 50, 128] or with a smartphone application [58]. While ICBT makes CBT more visible and accessible, it doesn't reduce the inherent difficulty of facing social exposure.

3.4 Affective Haptics and Application to Emotion Regulation

Affective haptic devices are used to communicate affective messages or elicit affective responses via a haptic modality [7] and can be used to emulate interpersonal affective touch [7, 54], evoke pleasant experiences [49, 71, 121] and modulate physiological responses [81, 147] (see Section 3.4.4). While there are many ways computers can support emotion regulation, haptic interfaces have particular utility in socially anxious settings as they can be used discreetly without interrupting any conversational faculties or inviting stigma. In this paper, we explored the concept of using vibrotactile comfort objects, informed by prototyping with socially anxious users, as an emotion regulation intervention which could be used during social exposure. This section grounds our approach in prior affective vibrotactile research and prior work specifically utilising vibrotactile cues and haptic stimuli for emotion regulation.

Researchers have explored many affective haptic modalities. For example, thermotactile cues have been used to elicit pleasant and unpleasant experiences based on temperature level [112, 141], and to widen or change the emotional range of other modalities, such as vibration or affective images [2, 44, 140]. Ultrasonic feedback is another example, as the complex patterns displayed by ultrasonic arrays can impact affective responses to affective images or artwork [9, 91].

In this research, we chose to utilise vibrotactile stimuli specifically due to their practical flexibility, as they can effectively radiate throughout rigid objects of different sizes and shapes. This allows deployment into objects that users find convenient, discreet, or preferential, and for those objects to be held in non-specific ways. While varying rich calming emotional experiences can be elicited by other actuation techniques - such heating elements, ultrasonic arrays [91], tactor arrays [26], or force-feedback - these may require users to place their hands in specific locations or utilise additional haptic interfaces beyond what they might be comfortable taking into a social scenario. The ability for vibrations to augment a variety of objects, while still evoking varied emotional responses via emotional resonance (see Section 3.4.3), not only makes them appropriate for deployment in social settings but also allows a greater level of personalisation of surface texture and form factor. This also potentially affords users a larger suite of affective, self-soothing tactile interactions discussed in prior work [24, 56] - such as hugging, squeezing, stroking or kneading - beyond what is facilitated by augmenting devices like smartphones or watches. In the following sections, we will ground our approach in prior work on affective responses to texture, social robots, and affective vibrotactile stimuli.

3.4.1 Texture. In Study 1 of this work participants were provided with a variety of textures they could add to their comfort object to allow them further customise their haptic experience. This approach was informed by prior work on affective responses to texture. Nagano et al. presented participants with 24 clay textures, varied by grooves, perforation, and smoothness, and found that textures were more inviting when dry, grooved and not glossy [87]. Iosifyan et al. explored emotional responses to texture perception, linking softness to pleasantness and roughness to unpleasantness [55]. They also found textures could be associated with emotionally charged concepts (e.g. Granite or Marble could be associated with gravestones). Etzi et al. asked participants to rate their emotional response to 10 textures, including satin, sponge, tinfoil and sandpaper, presented to their hands, cheeks, and arms [32]. Again, smoother materials were more pleasant and participants preferred materials they had prior experience with. Finally, a survey of 80 people by Macdonald et al. elicited texture preference suggestions [72]. Soft textures were again most prominent, but other texture attributes were also preferred including 'smooth', 'fabric', 'metallic' and 'plastic' textures.

3.4.2 Affective Vibrotactile Stimuli. This section will overview prior research exploring affective responses to vibrotactile stimuli. The most widely used and standard way to measure affective response in these works is Russell's Circumplex Model of Affect [107], a two-dimensional model of valence on the x-axis (pleasantness to unpleasantness) and arousal on the y-axis (alerting to non-alerting), which intersect at the origin (see Figure 3). A participant's given rating for valence and arousal can be plotted on this model to indicate an emotional state.

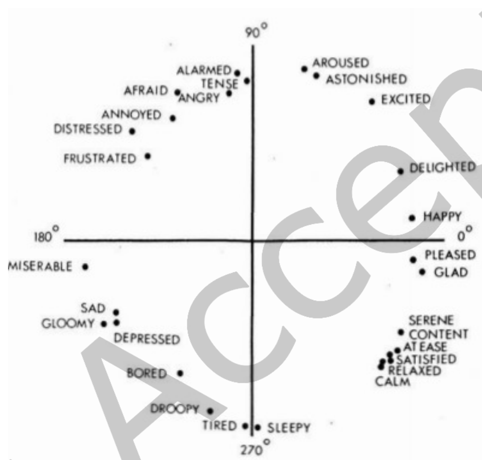

Fig. 3. Russell's Circumplex Model of Emotion [107]. The y-axis represents arousal or alertness, while the x-axis represents valence or pleasantness. Russell mapped 28 different affect terms around this circular model (extracted from [107]).

While the Circumplex Model provides a convenient method to map affective response - and is utilised by many prior affective haptic researchers - its lack of inherent qualitative detail necessarily restricts its ability to accurately reflect specific emotional states or to answer why an individual is having a specific emotional response. Thus, we chose a more qualitative approach for this work to better understand the emotional experiences of our socially anxious participants.

Early affective vibration research investigated how emotional responses were impacted by waveform parameters such as frequency, envelope, amplitude and duty ratio. Most research indicated stimuli with greater vibration intensity (by varying amplitude) received higher arousal and lower valence ratings [3, 48, 70, 140, 144]. Findings on the impact of frequency are divided: some found that higher frequencies lead to higher arousal and lower valence [140, 144], while others found that increasing frequency led to decreased arousal [48, 70]. Waveform rhythm also has an effect; stimuli interrupted with multiple pauses are more arousing and attention-grabbing, while uninterrupted stimuli are more pleasant with higher valence [48, 117]. While affective responses to vibrotactile stimuli can be impacted by varying these waveform parameters, many researchers found that the overall valence range of this modality is narrow, especially for low arousal cues [48, 70, 72, 140, 144] and this lack of ability to evoke pleasant or relaxing sensations limits the ability for vibrotactile cues to facilitate emotion regulation via calming or comforting affective display [73]. There is, however, a category of vibrotactile stimuli with a wider affective range: emotionally resonant vibrotactile stimuli.

3.4.3 Leveraging Emotional Resonance. Emotionally resonant vibrotactile stimuli are cues which evoke a real-world experience (e.g. a cat purr) in order to elicit an associated emotional response the user has with that experience (e.g. pleasant or relaxed memories of petting a cat) [70]. Prior to this vibrotactile application, emotional resonant stimuli were utilised in affective acoustic research, as natural soundscapes have been used to provoke calmer emotional responses in urban settings [92, 133]. In clinical contexts, participants have been observed to experience less pain and stress when listening to soundscapes with which they had a positive emotional association [6, 27, 46, 130]. Following this, vibrotactile interfaces which evoked real-world sensations to elicit related emotional responses were explored. Researchers have displayed vibrotactile patterns which represent natural phenomena via vibrotactile actuators arrays [57, 91, 119] and provoked a wider range of emotional responses, as observed by Shim et al., than the abstract cues used in prior affective vibrotactile work. A series of varied and ambiguous wearable affective haptic interfaces, developed by Zhou et al., allowed people to freely explore affective haptic design space to craft emotionally resonant or evocative sensations [146]. Work such as Czech et al.'s *Haptic Remembrance* book, or Ryding et al.'s *LYDSPOR* leveraged both acoustic and haptic stimuli to evoke rich, affective scenes from past or historical life experiences [28, 108]. Thermal cues have also been used to enhance the emotional resonance of other experiences [71, 88]. Macdonald et al. have demonstrated that vibrotactile cues generated from a single actuator can also be emotionally resonant [70, 71]. These stimuli have a wider affective range when directly compared to abstract waveforms and can evoke rich and meaningful emotional responses that are specific to each individual's experience with the real-world experience being evoked [71].

Several social robots, such as *Paro the Seal* [1] and *The Haptic Creature*, leverage emotional resonance to evoke real-world interactions with pets and animals, and this informs user interactions and provokes specific emotional responses to them [53, 118, 143]. Such robots have been used to promote emotion regulation [61, 118, 137] or as socially assistive devices for lonely or stressed individuals [61, 118, 137]. Isbister et al. explored the development of prototype tangible socially assistive robots alongside for and with children [56] which aimed to be calming to see, touch and engage with, encouraging children to form a bond with the device as a comfort object and allowing it to be socially assistive and facilitate emotion regulation for upset children. This work motivates further exploration of haptic comfort objects for emotion regulation and we echo core aspects of this approach, but with a different use case and requirements.

Social robots like these above make use of shape, texture and haptic modalities to holistically simulate emotionally resonant interactions that evoke users' prior positive experiences; and social touch with animals or pets. To achieve this, however, these robots often adopt specific, non-discreet forms and behaviours. In this work, we aim to explore if similar benefits can be achieved with more customisable and discreet vibrotactile comfort objects designed with adult socially anxious users, and social exposure, in mind.

3.4.4 Use of Haptic Cues for Emotion Regulation. Haptic cues have shown potential for emotion regulation. Miri et al. identified that haptic stimuli could facilitate emotion regulation in three ways: (1) allowing attentional redeployment from high arousal, unpleasant anxiety symptoms to calmer, low arousal haptic stimuli, (2) enabling cognitive change by cueing up reappraising thought patterns in response to stimuli and (3) providing biofeedback to improve response modulation [82]. In their comprehensive review of affective haptics research and applications, Vyas et al. [136] identified that exploration of Response Modulation makes up the majority of prior exploration.

[1]Paro. https://www.paroseal.co.uk/ - Accessed 02/24

Vibrotactile biofeedback, in the form of both implicitly and explicitly perceived heartbeat-like stimuli, has been utilised by many researchers to lower participants' heart rates and calm their emotional state [8, 22, 23, 96, 142, 147]. Vibrotactile arrays and breathing pacers have also been used to deliver heart and breathing rate biofeedback, with Miri et al. mounting actuators around the body [81], and both Paredes et al. and Balters et al. installing haptic arrays into car seats to facilitate breathing regulation which driving [10, 94]. In addition, Ghandeharioun and Picard used a combination of visual, vibrotactile and thermotactile cues paced below the user's current breathing rate to lower it [40].

Slovak et al. [123] highlight, however, a shortage of HCI research exploring emotion regulation in other ways, such as those outlined by Miri et al. [82]: enabling attentional redeployment and cognitive change. Maclean lists the use of calming and comforting haptic stimuli to "directly reduce stress" as an established example of an affective haptic design objective [73]. As noted in the previous section, applied examples can be seen in the field of social robotics [56, 61, 116], but not specifically designed for social anxiety or ongoing social exposure. Furthermore, there is a lack of HCI emotion regulation intervention research that explores on-the-spot, ongoing support[123]. Finally, the specific needs and requirements of socially anxious users for such interventions are not well explored. Our work addresses these gaps by exploring the use of emotionally resonant vibrotactile stimuli as a continuous calming haptic intervention for discrete use during social exposure, integrated into comfort objects co-designed with socially anxious participants.

4 STUDY 1: PARTICIPATORY PROTOTYPING OF VIBROTACTILE COMFORT OBJECTS

A participatory prototyping study was conducted to investigate the preferences and requirements of socially anxious people for a calming affective haptic intervention that aimed to facilitate both Attentional Redeployment from high arousal anxiety symptoms [60, 82], and distraction from negative rumination by leveraging emotional resonance to cue up positive thoughts [66]. Participants described their lived experiences with social anxiety and affective touch before designing a calming comfort object that suited their preferences for shape and texture. These objects were then augmented with emotionally resonant vibrotactile stimuli and participants chose one or more that they found most pleasant or calming. It was hypothesised that the customisation offered by prototyping would allow participants to craft comfort objects suited to their personal experiences, which were calming and pleasant to hold, as assessed with a post-session interview and survey. The results would detail the breadth and prominence of requirements and haptic preferences of socially anxious users and inform the design of higher-fidelity prototypes evaluated in Study 2.

4.1 Study Design

4.1.1 Apparatus and Stimuli. To construct their comfort object prototype, each participant was presented with a set of materials and tools (see Figure 4). Materials were chosen to be simple and functional to cut and shape while being grounded in haptic preferences identified in prior work [72]. Participants could build the base structure of their object from Lego, Play Dough or a phone case. To accommodate preferences for *Soft* and *Fabric* textures [55, 72], sheets of soft felt and faux fur were provided. Preferences for *Smooth*, *Plastic* and *Metallic* textures were accommodated with sheets of foam, plastic film and tin foil. Finally, a sheet of sandpaper was provided as a rough texture option as a contrast. Participants were provided with scissors, sticky tape and Blu Tack to cut, shape and stick materials together.

