Increasing Heart Rate and Anxiety Level with Vibrotactile and Audio Presentation of Fast Heartbeat

Ruoqi Wang
2518115w@student.gla.ac.uk
University of Glasgow
Glasgow, Scotland, United Kingdom

Haifeng Zhang
2641018Z@student.gla.ac.uk
University of Glasgow
Glasgow, Scotland, United Kingdom

Shaun Alexander Macdonald
shaun.macdonald@glasgow.ac.uk
University of Glasgow
Glasgow, Scotland, United Kingdom

Patrizia Di Campli San Vito
Patrizia.DiCampliSanVito@glasgow.ac.uk
University of Glasgow
Glasgow, Scotland, United Kingdom

ABSTRACT

Heartbeat is not only one of our physical health indicators, but also plays an important role in our emotional changes. Previous investigations have been repeatedly investigated to the soothing effects of low frequency vibrotactile cues which evoke a slow heartbeat in stressful situations. The impact of stimuli which evoke faster heartbeats on users' anxiety or heart rate is, however, poorly understood. We conducted two studies to evaluate the influence of the presentation of a fast heartbeat via vibration and/or sound, both in calm and stressed states. Results showed that the presentation of fast heartbeat stimuli can induce increased anxiety levels and heart rate. We use these results to inform how future designers could carefully present fast heartbeat stimuli in multimedia application to enhance feelings of immersion, effort and engagement.

CCS CONCEPTS

• **Human-centered computing → Haptic devices**.

KEYWORDS

haptic feedback, audio feedback, stress, heart rate

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1 INTRODUCTION

As emotions influence the heart rate and other physiological signals of the body [2], technology has often been used to report bio-signals back to the user to help them be more aware of their physical and emotional state[1, 5, 16]. Additionally, presenting users with stimuli that emulate a slower heartbeat can be used to facilitate emotion regulation, reducing stress and slowing their heart rate during stressful situations [3, 12, 18, 19]. The impact on users' emotional state or heart rate when presenting them with faster heartbeat stimuli in either stressful or calm situations is, however, far less explored and primarily with only subjective measures. There are many applications for inducing elevated emotional states or heart rates in users, such as heightening alertness, feelings of effort[10], elation, tension, scariness [17] or immersion in multimedia or virtual reality experiences. However, more exploration is needed to inform the future careful use of fast heartbeat presentation to influence a user's or physiological and psychological state.

Therefore, we investigated this gap by conducting two studies exploring the influence of heartbeat stimuli delivering via vibrotactile or auditory cues on heart rate and anxiety levels. In both studies, participants undertook a calming condition to capture calm/baseline physiological responses (a video of train ride/landscape) and a stressful condition during which they did a maths test, (Paced Auditory Serial Addition Test / modular arithmetic task). Each condition was tested without and with heartbeat cues. In the first experiment (N=8), vibration was presented in stressful situations on each hand in turn while collecting the heart rate on the other wrist, while in the second experiment (N=12), audio cues were added and vibration was presented on the non-dominant hand using a smartwatch, while heart rate was collected on the dominant wrist in both calm and stressed situations. Results showed that the presentation of a fast heartbeat with vibration and/or audio impacted the heart rate and the anxiety levels in both calm and stressed states. We then discuss the implications of this finding on the future interface designs which may seek to induce elevated heart rates or psychological states.

2 RELATED WORK

Previous research investigating heartbeat presentation to participants largely focused on either reporting (1) the participant's current heart rate to increase their awareness of their emotional or physical state, or (2) presenting a slow heartbeat to calm participants in stressful situations.

Azevedo et al. [3] showed that the presentation of slow heartbeat as vibration on the wrist decreased stress in socially stressful situations and Zhou et al. [19] found that vibrotactile presentation of a slow heartbeat led to changes in heart rate variability, while sound did not show any effect and anxiety ratings were not influenced by either. Macdonald and Pollick [13] found that presenting a slow heartbeat vibration elicited less calming emotional responses,

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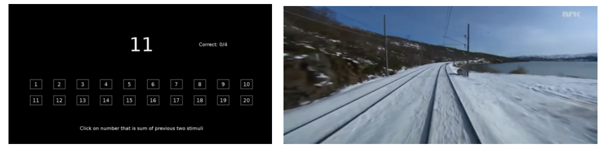
when compared to a set of other naturalistic vibrotactile cues. In contrast to these works, when Iodice et al. [10] presented adapted auditory heartbeat data to elicit a sense of effort during cycling in participants, their results showed higher levels of perceived effort when faster heartbeat was presented, compared to mirroring the actual heartbeat sound, whereas no differences were found when participants were presented with sound of a slower heartbeat. This suggests that, even in situations in which slower heartbeat presentation in one modality could potentially have no effect on emotions and potentially heart rate and anxiety, this might be different for fast heartbeat. This divergence in impact between slow and fast auditory heartbeat stimuli highlights that value of better understanding the effects of fast heartbeat cues and their implications on future interface design, motivating our investigation of both auditory and vibrotactile fast heartbeat cues in our second experiment. citeauthorCosta2016EmotionCheck:Emotions [7] presented a slow heartbeat as vibration on the wrist and investigated its effect on anxiety levels in stressful situations, a simulated job interview. They found that reported anxiety was reduced when the slow heartbeat was presented. Another study evaluated the impact of slow and fast heartbeat during another stressful task, a mathematical test, and investigated the impact on anxiety, heart rate variability and task performance and found that the slow heartbeat decreased stress and increased heart rate variability and task performance, while the fast heartbeat led to the opposite observation [8]. They focused on the potential calming effects and subjective descriptions from participants, however, and did not present differences in heart rate. They further did not investigate potential differences between presentation of vibration on the left or right hand, which we explore in this paper.

Other investigations of fast heartbeat presentation include the work of Ueoka and AlMutawa [17], who presented a false increased heart rate as vibrotactile feedback to increase the scariness of a virtual reality experience. Furthermore, Choi and Ishii [6] presented AmbienBeat: a wrist-worn heart rate regulator providing tactile heartbeat feedback. They presented the actual current heartbeat, a faster heartbeat of 120bpm (beats per minutes) and a slower one of 60bpm and compared the device to ambient audio and visual cues in different situations such as sitting and after jumping. They found that the fast vibrotactile heartbeat presentation led to the fastest increase in heartbeat and the tactile presentation of slow heartbeat decreased heartbeat the fastest compared to the other modalities. We adopted the fast heart rate frequency in our first experiment from this work when we presented the cues during stressed and calm events.

Our research focuses on changes in heart rate and anxiety levels elicited by the presentation of a fast heartbeat as vibration, comparing presentation on left and right hand, and as vibration and/or audio, filling a gap in previous research which mostly investigated calming effects of a slow heartbeat.

3 EXPERIMENT 1: VIBROTACTILE CUES PRESENTED ON WRIST OF EACH HAND

In this experiment, we observed how participant heart rate and self-reported anxiety was impacted by the presentation of a fast heartbeat via vibration, in a stress-inducing scenario. In addition, we investigated any differences on these factors depending on which hand the vibration was presented.



(a) Maths Test of Experiment 1: PASAT **(b) Calming Video of Experiment 1: train ride**

Figure 1: Tasks of Experiment 1: Maths test in stressed state and video of train ride to calm participants.

3.1 Study Design

The experiment used a 2x2 within-subjects study design with two independent variables: Modality (N/A - Vibration) and Hand (Left - Right). The two dependent variables were heart rate and state anxiety levels. We used an established stress-induction mathematics task, the Paced Auditory Serial Addition Test [9] (PASAT), for which we used the implementation provided by PEBL[1]; its interface can be seen in Figure 1(a). In this test, participants were presented with a number and they had to add this number to the number that was last presented and provide the sum. The difficulty consists in remembering the last presented number instead of the calculated sum for the addition to the new number. A calming video was played for 3 minutes before the maths test, to return participants to a calm state, which was shown as an effective measure in previous research [8]. The video was chosen as a calm train ride[2], see example in Figure 1(b), similar to prior work [7]. Anxiety levels were collected via the state half of the State-Trait Anxiety Inventory (STAI) [11] questionnaire immediately before and after each PASAT, where a higher total score in the inventory indicates higher anxiety level. Participants underwent the PASAT twice without and twice with vibrotactile feedback of a fast heartbeat presented on their wrist. Vibration was presented once on the left wrist and once on the right wrist. The heart rate was always collected on the wrist on which no feedback was presented. The order of conditions was counterbalanced over the participants. Previous research has shown that a heartbeat 30% faster than the average heartbeat was perceived as a fast heartbeat [8] and 120bpm could elicit an increase in heart rate [6], therefore we generated a sound file with 120bpm for this experiment, which was needed as input for the vibrotactile actuator.