Vibrotactile stimuli were conveyed using a Haptuator Mk II [2], an actuator used in prior affective and emotionally resonant vibrotactile work [70, 71, 140]. Nine emotionally resonant stimuli which exhibited high mean valence, low mean arousal, or high average emotional resonance in two prior Haptuator studies et al. [70, 71], were re-used for participants to choose from (see Table 1). Using these vibrotactile stimuli allowed each participant's prototype

[2]Haptuator Mk II, now referred to as the HapCoil-One https://tactilelabs.com/products/hapcoil-one/ - Accessed 02/24

Fig. 4. The set of building materials and textures provided to each participant for participatory comfort object prototyping.

to be augmented with affective haptic cues effectively, regardless of the object's specific form factor or how it was held.

These stimuli were originally produced by sourcing free-to-use sound files of the original sensation to be evoked from the online audio repository *Freesound.org*, before applying a 300Hz low-pass filter and volume normalisation of 89dB, removing frequencies not presented effectively by the Haptuator and reducing noise pollution [70]. Stimuli had a duration of 10 seconds to allow the acoustic patterns of real-world sensations, such as the slow crashing of waves, to be fully presented. A 2018 13-inch i5 MacBook Pro was used to deliver the stimuli through the Haptuator, via an aux cable, with the laptop's volume level set to 6. Participants were told that they could request a change in intensity if desired, which was performed in an *ad hoc* manner. Stimuli are provided in the supplemental materials, while intensity waveforms and spectrograms for each of the stimuli are shown in Appendix 8.1.

Emotionally Resonant Vibrotactile Stimuli				
Heartbeat	Cat Purr	Crashing Waves	Slow Breathing	Rain
Small Stream	Brushing	Car Engine	Underwater Bubbles	

Table 1. Nine emotionally resonant stimuli used (see Sec 4.1.1 for stimuli specifications)

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4.1.2 Participatory Prototyping Approach. We adopted a participatory prototyping approach, the practice of involving end-users in the design of a system [115] to bridge the gulf of experience between designer and user [19, 69, 121]. The procedure used in this study was directly inspired by Simm et al. in their paper *Anxiety and Autism: Towards Personalized Digital Health* [121] who proposed providing participants with a small kit of components from which they could construct a digital health device suited to their own aesthetic and tactile preferences. This study used a similar approach, as socially anxious participants designed personalised calming tactile objects. These objects are analogous to comfort objects, objects with which the user has a relationship, providing comfort and emotional regulation through interaction, including tactile interaction [4, 20]. While most commonly used by children, comfort objects are also used by adults [20]. Examples of comfort objects may include a favourite toy, item of clothing, blanket, jewellery or trinket.

The initial ideation of this study planned to utilise a focus group with an established *Keep, Lose, Change* structure [38] to promote iterative concept design for comfort objects around shared understandings of socially anxious experiences. The group setting presented an additional challenge of group social exposure for socially anxious participants, however, which could cause additional discomfort and stifle the discussion that underpins this approach. Thus, one-to-one prototyping sessions were chosen instead. As an additional benefit, this approach allowed each participant to delve more into their personal experiences when discussing, designing and customising their objects, rather than feeling pressured or concerned about the comments and feedback of others.

4.1.3 Participants. Twenty participants (6 male, 10 female, 4 non-binary) were recruited using university, email and social media channels. Mean participant age was 26.2 (σ = 3.76, Range: 20-32). Participants were recruited if they were at least 18 years old, had full haptic perception in their hands and scored 34 or above on the Social Interaction Anxiety Scale (sent via email to those who requested participation), indicating likely social anxiety [75].

4.1.4 Study Procedure. The study took place inside a large office space with the participant and researcher present, both wearing personal protective equipment (PPE), to reduce risk during the COVID-19 pandemic. Participants read an information sheet before signing a consent form to proceed. The study took approximately one hour to complete and participants were paid with a £10 Amazon voucher. The study was approved by the University ethics committee.

The study was comprised of three sections. The first was a short, semi-structured interview during which participants were asked three questions and open-ended discussion was promoted during each one.

1. *How has social anxiety or shyness manifested or impacted you in social situations?*
2. *Do you currently use something to make social situations easier, like a distraction or mental technique?*
3. *Have you found any kind of touch with an object, animal or person calming during social situations?*

These questions allowed us to better understand our participants in three ways: (1) each participant's experience of social anxiety and how this might impact how they benefit from or use, a calming haptic intervention; (2) which current emotion regulation techniques they employ and if they motivate providing a haptic alternative; (3) if they currently view any form of affective touch as a potentially calming intervention in social settings, which could contextualise their preferences (or lack thereof) when personalising their comfort object. Participants' voices were recorded during interviews. These recordings were then transcribed and anonymised.

In the second section, participants were asked to create a comfort object they felt would be calming to hold from the provided building materials. Participants were given a flexible timescale to build their object and took approximately ten minutes on average. Once a participant completed their comfort object, the Haptuator was attached with tack, tape or inserted into the play dough in an *ad hoc* fashion, depending on each prototype's shape and how the participant indicated they meant to hold it, producing an impromptu affective vibrotactile comfort object.

In the third section participants were asked two more questions in a semi-structured interview designed to explore their rationale and desires that informed the creation of their prototype:

1. *What was your intent in creating this object?*
2. *Is there anything you wish you could change or improve about your prototype?*

Participants then held their comfort objects and experienced all nine emotionally resonant vibrations. Participants could give feedback on each stimulus and then choose one or more as their favourite. This was followed by a final structured post-session survey which assessed the participant's experience in the study, their sentiment toward their prototype and the vibrotactile stimuli (see Figure 10). The vibration, shape, texture, materials, a short description and a photograph of their object were also recorded.

4.1.5 *Qualitative Analysis Methodology.*
Qualitative analysis followed an open-coding approach with follow-up axial coding to identify and categorise pertinent concepts and trends in participants' anonymised interview transcripts [110]. The transcripts were reviewed and initial codes were assigned to pertinent and reoccurring concepts and topics. Related codes were grouped into higher-level emergent themes that described that data. Qualitative coding was conducted by two coders in two iterative rounds for validity. Both researchers coded the entire data set once each initially, before conducting a synthesis meeting to produce one combined code scheme, whereby axial coding was used to group related codes into an initial hierarchy of higher-level themes. Both researchers then re-coded the data using this synthesised set of codes and then conducted a second synthesis meeting which resulted in a final set of codes and themes. These related codes and the identified themes were then discussed in a descriptive manner, illustrated with participant quotations, to highlight prominent themes in participant experiences with social anxiety, affective touch and their haptic comfort objects. The qualitative analysis software nVIVO [3] was used by both coders to create and apply codes and themes.

4.2 Results

In total, nine themes were identified across all interview questions: *Attention, Mental Association, Anxiety Effects*, Coping Strategies, Touch Interaction, Vibration Attributes, Object Attributes and *Social Interaction.* These themes were comprised of a total of 61 codes for concepts which were mentioned by at least two participants. Each of the nine themes, their composite codes, and the prevalence of each code are visualised on a series of thematic maps which can be found throughout the results and in the Appendix (8.2). Through the section specific themes and their codes are discussed throughout the section, alongside corresponding maps. The first semi-structured interview on experiences of socially anxious users provided first-hand context for how emotionally resonant haptic comfort objects could be used and what improvements this intervention could provide when compared to current coping strategies or affective touch experiences. It is worth noting that directly solicited accounts, such as these, may be subject to some amount of desirability bias or demand characteristics, which could incur some positive bias.

4.2.1 *Experiences with Social Anxiety.*
First, participants were asked how social anxiety impacted their social interactions and their answers were analysed for prominent trends and themes.

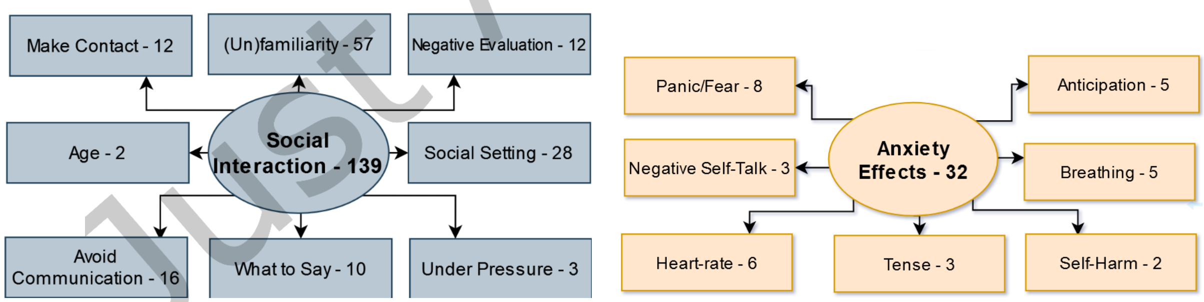


Fig. 5. Thematic maps of the qualitative codes regarding participant experiences with social anxiety, grouped by the themes of *Social Interaction* and *Anxiety Effects*.

Avoiding communication was a common talking point in participant interviews, mentioned by 16 people. Participants described either staying passive in social scenarios to avoid initiating social contact or avoiding them entirely.

[3]NVivo - Lumivero https://lumivero.com/products/nvivo/ - Accessed 02/24

> P10 - “My friend invited me to meet a bunch of his friends they just had like a flat gathering and I thought it wouldn’t be so bad, but I got there and there was just too many people and I just felt scared. So I just went away, (...) just being scared I can’t think straight I can’t really rationalise or just be like ’oh am I being rude by just leaving them?’, I just need to get out.”

The recent circumstances of the COVID-19 pandemic had presented socially anxious participants with new challenges, as social anxiety could also arise during the video-call environments which had become increasingly widespread.

> P14 - “I find tutorials very like scary, um, mainly because people don’t... a lot of people especially on Zoom don’t speak but it kind of feels like everyone’s looking at you.”

These experiences of avoidance highlight the potential benefit of calming interventions which can be used during social interaction, such as the one suggested in this work, as reducing the difficulty of facing one’s fears should allow more users to take part in social exposure, a core element of societal settings, as well as core psychotherapies.

Participants mentioned various physiological and psychological symptoms they experienced due to social anxiety (see Figure 5 for a thematic map of the theme *Anxiety Symptoms*). Six participants mentioned being overly aware of their *heart rate* during social situations, five noted elevated *breathing rate* and seven people raised other symptoms like tensing up, shivering, nausea and biting or picking at their nails.

> P7 - “I tense up in the back of my legs and sometimes my feet, which can either be painful or inhibits mobility, or I get like a wee bit panicked and can feel my heart racing a wee bit more, or like my breathing gets a little bit funny.”

Twelve participants felt a preoccupation with *negative evaluation*, making it harder for them to engage socially and keep in contact with others. Several specifically mentioned that they weren’t sure how to act ’normal’ or not ’weird’.

> P5 - “I’m always worried that like “oh you can’t say that because that’s just really weird” and I find myself, like, overthinking what I’m gonna say. You know, like, trying to pretend to be normal. Somehow it just doesn’t... I don’t know what to do.”

Anxiety or fear regarding interacting with *unfamiliar* people was one of the most prominent themes, mentioned by 15 out of 20 participants. This can cause people to lose access to practical and leisure spaces, as described by P11:

> P11 - “I’ve stopped taking public transport because [of] being in such close contact with other people and worrying about what they think about me and what a possibility of interaction with them was too difficult for me (...) In any situation that that you can you can think of where you would have people I’d rather avoid it.”

Overall, the experiences highlighted by participants echo much social anxiety research which predicts that, when people observe physiological symptoms such as heart or breathing rate or focus overly on perceived negative feedback, it can worsen their anxiety [101], causing a negative feedback loop. We aimed to address this by interrupting this feedback loop; using calming haptic comfort objects to reduce social anxiety symptoms by facilitating emotion regulation [60]. This facilitation may be achieved in two ways: (1) leveraging attentional redeployment from high arousal physiological symptoms toward non-threatening calmer cues [51, 82], (2) interrupting and distracting from negative self-evaluation [66] by cueing up positive thoughts evoked by emotionally resonant comfort objects.

4.2.2 Coping Strategies for Social Anxiety. Next participants were asked about which coping strategies, if any, they employ to deal with the challenges of being socially anxious.

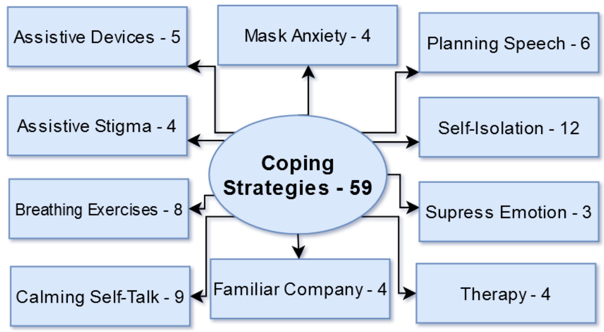


Fig. 6. Thematic map of the qualitative codes applied to participant interview transcripts, grouped by the theme *Coping Strategies*.

Familiarity with people or objects played a crucial role in a participant's ability to access social spaces (see Figure 6). Four participants they felt more comfortable attending or existing in settings with unfamiliar people when with one or more close friends, while five reported using a familiar device to calm them, such as distracting themselves with their phone, a plushie, or a fidget cube. Four highlighted, however, that using these devices in social situations could attract *assistive stigma*, discouraging their use. This highlights the need for discretion when designing a calming intervention for social use, supporting the strengths of vibrotactile stimuli which users can experience without being visually and audibly obvious to others, and can be embedded innocuously into different objects or wearables.

> P20 - "I still want to explore some places, so I usually try and like get a friend to come with me so that that really like helps a lot."

> P4 - "things that I would take with me to a public setting would be fidget toys. Yes at home I have things like plushies and stuff if I get anxious, but I would be embarrassed to take something like that."

The most popular coping mechanism, mentioned by twelve people, was *self-isolation*, a maladaptive strategy which prevents social exposure. Preparation before social interaction was a common coping strategy: *calming self-talk* was raised nine times and *planning speech* or conversation ahead of time was mentioned six times (see Figure 6). Response modulation was also employed, such as *breathing exercises* (raised eight times) and three participants who described attempting to *suppress emotion*. Only four participants had attended *therapy* to help them manage their anxiety.

4.2.3 Affective Touch and Social Anxiety. Finally, participants were asked if they found any kind of touch calming or comforting. Most prominent was touch with pets or animals, mentioned by 13 people, and fidgeting with objects, mentioned by six. Five people mentioned human touch and five others said none. As previously mentioned, participants reported holding or touching objects like a phone, a plushie, or clothing, as a potentially calming distraction.

> P11 - "I do find touching very soft things and so, for example, plushie things or even very soft fabric clothing very soothing as well I kind of… I don't know I scrunch it a little bit and then that is helpful. (...) A hamster that I used to have, which was quite like a furry animal as well (...) that was helpful to calm me down."

Emotionally resonant vibrations could provide a discreet way to evoke animal touch [70, 71] and pleasant associated emotional responses in settings where pets are not accessible or acceptable, while an active haptic element may provide a more effective distraction from interoceptive symptoms than passive object touch. Overall, participants did not reflect on many kinds of existing calming affective touch at this stage, instead providing more details about their anxious experiences and other coping mechanisms. The following prototyping session, however, allowed a better exploration of this space and provided a clearer view of how calming touch could be utilised in socially anxious settings (see Figure 7).

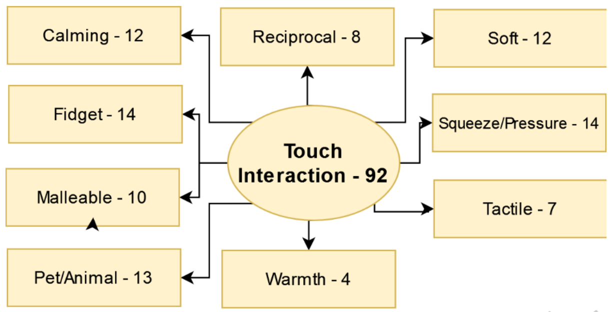


Fig. 7. Thematic map of the qualitative codes applied to participant interview transcripts, grouped by the theme *Touch Interactions*.

4.2.4 The Form Factors of Comfort Object Designs. Following the interview on anxiety experiences, participants were introduced to their primary task: constructing a comfort object they found pleasant or calming to hold from a variety of materials. Participants produced a wide array of objects which varied in texture, form factor and, in some cases, their intended meaning (see Figure 8 for each participant's object grouped by their most prominent form factor attribute), but some notable trends were observed. Objects were classified by form factor, the materials used for exterior texture and attributes identified during qualitative analysis (see Table 2). While most objects embodied one primary form factor, some objects were a combination of forms, such as P11's design which featured finger groves in a rounded shape.

Form Factor	n	Texture Materials	n	Attributes	n
Round	7	Play Dough	8	Soft	13
Finger-grooves	5	Fur	8	Multi-textured	10
Square	3	Felt	5	Smooth	9
Model	4	Cling Film	2	Malleable	6
Wearable	2	Lego	3	Rough	5
		Sandpaper	2	Fidgeting	4

Table 2. Table showing the prevalence (n) of the different properties of comfort objects produced during participatory prototyping. Form Factor indicates the shape of the objects, Texture Materials describes which materials participants used to give their objects texture and Attributes lists how often qualitative codes were assigned to different objects.

Seven participants produced *round* prototypes, making it the most prominent form factor. Several stated that they chose a round shape due to how it allowed them to hold the object, e.g.: "it fills the hand", "something that you could hold, you know like clutch, almost like so you could really apply pressure to it". Past personal experiences could also be important when choosing a comfort object's shape, as highlighted by P16:

> P16 - "I quite like throwing balls, stress balls and some things. I never really bought a stress ball, [it's] just always given. You know you win a game or something and I quite like playing with and I quite

Fig. 8. Comfort objects created by socially anxious participants via participatory prototyping from a variety of possible building materials (see Section 5.2.2). Prototypes are here grouped by their most prominent shape (some objects embodied more than one shape) and labelled by participant number.

> enjoy ball games, so I was like, what if it was just something I could hold like that and, you know, squish and throw, all the rest."

Five participants prototyped comfort objects which featured a series of *finger grooves*. These objects tended to have an elongated shape, allowing the user to hold it like the "grip on (...) some power tools", (P10). These grips were all created using Play Dough, allowing them to be moulded by each participant's hand, ensuring a fitting grip. Three prototypes were produced with a square-edged shape, with structure provided by Lego. They featured a mix of external textures, with all three participants utilising the inherent smooth and rough Lego textures and the addition of soft felt or fur. P15, who produced "three tactile steps" from Lego, added a felt texture as they felt "it needs to be soft". Two square objects featured fidgeting interactions that involved moving or detaching and re-attaching components, which one participant likened to the interactions on a fidget cube. Another prototype was formed in the shape of a spindle and the participant described spinning it between their fingertips to calm themselves.

Fourteen participants highlighted the desire to be able to squeeze, hug or put pressure on their objects and designed them accordingly. The thematic map for *Touch Interaction* displays all codes related to participant touch preferences (see Figure 7). Eight participants described fidgeting with their objects, helping distract them or make them feel grounded. P4 and P7 used a Lego core to give their prototype "a harder centre so that there's some resistance"(P4) and four participants noted that they wished for their object to emulate the squeezing interaction of a stress ball. Others valued an object's malleability when performing squeezing interactions, and engaging in playful interactions. P14 created an object with multiple Play Dough colours separated into cling-film compartments, achieving both visual and tactile malleability: "I can squeeze it in ways that like distorts how the colours are seen".

While some prototypes were constructed purely for their pleasant haptic properties, others wished to imbue their object with specific meaning. Objects were modelled after real-world concepts: a hedgehog, a small doll, a flower and a pillow which a participant imagined could be upholstered with fabric from the clothes of a comforting loved one.

> P13 - "I wanted something aesthetics like in the sense that it meant something for me. I can give it a name or an identity to comfort me as well and yeah I just wanted something that I can hold in my hand"

4.2.5 Textures Used in Comfort Object Designs. As expected from prior work [55], soft materials like fur and felt were most common, used 13 times out of the 20 prototypes. A common attribute combination was soft and round prototypes, appearing seven times. Several participants cited an emotional resonance effect as motivation for choosing soft textures:

> P6 - "I wanted to wrap it in this kind of furry sheet because to me it was almost like nurturing a little chick or a bird, you know you hold it in your hand and it's soothing to hold on to and it's relaxing and calming"

> P7 - "I've got a pet cat and the kind of furry one is like most of cat's fur."

While soft textures were most prominent, they often appeared on one side or area of an object which featured multiple textures, allowing the designer a range of tactile experiences. Half of the prototypes featured two or more textures, combining soft, smooth or rough textures depending on the participant's intent. P11 created a reversible felt/fur cover for their spherical object, allowing them to choose between the emotionally resonant experience of "touching a pet" or a more general soft experience. Three participants produced objects with soft and rough textures, highlighting the tactile "contrast"(P7, P20) it offered. Others enjoyed the base texture of the Play Dough and Lego building materials but wanted to partially augment them with soft surfaces:

> P12 - "At first I was just like 'oh you know like the two pieces of Lego are like good enough' but I was like oh you know I could have some felt and it would be a bit a bit more pleasing."

This trend highlights that participant preferences for texture should not be considered in isolation, but how different texture combinations can provide specific tactile experiences.

4.2.6 Emotionally Resonant Stimuli Preferences. Every emotionally resonant vibration was selected by at least two participants to augment their prototype (see Table 3) and their reasoning for their stimuli preferences were recorded and qualitatively coded (see Figure 9 thematic map). *Cat Purring* was most prominent, chosen by half the participants as one of their favourite calming stimuli. Six of the prototypes for which *Cat Purring* was selected featured a fur texture and several participants noted this connection: P6 - "That's very nice because it is very accurate. It fits [my comfort object]". Participants described having an emotionally resonant reaction to other vibrations:

> P12, on *Small Stream* - "Definitely feels like running water. Uh it reminded me a lot of like honestly like a stream. Like it reminded me of like tap water and stuff so, like, it was nice."

> P7, on *Rain* - "I think it's instinctual because uh there is that association with like especially with rain being kind of calming in certain circumstances especially if you're inside, it's one of those things."

As in prior studies, participants could find a stimulus emotionally resonant, but the resulting emotions were not always positive [70]. While P7 thought the *Car Engine* "could be quite reassuring and reinforcing", for P4 it brought to mind memories of "being carsick and my parents shouting at each other over directions", and several participants found Heartbeat "creepy", especially when combined with the texture of Play Dough.

Stimuli	n	Stimuli	n	Stimuli	n
Cat Purring	10	Brushing	6	Underwater Bubbles	4
Car Engine	6	Crashing Waves	6	Small Stream	2
Slow Breathing	6	Heartbeat	5	Raindrops	2

Table 3. Total selections (n) of preferred emotionally resonant vibrotactile stimulus by twenty participants when trialling every stimulus as part of their comfort object prototype, listed from most to least.

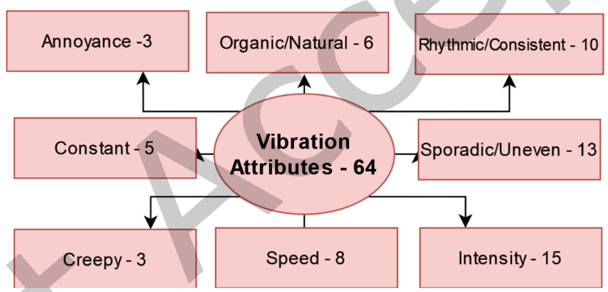


Fig. 9. Thematic map of the qualitative codes applied to participant interview transcripts, grouped by the theme *Vibration Attributes*.

Thirteen participants specifically mentioned preferring or disliking stimuli based on whether they were constant and regular or sporadic and irregular. P14 commented "I like the car engine and still breathing were like the same reasons that they were both quite chill and consistent" while after experiencing the *Crashing Waves* stimuli P15 said, "that's nice. I like the ones that have like a kind of shift, you know so it's not just kind of constant (...) there's like a movement too". While all peak intensity of stimuli was normalised by volume and a low pass filter, the perceived intensity of vibrations was mentioned 15 times by participants as a factor that influenced their preference. The most common comment made by nine participants was a preference for specific stimuli that they felt were 'gentle', or disliked vibrations that were 'too strong', but there were cases where participants preferred specific stimuli to be more intense:

> P18 - "It did remind me of a cat. [...] with these ones like I would just would crank up the vibrations."
> Researcher - "Okay, let's try that a bit stronger."
> P18 - "That's so much better a little bit stronger yeah."

The impact of intensity also depended on the consistency of the stimuli. Two people found the anticipation and crescendo of *Crashing Waves* to be specifically stressful, while the natural variance in intensity of *Raindrops* and *Bubbles* were noted as potentially shocking or stressful. This supports the inclusion of intensity modulation as another important personalisation option when utilising emotionally resonant vibrations in this context.

The effective emotional resonance of a stimulus varies between stimuli, as does their subsequent emotional response, and some participants had positive or negative responses to stimuli for other reasons such as consistency or intensity. By providing a varied set of stimuli, every participant was able to find at least one they preferred. Fifteen participants chose two or more preferred stimuli and seven chose three or more.

4.2.7 Final survey: Participant Sentiment Toward Vibrotactile Comfort Objects. Post-session survey feedback further supported the augmentation of comfort objects with emotionally resonant vibrations (see Figure 10). Sentiment about the prototypes was largely positive: the majority of participants (90%) found their vibrotactile prototype pleasant to hold and 70% found it calming to hold. The most important aspect of the comfort objects was their shape and texture, as indicated by 95% of participants, but 70% felt that the vibration was also an important component. 60% of participants specifically wanted the vibration they chose to match its texture and shape, creating a holistic, resonant experience. All this indicates that, while participants did not view the emotionally resonant vibrations as the most crucial aspect of their comfort objects, they were still well received and added value. 85% of the socially anxious participants felt that a comfort object like their finished vibrotactile prototype could be helpful in an anxious situation, demonstrating the willingness of socially anxious users to adopt this intervention and motivating evaluation in social settings.

Given the possible distress caused to socially anxious participants due to the one-to-one conversations in this study design, they were also asked for feedback on their participatory prototyping experience. All participants reported that the researcher made them feel comfortable and informed during the sessions and felt their input was valued. 95% found the experience rewarding and satisfying. 15% of participants reported that the experience made them feel anxious.