3.2 Apparatus

The 32x9x9mm Haptuator Mark II vibrotactile actuator by Tactile Labs[3] was used for providing the fast heartbeat after being attached to the wrist with a strap and the Empatica E4 wristband[4] collected the heart rate throughout the experiment, which could then be downloaded at the end of the session and visually observed on their

[1] https://pebl.sourceforge.net/ (accessed 30/04/2023)
[2] https://www.youtube.com/watch?v=uz_xVP00soo (accessed 05/05/2023
[3] http://www.tactilelabs.com/wp-content/uploads/2012/07/TL002-09-A_v1.01.pdf (accessed 04/05/2023)
[4] https://www.empatica.com/en-gb/research/e4/ (accessed 04/05/2023)

Figure 2: Setup of Experiment 1: Empatica E4 on the left wrist, vibrotactile actuator attached to wrist of right hand with a strap.

app throughout the experiment. A 13-inch Mac Book Pro laptop was used to run the mathematical test and play the calming videos and the questionnaire data was collected on printouts. The setup can be seen in Figure 2.

3.3 Participants and Procedure

Eight participants (5 female, 3 male, none non-binary or third gender) between 22 and 24 (Mean=23.38, SD=0.70, Median=24) took part in this experiment. All the participants were students and volunteered for the experiment after a recruitment call in a student group chat. No sensory impairments in the hands or any cognitive problems were reported. All participants were right-handed.

The participants were welcomed in a university room and presented with an information sheet, which explained the whole procedure of the experiment with a chance to ask questions. After signing the consent form, the experimenter helped the participants to fit the hardware to both wrists in a firm but comfortable position. The participants were then introduced to the PASAT test, with a short test phase to familiarise them with the technology. They then watched the calming video for 3min, after which they filled in a STAI questionnaire. This was followed by the PASAT task for 3 minutes, with or without vibration on either the left or right wrist, depending on the counterbalancing of conditions. After the PASAT task was finished, participants filled in the STAI questionnaire again and watched the calming video. The previous procedure was repeated for each condition of the experiment and at the end, participants filled in a questionnaire capturing demographic data. The study was evaluated and approved according to our institution's Ethics guidelines for undergraduate projects and participants were not compensated.

3.4 Results

The data was evaluated using repeated measures ANOVA. As there were only two levels in each independent variable in this experiment, no post hoc tests were conducted, but instead the marginal means and standard error of the levels provided for context. Data were tested for normality with Shapiro-Wilk and found to be normally distributed.

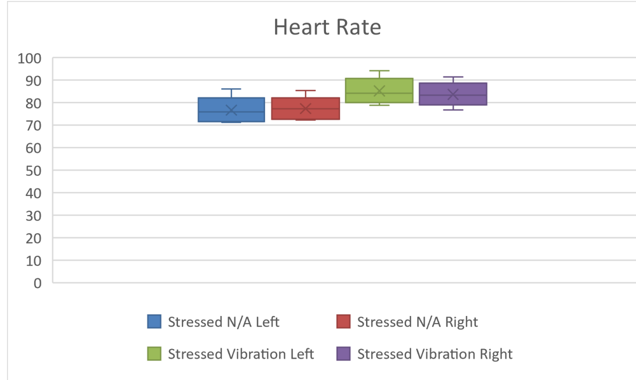


Figure 3: Heart Rate for all Modalities of Experiment 1: showing the mean heart rate over all participants for each modality, where the coloured box highlights the first and third quartile of the data, with the median being depicted as the coloured line within the box with the x-marking and the whiskers showing the minimum and maximum values.