4.3 Study 1 Discussion

4.3.1 Motivating the Use of Emotionally Resonant Vibrotactile Comfort Objects. The results of this prototyping study suggest a willingness of socially anxious users to utilise emotionally resonant comfort objects as a calming intervention. Our findings supported the hypothesis that participants would consider their comfort objects calming and pleasant to hold, as well as potentially useful in anxious situations. Results also indicated that emotionally resonant vibrotactile comfort objects could facilitate emotion regulation. Participants said that their prototypes were able to provide them with pleasant and relaxing haptic experiences, which could enable Attentional Redeployment from their internal anxiety symptoms [41, 60, 82] or divert negative focus on perceived social performance [66], interrupting the negative feedback loop that characterises social anxiety [101]. Interviews indicated that participants found specific vibrotactile stimuli emotionally resonant of past experiences, cueing up associated thoughts and eliciting pleasant emotional responses as a result, and participants designed their comfort objects to enable these positive emotional associations. While Study 1 feedback was mostly positive, and highlighted ways in which this intervention could facilitate emotion regulation, this feedback was necessarily subjective and often speculative. As such only speculative conclusions could be drawn from it at this stage, especially considering the potential for positive biases in these responses, particularly from socially anxious participants (see Section 6). At the least, this feedback motivated the further investigation of whether emotionally resonant vibrotactile comfort objects could effectively support emotion regulation as a calming intervention.

Despite the low fidelity and impromptu nature of these comfort object prototypes, the emotionally resonant vibrations delivered by the Haptuator were able to augment each design effectively, adding pleasant stimuli to the overall experience. The ease at which vibrotactile actuators could augment these prototypes demonstrates

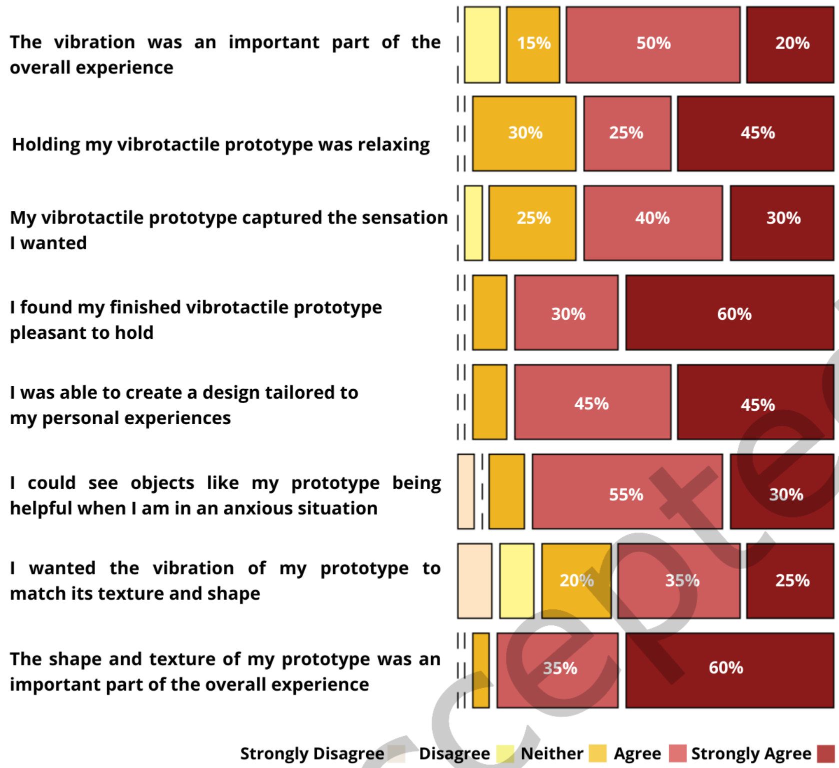


Fig. 10. Post-prototyping survey results indicating participant sentiment around various aspects of their comfort object.

this practical flexibility, highlighting the potential for vibrotactile stimuli to effectively augment a variety of holdable and wearable devices usable in public or social settings. This flexibility makes them well suited to a personalisation approach, which the range of emotionally resonant haptic preferences found by this and prior studies [70, 72] already supports.

4.3.2 Personalisation and the Haptic Preferences of Socially Anxious Users. The range of form factors and textures utilised in the creation of comfort objects, and the breadth of preference for emotionally resonant vibrations demonstrated how the personalisation approach allowed a group of individuals to tailor their comfort objects to their own needs and wants. 90% of participants felt they could create a design tailored to their personal experiences and the positive feedback about these objects further supports this approach.

Every vibration was chosen as a participant's favourite, or joint-favourite, at least twice, with the most popular being *Cat Purring*, which allowed many participants to evoke calming animal touch. Half of the participants discussed the relaxing qualities of animal touch during the initial interviews, suggesting the potential for emotionally resonant vibrations to enable desirable affective touch experiences in situations where they would otherwise be inaccessible (e.g., one cannot take their pet into a job interview). While *Cat Purring* was the single most preferred vibration, selected 10 times, the other cues were selected 37 times in total and motivation for these choices was grounded in emotional resonance or in preferences for either consistent or sporadic vibration. The breadth of preferences, and the individualistic reasons for these preferences, reinforced the benefit of providing a wide set of emotionally resonant vibrations to choose from, affording each user a better chance of finding a suitable cue for their desired tactile experience.

While emotionally resonant vibrations were important to participants, form factor and texture were even more so. The lack of prototypes which incorporated the phone case as a base was surprising and it was also never mentioned by participants during post-design discussion. Participants focusing on their phone during anxious situations was a theme in prior work [72] and during interviews, but it appears that, when given the opportunity to design an object with the express purpose of being pleasant to hold, this form factor was not preferable. In real-world use, the discretion provided by integrating calming vibrations into a phone case may provide a convenient delivery method, but participants in this study strongly valued the opportunity to choose the form factor of their comfort object, with objects often built specifically to fill (round objects) or fit (finger-grooved objects) the hand. In a similar manner to the 'Anxious Creature' robot prototypes developed by Isbister et al. [56], these more varied form factors and textures afforded participants self-soothing affective tactile interactions - such as P6, who used their object to practise nurturing touch behaviour - providing a more holistic calming experience than affective vibrations housed in a smartphone could deliver.

As expected from prior work [55, 72], soft textures were the most commonly used and were associated with past animal touch experiences, reinforcing that socially anxious users desire more access to this affective touch experience. Smooth textures were also prominent, echoing findings by Etzi et al. [32]. While soft and smooth textures were commonly used, every texture was utilised at least twice, and 10 of the prototypes were built with two or more contrasting textures. This again highlights the breadth of participant preferences and that providing a choice between many textures allowed each individual to fulfil their own desired experience.

Study 1 suggested that emotionally resonant vibrotactile comfort objects could serve as a calming intervention for socially anxious users and highlighted the willingness of users to adopt it. It was unclear, however, what potential impact this intervention may have during actual social exposure. Therefore, we followed up with Study 2, an initial between-groups evaluation of emotionally resonant vibrotactile comfort objects as a calming intervention for socially anxious users during a social exposure task.

5 STUDY 2

To explore how the proposed calming intervention would perform during social exposure, we conducted a between-groups study with socially anxious participants. Participants in a treatment group personalised a haptic comfort object before undergoing a three-minute social exposure task, during which they presented a topic of their choice to a researcher via a video call while holding their object. State anxiety (the emotional anxiety response actively being experienced [31]) between rest and the task was measured physiologically and psychologically. State anxiety of the treatment group was then compared to a control group, who undertook the exposure task with no haptic intervention. The results could indicate whether the intervention developed could result in lower state anxiety measures, suggesting a reduction in social anxiety symptoms and making social exposure more comfortable and easier to adhere to.

5.1 Methodology

This between-subjects study observed the state anxiety of two groups of socially anxious participants before, during, and after a social exposure task, using physiological and psychological measures. Participants in the *treatment* group personalised an emotionally resonant vibrotactile comfort object by choosing one of three objects, which were varied by shape and texture, then chose an emotionally resonant vibration from the set used in Study 1 to their object. They then held their object while giving an unprepared three-minute presentation on a topic of their choice to another researcher via video call. Participants in the *control* group undertook this presentation task without customising or using the haptic comfort object intervention. Anxiety measures and feedback were compared between both groups. It was expected that, by adopting a personalisation approach, each participant would find at least one combination of comfort object and emotionally resonant vibration that they found pleasant and calming to hold.

Three dependent variables were measured to indicate state anxiety response: heart rate, skin conductance and the state version of the State-Trait Anxiety Inventory (STAI) (see Section 5.2.2 for discussion on applied and analysis). The social exposure Behavioural Assessment Task (BAT) used to assess the intervention's impact on social anxiety was a three-minute impromptu presentation given by the participant on a topic of their choice to another researcher via video call. This format of BAT has been used many times in prior work to provoke a social anxiety response from participants [16, 52, 64, 66, 104]. Asking participants to choose their own topic, rather than providing one is an established method and alleviates the risk of providing topics a participant may not understand or be familiar with[16, 52, 104]. Initially, this was planned with an in-person audience, as is standard BAT procedure. Due to the restrictions of the COVID-19 pandemic that were present when this study was conducted, however, this task was adapted to utilise a video call between the participant and a second researcher. Under university policy at the time, gatherings of three or more people were not feasible and scheduling became challenging. The single allowable in-person researcher was already required to administer the physiological measures, operate the apparatus and conduct the study, hence the audience researcher had to join remotely. While there is evidence that the face-to-face social exposure of video calls still causes social anxiety [79, 93, 138], this approach was unconventional and so its efficacy was also assessed via observation of anxiety measures in the control group and participant feedback, to contextualise the results (see Section 5.5.1).

Hypotheses. This study had four hypotheses:

- **H1:** Participants in the control group would experience a significant increase in state anxiety between resting measures and exposure task measures, and would report that the task made them feel socially anxious;
- **H2:** Every comfort object combination option would be utilised by at least one participant;
- **H3:** Participants in the treatment group would exhibit significantly lower state anxiety gain over their resting measures when compared to those in the control group;
- **H4:** Participant post-session survey feedback would indicate that they felt the emotionally resonant comfort objects were calming to hold, and could be helpful during social exposure, as in Study 1.

Hypothesis 1 predicted that the BAT video call would still prompt a significant increase in social anxiety measures. If this did not bear out the video call task would not be a suitable method for this study, requiring an alternative. Hypothesis 2 was founded on the observed breadth of stimuli and form factor preferences exhibited in prior studies. If H2 was supported and all, or the majority, of options were utilised, it would motivate future work to provide users with these customisation options, to allow them to produce comfort objects better suited to their individual preferences and emotional associations. Hypothesis 3 formalised the expectation that holding a personalised emotionally resonant comfort object would have a significant effect on anxiety symptoms, grounded in feedback from Study 1. Finally, in Study 1 participants rated their haptic prototypes as pleasant to hold and potentially useful during social exposure and Hypothesis 4 predicted this would remain true in Study 2.

5.2 Apparatus, Physiological and Psychological Measures

5.2.1 Synthesised Comfort Object Prototypes. For Study 2, we constructed three synthesised comfort objects from similar building materials to those used in prototyping (see Figure 11) which encompassed the most prevalent haptic preferences we identified in Study 1. Producing these prototypes allowed each object to be (1) durable for continued use throughout the study when compared to the impromptu prototypes built in Study 1, and (2) built with a solid core and a fitted groove, allowing a flush fit of the Haptuator to best convey vibration through each object (see Figure 12), rather than be fitted to the object in an *ad hoc* manner, as in Study 1.

(a) The Haptic Ball, a fluffy, spherical and squeezable object.

(b) The Haptic Cube, a solid and square object with contrasting textures.

(c) The Haptic Grip, a malleable grip-shaped object.

Fig. 11. Three synthesised comfort objects offered to participants in Study 2, built to encompass the most prevalent haptic preferences observed during Study 1 prototyping.

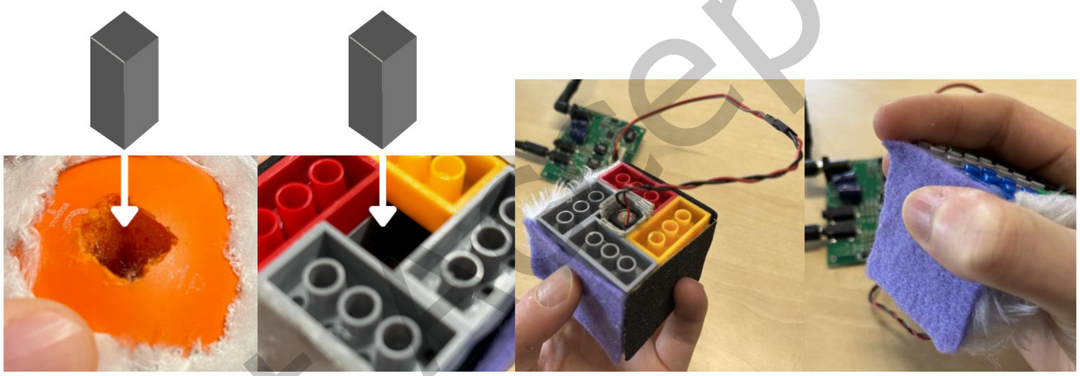


Fig. 12. Building synthesised prototypes in Study 5 allowed objects to be designed with a fitted slot for the Haptuator V2.

(1) The *Haptic Ball* was a stress ball 6.5cm in diameter with a soft furry outer texture. This object served the most prevalent user preferences found in Study 1 for texture (*Soft*) and form factor (*Round*), which was also the most common single combination of texture and form factor during Study 1 prototyping. This object allowed participants to perform squeezing interactions and experience a soft texture filling the hand while experiencing vibrations.

(2) The *Haptic Cube* was a rigid cube with sides 4.3cm in length. With six distinct faces, it provided an opportunity to serve preferences for *Multi-textured* comfort objects, housing different textures on each surface for varied haptic experiences, similar to prototypes built in Study 1 by P12, P15 and P19. The five textures were soft fluffy fur, soft thin felt, smooth thin foam, rough sandpaper and a 6x6 array of Lego studs, encompassing preferences found for *Felt*, *Fur*, *Sandpaper*, *Smooth* and *Lego* textures and the *Square* form factor. The sixth side contained a fitted slot for the Haptuator. This object allowed participants to hold their preferred sides and swap between them for a haptic contrast.

(3) The *Haptic Grip* was a 9cm long Play Dough cylinder built around a rigid cardboard core with cling film wrapped around the exterior. It was designed for participants to wrap their fingers around the length and squeeze, forming a malleable finger grip. Five participants built finger-grip comfort objects during Study 1 and the *Haptic Grip* embodied both this trend and the prominent preferences for a *Malleable* and *Smooth* object. The cling film wrapped around the Play Dough allowed the object to better retain its shape through repeated exploration.

5.2.2 Physiological Apparatus and Measurement. Heart rate (HR) is a prominent indicator of stress and anxiety in prior work [11, 30, 68, 80, 98, 145], and in prior affective HCI research on emotion regulation interventions [8, 22, 34, 49, 97]. A Polar OH1 Optical Heart Rate Sensor[4] was used to record HR readings every second via Bluetooth. Prior work has also found skin conductance response (SCR) (also known as electrodermal activity (EDA) or galvanic skin response (GSR)) has a positive correlation with anxiety [68] and it has been used as a physiological indicator of anxiety and emotional response in prior studies [34, 39, 95, 129]. A BITalino PsychoBIT device[5] and its accompanying OpenSignals (r)evolution software[6] were used to monitor SCR data via two electrodes, with a sample rate of 1000Hz.

While electrodes used to measure SCR are often placed on the hand or the fingers [22, 81, 95], due to their accessibility and sensitivity [134], placement on the hand in this study would have interfered with participants holding their comfort objects in a natural manner. Furthermore, placing them in other sensitive but visible locations, such as the forehead and neck, or in a location which requires partial undress, such as on the foot, abdomen or shoulder, could make users feel more self-conscious during social exposure. The wrist was instead chosen as the least obtrusive viable location, as a study by van Dooren et al. [134] found the wrist to be comparable in sensitivity when measuring the total phasic skin conductance per minute (used in this experiment) with other sensitive areas.

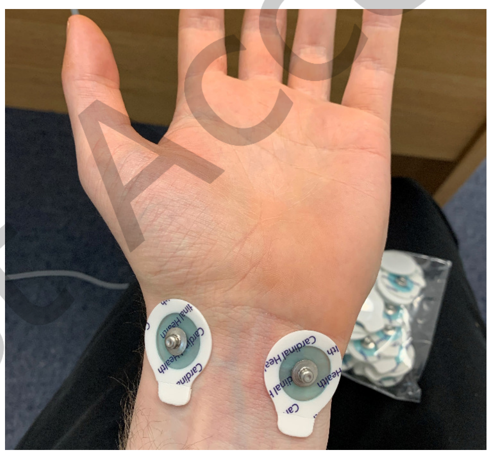


Fig. 13. Figure showing the placement of PsychoBIT electrodes on a participant's wrist to measure SCR without interrupting comfort object interaction.

SCR signal can be broken into continuous tonic and phasic activities using Continuous Decomposition Analysis (CDA) [12, 17, 81]. Tonic activity represents long-term baseline SCR, while the phasic component responds in the short term to emotional activity and thus is most important for affective response research [39, 81]. This

[4]Polar OH1+ https://www.polar.com/uk-en/sensors/oh1-optical-heart-rate-sensor - Accessed 02/24
[5]BITalino PsychoBIT https://www.pluxbiosignals.com/collections/bitalino/products/psychobit - Accessed 02/24
[6]OpenSignals (r)evolution https://support.pluxbiosignals.com/knowledge-base/introducing-opensignals-revolution/ - Accessed 02/24

experiment compared the overall level of emotional arousal between a five-minute resting period and the three-minute social exposure task. CDA was conducted using the MATLAB toolbox Ledalab[7] [12, 13], software used prominently in prior work performing skin conductance analysis [39, 67, 81, 94]. The raw signal data captured by the OpenSignals software was converted into the required unit of electrodermal activity, microSiemens (μS), for Ledalab analysis using the formula provided in the OpenSignals documentation [8] (see Appendix 8.3). Ledalab produced the output measure 'CDA.AmpSum', the sum of amplitudes of the phasic activity peaks above tonic activity during each measurement period. As the resting measures period and social exposure tasks were different lengths, this was then divided by the number of minutes of observation to produce the skin conductance measure used in this experiment, CDA.AmpSum/Min.

5.2.3 Psychological State Anxiety Measurement. To further observe short-term anxiety changes in response to the social exposure task, we employed the Spielberger State-Trait Anxiety Inventory - State version (STAI-S) [125] as a psychological anxiety measure. The STAI-S measures a participant's current level of anxiety at the time of undertaking and has been used in many prior works to assess the impact of experimental conditions or treatments [30, 34, 47, 49, 64, 98, 131]. The STAI-S is a twenty-item inventory which asks participants to rate their agreement with statements (e.g. 'I feel at ease') on a four-point scale from 1 (Not At All) to 4 (Very Much So). The resting state anxiety score of working adults and college students averages between 35.2 and 38.8, as stated by the operating manual.

5.3 Participants

Twenty-nine participants were recruited using university, email and social media channels. Participant recruitment criteria were the same as in Study 1; participants were recruited if they were at least 18 years old, had full haptic perception in their hands and scored 34 or above on the Social Interaction Anxiety Scale (SIAS) [75]. One participant was excluded from the results due to a low SIAS score indicating they were likely not to be socially anxious, leaving 28 participants (8 male, 17 female, 3 non-binary), 14 randomly assigned to the treatment group and 14 to the control group. Mean participant age was 26.7 (σ = 8.26, Range = 19-49). Recruitment conditions during the COVID-19 pandemic resulted in a comparatively small sample size for a between-groups study, rendering this study somewhat more exploratory in nature, but provided an opportunity to observe both any strong impact made on anxiety measures and participants' impressions and experiences with the emotionally resonant haptic comfort objects.

5.4 Procedure

The study was approved by the University ethics committee. Participants read an information sheet before signing a consent form in order to proceed. Once they had consented to take part, participants were given the SIAS to assess their long-term social anxiety, which could be used to exclude their data from the analysis if they were not likely to be socially anxious. Participants were then fitted with the HR monitor and electrodes to monitor SCR. The experiment took place inside a lab room with only the participant and researcher present, both wearing PPE as a COVID-19 precaution. On the table in front of the participant were a computer monitor, a webcam, a pair of headphones and a box containing three haptic comfort objects and the Haptuator and accompanying electronics. The experiment took approximately 40 minutes to complete and participants were paid with a £10 Amazon voucher.

5.4.1 Resting Measures. The Polar OH1, which measured HR, was placed on the participant's right wrist and the PsychoBIT electrodes, which measured SCR, on their left wrist. A five-minute resting measure was taken

[7] Ledalab. http://www.ledalab.de/ - Accessed 02/24
[8] Bitalino EDA User Manual. https://www.bitalino.com/storage/uploads/media/electrodermal-activity-eda-user-manual.pdf - Accessed 02/24

for both HR and SCR, during which participants sat quietly with no external stimuli beyond their immediate surroundings, followed by completion of the STAI. These measures were later compared to those taken during, and after, the social exposure task. After this point, the procedure varied between participants in the treatment and control groups (see Figure 14).

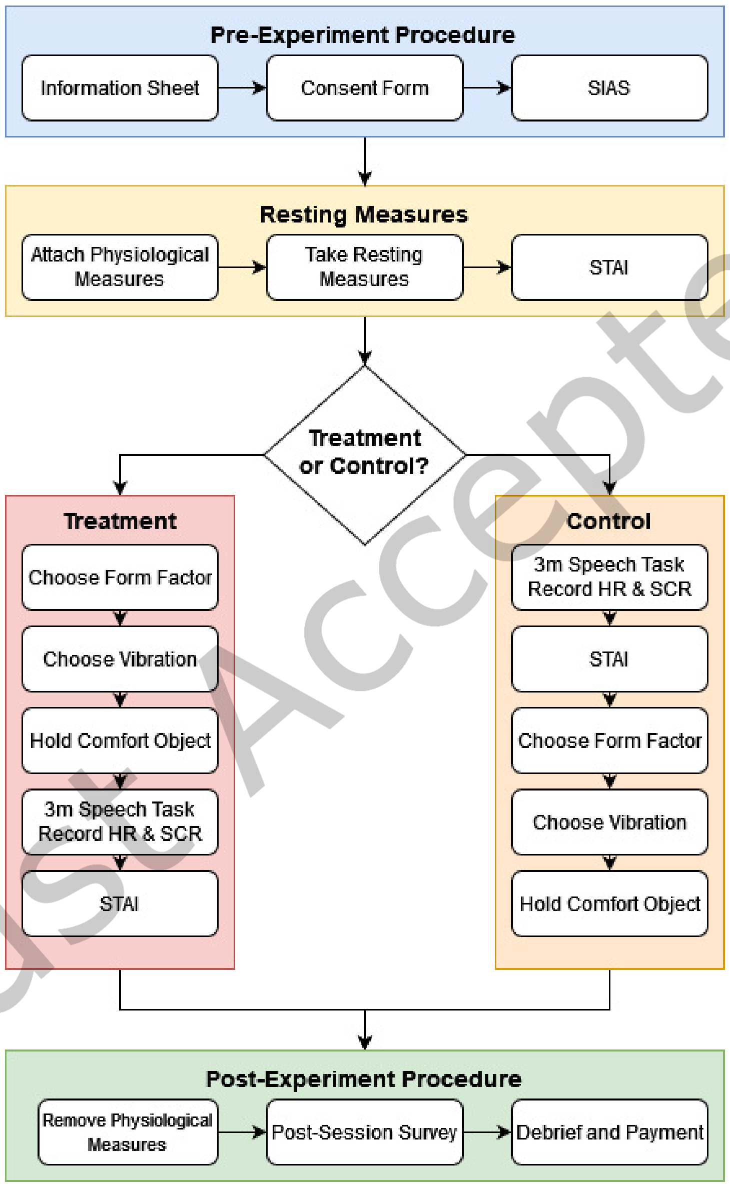


Fig. 14. Figure showing the procedure for Study 2. Participants underwent the experimental steps in a different order depending on if they were randomly assigned to the treatment or control group.

5.4.2 Comfort Object Personalisation. Participants in the treatment group began by selecting the comfort object and emotionally resonant vibration that they would feel during the social exposure task. The researcher gave them each of the three form factors, the Haptic Cube, Haptic Ball and Haptic Grip, and asked them to explore each one with their hands and choose a favourite. Once they had done so, the researcher fitted the Haptuator inside that object and participants held it while experiencing each of the nine emotionally resonant stimuli utilised in Study 1: *Cat Purr*, *Heartbeat*, *Crashing Waves*, *Rain*, *Small Stream*, *Car Engine*, *Slow Breathing*, *Brushing* and *Underwater Bubbles*. As in Study 1, stimuli were presented via a 2018 13-inch i5 MacBook Pro with the volume level set to 6 and participants were advised that they could request *ad hoc* intensity adjustment, but none did. Once the participant had experienced all the vibrations, the researchers asked them to verbally indicate a single stimulus they would like to augment the object. This resultant combination of preferred form factor and vibration made up each participant's personalised comfort object.

Prior work found that haptic adaptation, and thus sensation deadening, can begin between 10 and 20 seconds of continuous exposure to these emotionally resonant vibrotactile stimuli [70]. Given this, continuous exposure to the vibrotactile cues during the 3-minute BAT could result in loss of sensation, preventing participants from experiencing their comfort object fully. To counteract this, emotionally resonant vibrations were displayed at 100% intensity (89dB at laptop volume level 6) for 10 seconds at a time before their intensity was reduced to 0% over an interval of one second. After 10 seconds without vibration, the intensity would then ramp up to 100% over one second and play at 100% for 10 seconds again. This loop would continue until the researcher stopped the device.