	Sum of^2	df	Mean^2	F	p
Modality	461.928	1	461.928	143.171	< **.001**
Residual	22.585	7	3.226		
Hand	0.092	1	0.092	0.012	0.916
Residual	53.834	7	7.691		
Modality * Hand	7.644	1	7.644	1.989	0.201
Residual	26.908	7	3.844		

Table 1: Repeated Measures ANOVA on Heart Rate in Experiment 1.

3.4.1 *Heart Rate.*

The heart rate data of Experiment 1 for each Modality can be seen in Figure 3. The repeated measures ANOVA showed statistically significant differences for Modality (see Table 1, where the marginal means can be seen in Table 2 and showed that the heart rate was higher when vibration was presented than without vibration. There was no significant difference found between the hands or the interaction between Modality and Hand.

			95% CI	
Modality	Marginal Mean	SE	Lower	Upper
None	76.586	1.636	72.773	80.400
Vibration	84.185	1.636	80.372	87.998

Table 2: Marginal Means - Modality of Heart Rate in Experiment 1.

3.4.2 *Anxiety Levels.*

The anxiety levels of Experiment 1 are presented for each condition in Figure 4. The repeated measures ANOVA (see Table 3) showed significant differences for Modality, with Anxiety levels being higher for conditions including vibration (see marginal means in Table 4). A significance difference was also found

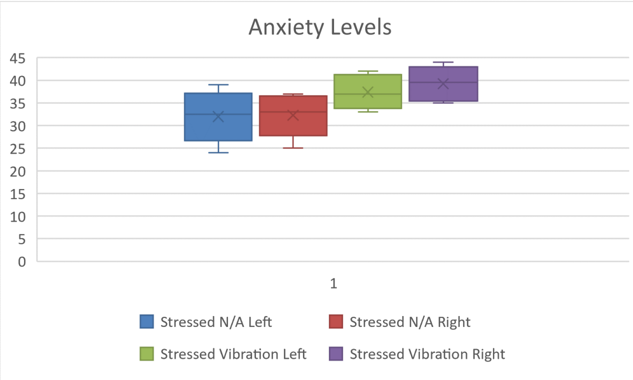


Figure 4: Anxiety Levels for all Modalities of Experiment 1:: showing the mean anxiety levels over all participants for each modality, where the coloured box highlights the first and third quartile of the data, with the median being depicted as the coloured line within the box with the x-marking and the whiskers showing the minimum and maximum values.

between presentation to the left or right hand, where marginal means (see Table 5) showed a slightly higher value for the right hand than the left hand. No interactions were found.

	Sum of^2	df	Mean^2	F	p
Modality	300.125	1	300.125	35.989	< **.001**
Residual	58.375	7	8.339		
Hand	8.000	1	8.000	5.895	**0.046**
Residual	9.500	7	1.357		
Modality * Hand	4.500	1	4.500	1.212	0.307
Residual	26.000	7	3.714		

Table 3: Repeated Measures ANOVA on Anxiety Levels in Experiment 1.

			95% CI	
Modality	Marginal Mean	SE	Lower	Upper
None	32.125	1.434	28.880	35.370
Vibration	38.250	1.434	35.005	41.495

Table 4: Marginal Means - Modality of Anxiety Levels in Experiment 1.

3.5 Limitations

One of the limitations of this study is the small sample size with non-diverse participants especially in terms of age and educational background. All participants were right-handed, so any comparison between hands might not be representative. Furthermore, this experiment only investigated effects during stressful situations and

			95% CI	
Hand	Marginal Mean	SE	Lower	Upper
Left	34.688	1.356	31.510	37.865
Right	35.688	1.356	32.510	38.865

Table 5: Marginal Means - Hand of Anxiety Levels in Experiment 1.

no comparison to calm situations was made, which we was addressed in Experiment 2. The choice of video, mathematical test and heart rate device could potentially have an influence on the observed effects, therefore, we will use different options for these in the second experiment, to ensure that the observed effects could be more generalised.