5.4.3 Social Exposure Task. The researcher then explained the upcoming social exposure task described in the information sheet to the participant, then readied the video call with another researcher, who would act as the audience member, on a laptop facing away from the participant. Once the call was confirmed as functioning correctly, the participant put on the headphones, the vibrations in their comfort object were turned on, and they were asked to hold their comfort object for the entire duration of the task but could hold it in whatever way they found comfortable.

The monitor facing the participant was then turned on, allowing the participant and audience researcher to see each other and exchange greetings to confirm they could hear each other. Participants were then told that their time to give a three-minute presentation on the topic of their choice was starting and their physiological measurements were initiated. Prior instruction given to the audience researcher specified that they maintain eye contact with the participant and keep a neutral expression. Once three minutes had expired, the researcher signalled to the participant that they could stop, physiological measures were stopped, the monitor was turned off and the participant took off the headphones, removing them from the social exposure scenario. The participant was asked to immediately complete the STAI once more, and then given the opportunity to calm down for a few minutes.

Participants in the control group underwent the same steps as the treatment group, except that the social exposure task was conducted before comfort object customisation and the object was not therefore not held during social exposure. Physiological measures were removed from the participant and a post-session survey was completed which assessed participant experiences with the social exposure task, their chosen comfort object and their sentiment toward future use of emotionally resonant vibrotactile comfort objects in social settings (see Figure 17). Having both groups perform custom object customisation provided more data about form factor and emotionally resonant vibrotactile preferences, and allowed them to comment on their comfort object in the post-session survey.

5.5 Results

During 4 of the total 56 SCR measurements, the electrodes were dislodged from the participant's wrist, resulting in no data capture for those measures. Two of these were baseline measurements, while two were task measurements. As a result, these data points were omitted from the calculation of mean SCR responses and the calculation of proportional SCR gain between baseline and task measurements. To allow two-factor parametric tests to be conducted during the analysis on the Likert scale data or non-normally distributed anxiety measures, the Aligned Ranked Transform procedure was performed [59] where appropriate.

5.5.1 H1 - Control Group State Anxiety Measures. Hypothesis 1 predicted that the exposure task would cause the state anxiety of control group participants to increase, indicating that using a video-call BAT was still effective at provoking an anxiety response. To investigate this, three one-way ANOVAs were conducted to search for significant differences in STAI scores, HR and SCR between resting measurement and exposure task measurement for control group participants. Before each of these tests was conducted, a Shapiro-Wilk Test of Normality. Mean heart rate ($p = 0.808$) and STAI scores ($p = 0.533$) were found to be normally distributed. The mean SCR was not ($p < 0.0001$), hence the Aligned Rank Transform was performed before the ANOVA. A significant difference was found for each measure (see Table 4).

Baseline Vs Task Measurement - Control Group	F	Df	P.Value
STAI	14.23	1	**<0.05**
HR	6.014	1	**<0.05**
AmpSum/m	62.24	1	**<0.001**

Table 4. Table showing the outcome of three ANOVAs investigating if there was a significant difference between baseline and BAT measurements for three anxiety measures for control group participants.

Control group participants scored a mean baseline STAI of 43.4 during resting measures, and 52.7 after completing the 3-minute presentation task (see Table 5). Mean HR increased from 86.2bpm (beats per minute) at baseline to 93.0bpm during the social exposure task, while mean total phasic skin conductance activity per minute increased from 4.08μS at baseline to 23.2μS during exposure. This result was corroborated by participant responses in the post-session survey. When asked to rate the statement "I found the social task caused me significant social anxiety" on a five-point scale from 1 (Strongly Disagree) to 5 (Strongly Agree), 64% of control group participants agreed or strongly agreed, 21% neither agreed nor disagreed and 15% disagreed or strongly disagreed. These results indicate that the 3-minute speech BAT was successful at prompting an anxiety response from participants, even when conducted via a video call with a single audience member. As an aside, this adapted method allowed the study to function under COVID-19 conditions and could allow for future researchers who are unable to provide in-person audiences to utilise BATs in future. Future work to compare in-person and online BAT speech tasks would be valuable to inform their use.

Group	Base STAI	Task STAI	Base HR (bpm)	Task HR (bpm)	Base AmpSum/m (μS)	Task AmpSum/m (μS)
Control	43.43	52.71	86.23	92.98	4.082	23.23
Treatment	44.13	48.67	83.86	86.81	4.521	34.46

Table 5. Table showing the mean psychological and physiological anxiety measures for participants in the control and treatment groups both during a baseline resting measurement and social exposure task measurement.

5.5.2 H2 - Comfort Object Personalisation Preferences. Hypothesis 2 predicted that each object and emotionally resonant vibration would be used by at least one participant, which bore out (see Table 6). There was a spread in stimulus preference, as half the participants chose the two most popular stimuli (*Car Engine*: 8, *Cat Purring*: 6), while five of the nine stimulus options were chosen by only one or two participant(s). Participant feedback supported that providing this set of nine stimuli to choose from was an effective strategy, as, when asked to rate the statement "I was able to choose a vibration which I connected with and found pleasant" on a five-point scale from 1 (Strongly Disagree) to 5 (Strongly Agree), 57% of people strongly agreed, 39% agreed and one person strongly disagreed. Of the three three comfort object form factors available, the *Haptic Cube* was chosen the least, by 5 participants, while the *Haptic Grip* was chosen 13 times and the *Haptic Ball* 10 times. When asked to rate the statement "*The comfort object I chose was suited to my preferences*", 28% of people strongly agreed, 57% agreed and 14% neither agreed nor disagreed.

Object	n			Stimulus	n		
Grip	13	Car Engine	8	Slow Breathing	3	Raindrops	1
Ball	10	Cat Purring	6	Brushing	2	Heartbeat	1
Cube	5	Small Stream	4	Crashing Waves	2	Underwater Bubbles	1

Table 6. Table showing how often each object form factor and each emotionally resonant vibrotactile stimulus were chosen in total by participants in Study 2 when customising their preferred comfort object.

5.5.3 H3 - Treatment Group versus Control Group State Anxiety. Hypothesis 3 predicted that treatment group participants would experience a significantly smaller increase in anxiety measures between the resting measurement and social exposure task measurement when compared to participants in the treatment group, indicating that the personalised comfort objects had a calming effect. To investigate this, three two-way ANOVAs were conducted to investigate whether there was a significant difference in the three anxiety measures, STAI, HR and SCR, between both resting and speech task measurements and between control and treatment groups, blocked by participant [8]. Again, Shapiro-Wilk Tests of Normality were conducted for each measure and mean heart rate ($p = 0.217$) and STAI scores ($p = 0.247$) were normally distributed, while mean SCR was not ($p < 0.0001$), leading to an Aligned Rank Transform. A significant difference was found for all three anxiety measures between baseline and BAT measurement, but no significant difference was found between control and treatment groups, and there were no interaction effects (see Table 7 and Figure 15).

Having previously observed a significant difference within the control group between baseline and task anxiety measurement for all three anxiety measures, three further ANOVAs were used to establish if this held true for the treatment group. Again Shapiro-Wilk tests revealed a normal distribution for mean HR ($p = 0.567$) and STAI scores ($p = 0.307$) and not for SCR ($p < 0.0001$). There was still a significant difference between baseline and task SCR measurement, but unlike the control group, there was no significant difference between baseline and task measurements of STAI and HR (see Table 8), which may indicate that the addition of the haptic comfort objects confounded these established anxiety measures. A side-by-side visual inspection of STAI scores following the BAT between the control and treatment groups showed more than a threefold difference in distribution. The interquartile range of speech task STAI scores for control group participants was 8.25 ($\sigma = 10.4$), while the interquartile range of treatment group participants of 28.0 ($\sigma = 15.6$) (see Figure 16). A chi-squared test was conducted and found a significant difference in the interquartile distribution of treatment participants' STAI scores across the full range of responses when compared to the distribution of control group participants' scores ($\chi^2 = 18.63$, $df = 3$, $p < 0.05$).

ANOVA - Effects on Mean Heart Rate (bpm)	F	Df	P.Value
Measurement Time: Baseline or Task	8.541	1	**<0.05**
Condition: Control or Treat	0.517	1	0.478
Interaction between Measurement Time and Condition	1.830	1	0.188
ANOVA - Effects on SCR (AmpSum/m)	**F**	**Df**	**P.Value**
Measurement Time: Baseline or Task	42.59	1	**<0.001**
Condition: Control or Treat	0.498	1	0.487
Interaction between Measurement Time and Condition	0.940	1	0.342
ANOVA - Effects on State Anxiety Score (STAI)	**F**	**Df**	**P.Value**
Measurement Time: Baseline or Task	8.586	1	**<0.05**
Condition: Control or Treat	0.058	1	0.811
Interaction between Measurement Time and Condition	1.888	1	0.181

Table 7. Table showing the outcome of three ANOVAs investigating variance between baseline and task measurement and the control group and treatment group for each anxiety measure, blocked by participant.

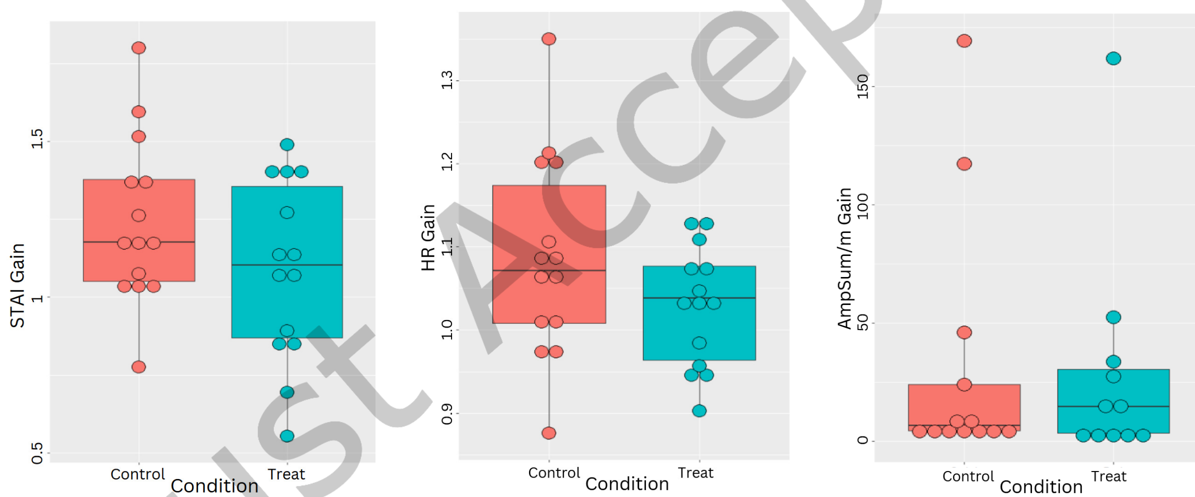


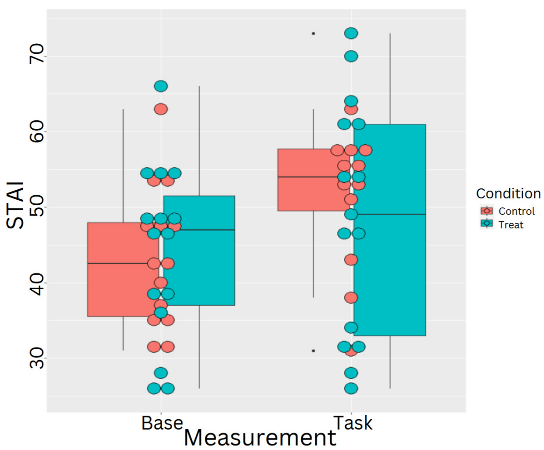
Fig. 15. Three graphs showing the box plots comparing the distribution of the proportional increases in STAI, HR and SCR anxiety measures for participants in control and treatment groups.

This result could raise the possibility that haptic comfort objects may (depending on the individual) have a varied impact on participants' feelings of anxiety as indicated by STAI scores, both beneficial and detrimental. Despite the affordance of customisation objects which participants used to produce objects they felt were tailored to their experiences (see 17), this did not result in a consistent reduction effect and Hypothesis 3 was rejected.

5.5.4 H4 - Participant Comfort Object Sentiment. The final hypothesis stated that participants would consider the haptic comfort objects as calming to hold and useful during social exposure, an expectation grounded in similar feedback garnered during Study 1. This expectation was investigated with the post-session survey which

Baseline Vs Task Measurement - Treatment Group	F	Df	P.Value
STAI	0.619	1	0.445
HR	2.019	1	0.179
AmpSum/m	22.58	1	**<0.001**

Table 8. Table showing the outcome of three ANOVAs investigating if there was a significant difference between baseline and BAT measurements for three anxiety measures for treatment group participants. P values which indicated significant main effects are marked in bold.



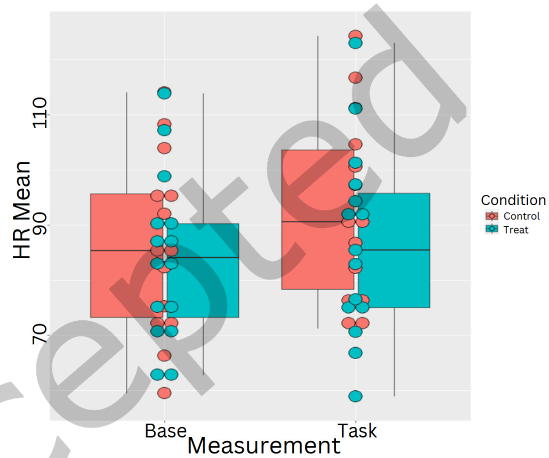


Fig. 16. Two graphs which compare the control group and treatment group distribution of average STAI and HR at both base and speech task measurements.

contained three relevant Likert-scale questions and two open-ended text fields where participants could provide reasoning for their responses (see Figure 17). Feedback indicated that the majority of participants viewed their comfort objects and the emotionally resonant vibrations as calming and effective, as well as potentially helpful in anxious situations. When asked to rate the statement "The comfort object I chose made me feel comforted or calm when held" on a scale of 1 to 5, where 1 meant Strongly Disagree and 5 meant Strongly Agree, 78% agreed or strongly agreed and 14% were neutral. When asked if the "vibrations made the comfort object more effective" 68% agreed or strongly agreed and 21% were neutral.

Finally, when asked to rate the statement "I could see objects like my chosen comfort object being helpful when I am in an anxious situation" 43% strongly agreed, 36% agreed and 18% were neutral. As only half the participants who gave feedback (those from the treatment group) had experience using their comfort object during the social exposure task, a pair of ANOVAs were used to investigate if the group a participant was assigned to impacted how anxious they reported feeling in the post-session survey, or how useful they thought their comfort object was. The ANOVAs searched for a main effect of the participant group on two statements: (1)"I found the social task caused me significant social anxiety" and (2) "I could see objects like my chosen comfort object being helpful when I am in an anxious situation". No significant difference between groups was found ((1) $F = 0.1814$, $Df = 1$, $p = 0.067$; (2) $F = 0.1904$, $Df = 1$, $p = 0.662$).

Participants were asked to explain whether or not they felt their comfort object would be useful in future social exposure in an open-ended qualitative survey question. The responses to these questions across both groups

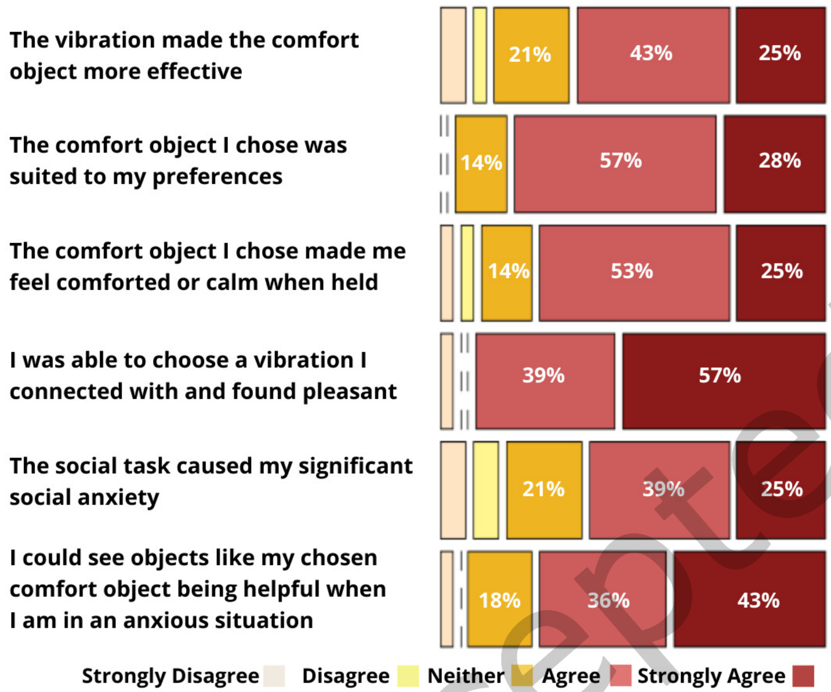


Fig. 17. Study 2 post-session survey results indicating participant sentiment on how calming and helpful they felt their comfort object was.

were assigned themes to identify pertinent trends. Fifteen responses noted that the haptic comfort objects could enable *attentional redeployment*, distracting them from their physiological or psychological anxiety symptoms.

> P13: "The object was a good distraction, in the sense that my senses were distracted, which is typically helpful for anxiety."

> P21: "It's helpful to have something to hold and distract you from just the anxiety right in front of you. Especially when it is something so mindless, like squeezing the dough, yet it helps ground you and bring you away from the anxiety. The vibrations were a nice gentle reminder to relax, breathe and present."

Eighteen participants specifically mentioned the emotionally resonant vibrations, with 11 people noting they were *pleasant* or *calming*. Five of them specifically noted that their emotional response was tied to emotional resonance and six wrote that the vibrations allowed them to feel more grounded or focused.

> P9: "It reminded me of holding a small animal (fluffy ball with cat purring), which has always helped me reduce anxiety."

> P8: "I chose the stress ball with the fur. It would have been helpful in a stressful situation as I can squeeze it, 'pet' it and pass it from one hand to another. The vibrations were also helpful - especially the slow heartbeat - because it could make me concentrate and focus, also remind me how to breathe."

Three participants noted that, during the BAT, they did not notice the vibrations as they were "too nervous" or "couldn't pay attention", highlighting that some users may not split attention between social interaction and an external haptic stimulus, or its potentially calming effects.

Eleven comments were about comfort object *form factor*, i.e. shape and texture, highlighting how the specific touch interactions afforded by different objects could be important. Nine participants mentioned squeezing or kneading interactions; for example:

> P1: "I was able to focus on kneading the play-dough if I was feeling overwhelmed"
>
> P18: "when I am anxious, I just want to squeeze something tightly or break something to release tension. The gripping object is something that can be grabbed/squeezed without consequences (I often don't have an object to squeeze and end up squeezing myself which sometimes makes my anxiety worse)."

The prevalence of these interactions may explain why the Haptic Cube was the least popular form factor, as it was the only fully rigid object. The practicality of the objects in real conversations was of concern to three participants who were worried about drawing attention to themselves or having their normal behaviour obstructed.

> P4: [I would be] "worried now others would perceive me using it in social situations"
>
> P5: "I use my hands when I talk so, while comfortable, it would hinder how I express myself."

Comfort objects which are smaller or wearable (for those who do not desire to directly interact with the object) could be more discrete and less obstructive, addressing these issues in real-world use cases.

6 LIMITATIONS

These studies collected both closed and open-ended self-reported measures to explore the experiences of the socially anxious participants and their impressions of their emotionally resonant vibrotactile comfort objects. This approach provided vital context to the quantitative data collected but has some limitations. As always, self-reported data may be subject to incorrect self-assessment and biases, such as desirability bias or demand characteristics, whereby respondents may answer questions in a way they feel is socially desirable, agreeable, or in line with perceived research goals, potentially biasing them toward positive assessments [18]. This is especially pertinent for socially anxious participants, who may further seek to avoid any social conflict or negative evaluation that they feel could occur when they give negative feedback. Our work found promising feedback from participants and an interesting distribution of psychological measures, but no change in psychological measures, a pattern of results observed in prior work with socially anxious participants [65]). The impact of these biases is not easily quantifiable but may contribute to this disparity. While the results of these studies must be understood in this context, they are interesting insights to be gleaned from participants' experiences with these calming haptic objects, particularly when they chose between equally-presented haptic elements, tactile interactions or emotionally resonant vibrations, where a perceived 'correct' option is less clear.

Another limitation was the relatively small sample size of Study 2. While similar studies have utilised short anxiety/stress-inducing tasks to assess emotion regulation interventions, prior studies with a between-groups structure have featured larger samples [8] or fewer participants in a within-groups structure [22, 147]. We assessed our intervention within the target context of a face-to-face social exposure task, which is typically not conducted within-groups. Thus, a between-groups structure was chosen, which posed a problem when recruiting specifically socially anxious participants during the second year of the COVID-19 pandemic. Given this, we describe this evaluation as less definitive and more exploratory, as well as an excellent opportunity to engage with socially anxious participants regarding their experiences with, and their haptic preferences for, calming vibrotactile comfort objects.

Finally, our participant pool was also limited by age distribution. Study 2 featured a wider age range, from 19 to 49, but the majority of participants skewed below 37. In Study 1 there was an even narrower range, from 20 to 32 years old, and most participants were in their 20s. There was also a skew in gender distribution, as in total across both studies 56% of participants self-described as female, while only 29% as male and 15% as non-binary, although this limitation is somewhat offset by similar levels of social phobia found across genders in prior work [75].

7 DISCUSSION AND DESIGN RECOMMENDATIONS

7.1 Evaluation of Haptic Comfort Objects as a Calming Intervention for Social Anxiety

To accommodate the breadth of haptic preferences observed in prior work [55, 70, 72] and Study 1, we explored an intervention that was personalised by each participant to suit their preferences, in an effort to normalise efficacy. This did not, however, result in a consistent effect across users and this evaluation found no evidence that emotionally resonant vibrotactile comfort objects have an impact on the physiological symptoms of anxiety. Further investigation with a larger participant pool would be needed before considering this intervention to manage these symptoms.

The only notable difference between groups was the statistically wider distribution of STAI scores for treatment group participants compared to the control group. Considering this alongside positive participant feedback could indicate that the vibrotactile comfort objects caused some participants to exhibit less psychological anxiety symptoms and view themselves as less anxious. Participant feedback regarding their personalised objects was positive, as the majority rated their comfort objects as calming and pleasant to hold in both studies and commonly described feeling more "focused", "calm" or "grounded" while holding their object. This disparity between anxiety measures and participant feedback is not unexpected, however, as it may be explained by the potential influence of positive biases and limitations of subject pool size [65] (see Section 6). To further investigate this, future work could aim to expand the subject pool and explore if individuals who perceive affective haptic comfort objects as calming and effective are more confident and willing to adhere to future social exposure events. It would also be valuable to observe the use of such an intervention *in situ* over a longer overall timespan, reducing the impact of novelty effects and demand characteristics.

Study 2 did not make a compelling case for the use of emotionally resonant vibrotactile comfort objects as an emotion regulation intervention for social exposure. Our findings can, however, inform the future development of affective haptic experiences, both in regard to the needs of socially anxious users, and other applications which seek to utilise personalised haptic interfaces or affective vibrotactile stimuli to craft calming or pleasant experiences. Given this, we will now discuss a series of design considerations and recommendations for affective haptics designers and researchers.

7.2 Crafting Comfort Objects that Encompass User Preferences

The results of both studies highlighted the benefits of adopting a personalisation approach when delivering calming, evocative and pleasant haptic experiences. Participants were able to choose shapes, textures and vibrations that best reflected their personal preferences and, in some instances, combined these to create meaningful comfort objects that reminded them of prior experiences, such as affective touch with animals. This approach allowed participants to make the object their own and, in both studies, over 85% reported that their comfort object was suited to their preferences and 96% of Study 2 participants were able to choose a vibration they connected with and found pleasant. It could be viewed as surprising that participants in Study 1 mostly chose not to explore the augmentation of the phone case, or to model already commonly held or worn devices as haptic comfort objects. Rather, they used the session as an opportunity to explore form factors and textures that afforded them specific calming tactile interactions, often evoking an emotionally evocative idea or past experience. This aligns with prior social robot research [56] and further emphasises the importance of facilitating a holistic haptic experience, beyond just the delivery of calming stimuli.

While our results show the benefits of personalisation, accommodating the breadth of user haptic preferences presents a feasibility challenge for designers. One way to address this would be to create a set of comfort object variants, as demonstrated in Study 2. While this was an effective solution, it had limitations which could be addressed in future iterations. For example, while in Study 2 comfort objects were built with a set form factor and texture (see Figure 11), texture skins or sleeves could allow these elements to be decoupled and more finely customised to the user's preferences. Another approach could be to supply users with a kit of components [121], which they could then assemble into a modular, higher fidelity comfort object which retains customisability while allowing for more durability and quality control than impromptu prototypes. This approach could provide more agency and control to each user but would increase the complexity of the intervention for both designer and user as each possible combination of components would have to be tested to ensure effective vibrotactile conveyance and a comfortable, secure holding experience. Finally, while this study explored holdable objects, it did not explore how wearables could also be used as a platform for emotionally resonant vibrations and different textures and used discretely during social exposure. Future work exploring this application of pleasant emotionally resonant vibrotactile stimuli would be valuable.

7.3 Considerations when Delivering Haptic Feedback

These two studies established that providing a set of emotionally resonant vibrations allowed users to choose stimuli they found pleasant and suited to their preferences. Beyond the more fixed calming tactile experiences explored in prior work [8, 56, 61], this personalisation approach allowed individuals to seek varied benefits from this active affective haptic component. For some the emotionally resonant stimuli afforded tactile experiences evocative of calming real-world phenomena, often in conjunction with their chosen comfort object. Others used their preferred stimuli as a simple sensory addition that helped them feel grounded, concentrate, or distract from anxiety symptoms. In general, the use of a set of emotionally resonant vibrotactile cues, alongside a set of comfort objects, allowed for personalised tactile experiences beyond prior work and provides a promising avenue for future work to build upon.