3.6 Experiment 1 Discussion

The results showed a clear increasing effect of the presentation of a fast heartbeat on heart rate and self-reported anxiety levels, mirroring and complementing aspects of previous research [6, 8]. While side of vibration presentation had no effect on heart rate, a small increase in self-reported anxiety levels could be seen, where anxiety was slightly higher (only one full point) when vibration was presented on the right hand. As all participants were right-handed and would, therefore, use their right hand to navigate through the mathematical test, this increase could be an effect of the vibration being on the actively used hand, potentially eliciting a feeling of interference with the task, rather than an influence of the vibrotactile pattern itself. The lack of differences in heart rate between hands strengthens this interpretation. However, future research with a larger sample size and participants with a split of hand dominance are needed to confirm this. For the immediate future, we decided to investigate vibrotactile presentation of a fast heartbeat only on the non-dominant hand to control this variable, while also measuring heart rate and state anxiety in both calm and stressful scenarios. Further, we explored combination and comparison with sound-based heartbeat cues, such as those used in prior work [10].

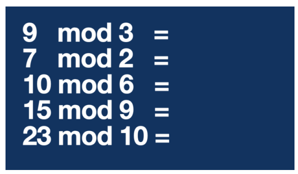
4 EXPERIMENT 2: VIBROTACTILE AND AUDIO CUES PRESENTED ON SMARTWATCH

Building on the findings of the first experiment, in this second experiment we investigated the influence of fast heartbeat not only as vibration, but also as sound and their combination, on heart rate and anxiety levels. In addition, we observed the effects during stressed and calm states.

4.1 Study Design

The experiment was designed as a 4x2 within subject study, with Modality (None / Sound / Vibration / Sound and Vibration) and State (Calm / Stressed) as independent variables. The dependent variables were again heart rate and state anxiety levels. Similar methods for calming and stressing participants were chosen. Videos of landscapes[5], see an example in Figure 5(a), were chosen for calming participants in the calming state, as previous research has shown that nature videos can be effective for this purpose [14]. Participants were asked to rest without any cues or videos presented, in order to return to a baseline after the tasks, so there was a difference between calm tasks and resting between tasks. Another mathematical test, which was also used successfully in previous research [4], was used in this experiment: the modular arithmetic task, which is the division with remainder, see Figure 5(b). All modalities were presented in each state and the order was counterbalanced. State

(a) Calming Video of Experiment 2: landscape



(b) Maths Test of Experiment 2: Modulo Test

Figure 5: Tasks of Experiment 2: Video of landscape in calm state, maths test in stressed state.

anxiety levels were again measured via the state half of the STAI in paper form, and the heart rate data was collected on the wrist via smartwatch, while another smartwatch on the other wrist presented the vibrotactile feedback. The heart rate frequency was not fixed in this experiment, but adapted from the participant's own heart rate collected in a resting phase at the beginning of the experiment and then presented 30% faster than the resting heart beat, with previously recorded heartbeat sound being adjusted in speed to adapt to the correct frequency and the vibration being generated on the smartwatch in the needed frequency pattern.

4.2 Apparatus

Figure 6: Hardware of Experiment 2: Two Apple smartwatches (Series 6 (44mm) and 7 (40mm), watchOS 8.5) were used in this study.

[5]https://www.youtube.com/watch?v=SMKPKGW083c&list=WL&index=2&t=1873s (accessed 05/05/23)

In this second experiment, two Apple Watch devices were used in connection with an iPhone 13 Pro (iOS 15.5): the Series 6 44mm Watch with watchOS 8.5 was used to present the heartbeat vibration, while a Series 7 40mm watch, also with watchOS 8.5, was used to collect the heart rate data. AirPods Pro were connected to the phone on which the heartbeat sound was played. The apps for stimuli presentation and adaptation of heartbeat sound were implemented with playHaptic: WKHaptic, an Apple API, with apps on the phone and watch communicating to present the correct stimuli and the conditions could be chosen on the phone app. The auditory heartbeat data was recorded from the researcher and then adjusted in frequency by the app to present a 30% faster heartbeat than collected for this participant in their resting phase. A MacBook Pro (14", 2021, macOS Monterey 12.5) was used to conduct the other parts of the experiment.

The hardware was changed for this experiment to ensure that the collected heart rate of the participant could be used as baseline for the adaptation as an integrated part of the overall system. The Empatica E4 does not allow for real-time access of the data, only a visual presentation of the heart rate data in their custom app in real-time and export of the data from their cloud system after the fact. In addition, the Apple Watch is easily accessible, widely used and well known, challenging the feeling of dealing with a prototype.