Exactly how, and when, vibrotactile stimuli should be actuated during social exposure is, however, not yet defined. For example, some people may prefer to activate and de-activate feedback 'intentively' [35], while others might benefit from feedback triggering automatically in response to elevated anxiety symptoms, or the user arriving at a specific location or scheduled event. If stimuli are to be activated manually and in-the-moment, the ability to do so discretely is vital to avoid assistive device stigma [120]. If stimuli are to be activated in response to anxiety symptoms, it may require integration with wearables like smartwatches that can monitor heart-rate variability.

Additionally, software could enable further personalisation of the stimuli themselves, allowing users to tweak playback speed, intensity and pitch, as we found preferences for certain emotionally resonant cues could be impacted by these factors in Study 1 interviews. It could also be used to allow participants to browse and preview a library of stimuli, or set up playlists of preferred sensations. Recent work by Zhou et al. demonstrates how a series of modular haptic armbands could deliver customisable haptic sensations, including presets with metaphorical meanings ascribed by participants [146], which could inform a similar approach using adjustable vibrotactile stimuli. Finally, it would be valuable to observe the affective properties of emotionally resonant vibrotactile stimuli when they are displayed by common smart devices, such as phones, watches or gamepads, using their pre-installed haptic actuators. While comfort objects installed with emotionally resonant vibrations are specifically designed to be calming and comforting, and thus may achieve the best performance, the flexibility and availability of vibrotactile stimuli could allow these other devices to provide new affective haptic experiences without the user needing to adopt any new hardware.

7.4 The Need for Discretion During Social Exposure

Interviews in Study 1, and post-session feedback in Study 2, highlighted a concern around the unobtrusive use of affective haptic comfort objects during social exposure. Two participants in Study 1 specifically noted that their comfort objects were built to be socially discrete, with P14 noting that they chose not to include a fluffy surface in their object as "I thought I would look weird like stroking something (..) and then I would feel like nervous about the fact that people like I looked weird", and two more participants in Study 2 also echoed concerns about discretion. Given that social anxiety can cause individuals to over-scrutinise potential negative social assessment by others [101], and assistive device use can result in stigma [120], future haptic comfort object implementations must ensure discrete use is possible if the objects are to be used in social settings. While the prototypes built in these studies used craft materials, often available in bright colours, real-world implementations could seek to use muted colours. The prototypes built in this study were also quite large, and smaller objects which could be concealed completely within a closed hand would alleviate this concern. Designers could also explore integrating comfort objects, or more specifically textured surfaces and emotionally resonant vibrations, into pre-existing objects such as wallets, purses, clothes, or smartphones. However, participants prioritised bespoke shapes and textures that facilitated tactile experiences beyond these objects. Meeting both these requirements presents a challenge for designers when aiming to provide support during social exposure, as devices built specifically to afford these tactile experiences are liable to be less discrete in practical use than augmenting existing devices. Future work could explore the discrete customisation of these common objects, for example by applying textured 'skins' or surfaces. Finally, it would also be valuable to explore how effectively emotionally resonant vibrations can convey pleasant or calming feedback from different locations on the user's body, as they could allow them to be experienced in discrete locations, such as inside a pocket, or worn around the wrist.

8 CONCLUSION

This paper presented two studies exploring the use of emotionally resonant vibrotactile comfort objects as a calming intervention for social anxiety during social exposure. The first study conducted participatory prototyping with socially anxious users to assess the potential of the calming intervention, observe haptic preferences for affective vibrotactile comfort objects to house them, and investigate the requirements these users may have when using this intervention in social settings. Participants displayed a wide range of preferences for emotionally resonant vibrations, form factor, and texture, supporting a personalisation to facilitate bespoke calming tactile experiences. Preferences for vibrotactile actuation, texture and form factor were identified and informed the development of three synthesised comfort object prototypes. A second between-groups study was then conducted, during which socially anxious participants chose their preferred comfort object and emotionally resonant vibration, then held their objects during a social exposure task. When compared to a control group, we found using affective haptic comfort objects did not have an impact on physiological anxiety measures, but did result in a significantly wider distribution of psychological anxiety scores. In both studies, comfort object prototypes demonstrated the potential to be emotionally resonant and participants reported that they were able to create comfort objects tailored to their experiences, and found holding them both relaxing and pleasant. Participants also reported feeling that their objects could be useful in future anxious situations. The applicability of emotionally resonant vibrotactile comfort objects as a calming intervention for social anxiety, and the willingness of users to adopt such an intervention, is discussed. Our observations about how participants designed these objects, and their experiences using them, provide foundational design insights for crafting emotionally resonant affective haptic experiences with vibrotactile cues and contribute to a better understanding of how to provide the calming tactile experiences desired by socially anxious users.

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8.1 Emotionally Resonant Stimuli

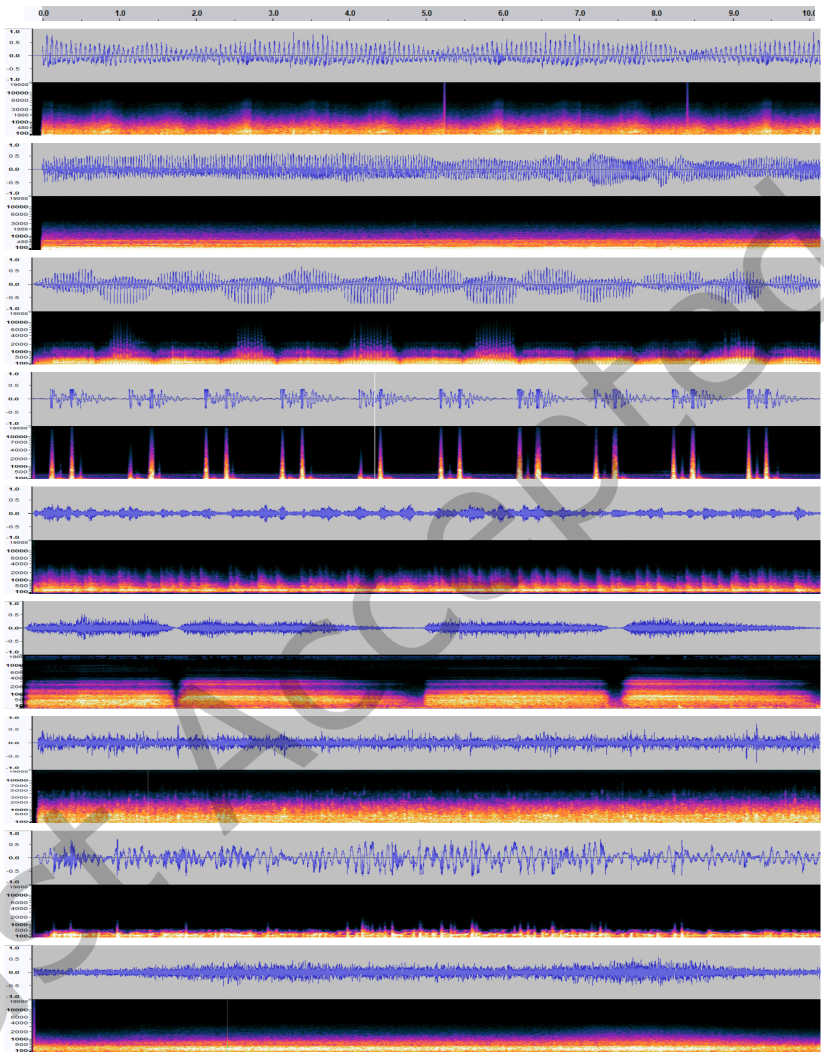
Stimuli	Intensity Waveform and Frequency Spectrogram
Brushing	
Car Engine	
Cat Purring	
Heartbeat	
Raindrops	
Breathing	
Small Stream	
Bubbles	
Waves	

Table 9. Intensity waveform diagrams and frequency (Hz) spectrograms for all stimuli used in the study. All stimuli are 10 seconds in duration, with a max sound intensity normalised to 89dB. Waveform intensity is shown as a proportion of the maximum.

8.2 Qualitative Analysis Thematic Map

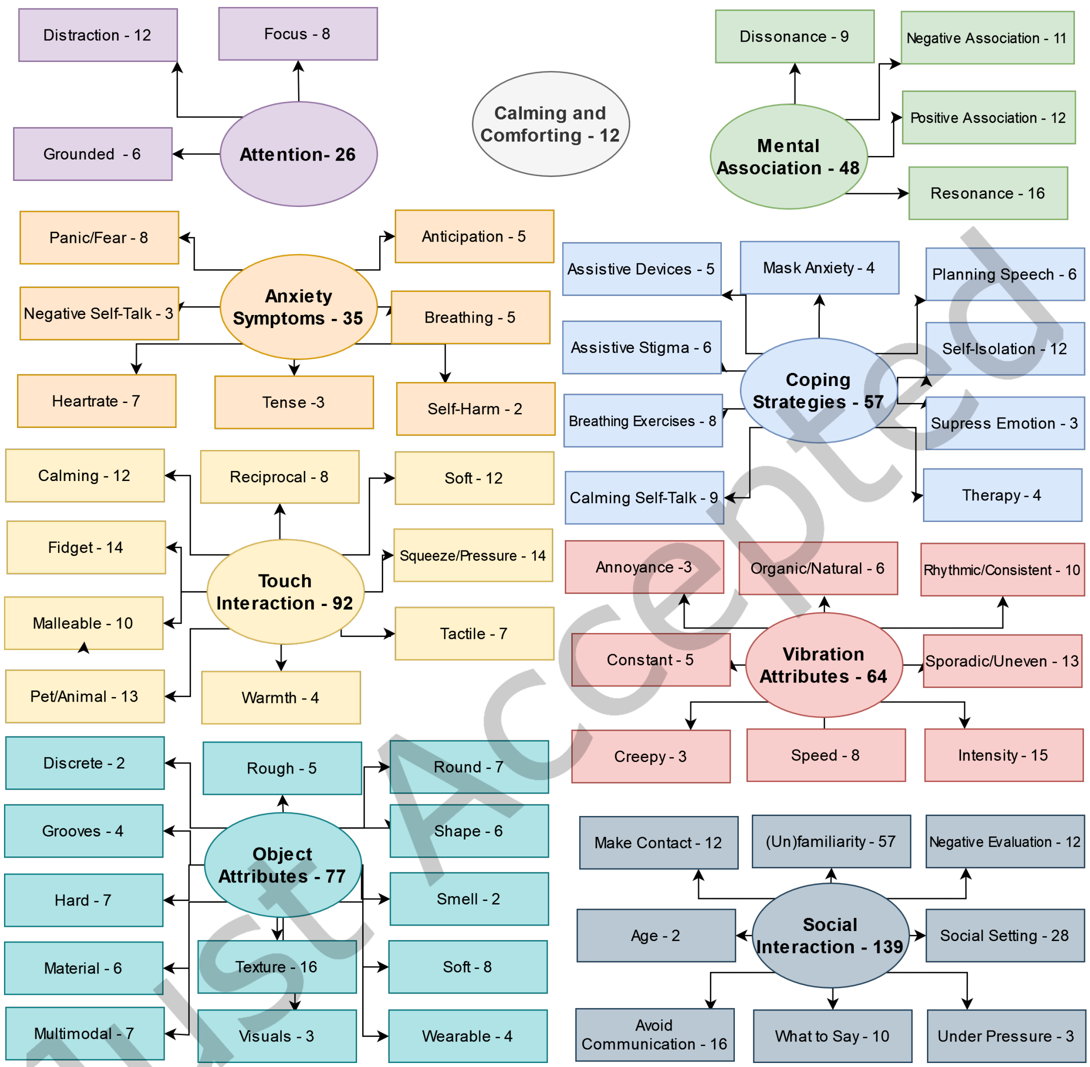


Fig. 18. Thematic map of the qualitative codes and themes created to represent the data from 20 semi-structured interviews with socially anxious participants regarding their experiences with social anxiety and their comfort object prototypes.

8.3 OpenSignals SCR Signal Conversion Formula

$$EDA(\mu S) = \frac{\frac{ADC}{2^n} \times VCC}{0.12}$$

$$EDA(S) = EDA(\mu S) \times 1 \times 10^{-6}$$

Valid sensor range: $[0\mu S, 25\mu S]$

with:	$EDA(\mu S)$	EDA signal in microsiemens (μS)
	$EDA(S)$	EDA signal in siemens (S)
	ADC	Value samples from the sensor/channel (digital value)
	n	Sampling resolution (default: 10-bit resolution (n=10), although 6-bit may also be found)
	VCC	Operating voltage (3.3V when used with BITalino)

Fig. 19. Figure showing the formula required to convert the raw SCR sensor signal measured by the OpenSignals software into an electrodermal activity signal which could be analysed by Ledalab. Extracted from the BITalino Electrodermal Activity Sensor User Manual.