4.3 Participants and Procedures

Twelve participants (8 male, 4 female, none non-binary or third gender) were recruited online to participate in this experiment. The participants were all right-handed with no physical impairment and all were students between 19 and 31 years (Mean=22.83, SD=3.16, Median=22).

The experiment was conducted in a university room and participants were welcomed and introduced to the experiment when the experimenter read out the introduction script explaining the study and its purpose, with the opportunity to ask questions. Afterwards, participants filled in the consent form and were then given the smartwatches to attach to their wrists: the one to present the cues on the non-dominant (left) hand and the watch collecting the heart rate on the right hand. The tightness and functionality of the watches was checked by the experimenter. In addition, participants were given the AirPods Pro, with noise cancelling turned on, to wear during the experiment. Afterwards, participants were asked to rest without provision of any stimulus or feedback to collect baseline resting data, which was then used to calculate the 30% faster heartbeat for this participant. After the resting phase, participants filled in the anxiety questionnaire. Depending on the counterbalanced condition, participants then started either the calm or the stressed task with one of the modality conditions. In the calm states, one of the calm videos was played to participants for 3min with one of the modality conditions. The videos were not repeated. Afterwards, the participants filled in the anxiety questionnaire and were told to rest for 3min and to fill in another anxiety questionnaire afterwards. In the stressed state, the modular maths test was presented to the participants with one of the modalities for 3min, at which point they filled in another anxiety questionnaire and then rested again for 3min. The procedure was repeated for each condition twice. At the end of the experiment, the participants filled in a questionnaire on demographic data and were debriefed by the experimenter. The user study was evaluated and approved by our institution's Ethics guidelines for undergraduate projects and the participants were not compensated.

4.4 Results

The data of Experiment 2 was evaluated with repeated measures ANOVA with Bonferroni corrected *post hoc* tests for variables more than two levels, while marginal means are presented for only two levels to add context. Data were tested for normality with Shapiro-Wilk and found to be normally distributed.

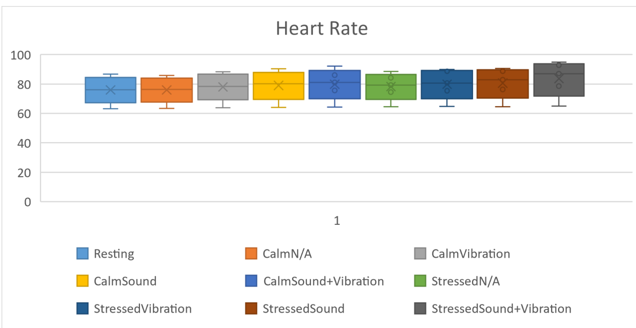


Figure 7: Heart Rate for all Modalities of Experiment 2: showing the mean heart rate over all participants for each modality, where the coloured box highlights the first and third quartile of the data, with the median being depicted as the coloured line within the box with the x-marking and the whiskers showing the minimum and maximum values.

4.4.1 Heart Rate. The heart rate data of Experiment 2 for each Modality in Figure 7. The repeated measures ANOVA found statistically significant differences for both Modality and State, as well as their interaction, see Table 6. We will present all *post hoc* test results, but further only discuss the interaction, as it provides the most precise results.

	Corr.	Sum of^2	df	Mean^2	F	p
Modality	None	330.257	3.000	110.086	47.588	< **.001**
Residual	None	76.340	33.000	2.313		
State	None	206.890	1.000	206.890	40.729	< **.001**
Residual	None	55.876	11.000	5.080		
Mod*State	G-G	15.787	1.642	9.612	4.325	**0.035**
Residual	G-G	40.153	18.066	2.223		

Table 6: Repeated Measures ANOVA on Heart Rate in Experiment 2; Mauchly's Test revealed that sphericity was violated for Modality*State and Greenhouse-Geisser (G-G) corrections were applied.

Post hoc tests with Bonferroni corrections for Modality showed differences between all modalities apart from the single modalities

		MeanDiff	SE	t	p_{bonf}
None	Sound	-3.166	0.428	-7.396	< **.001**
	Sound+Vib	-5.176	0.633	-8.177	< **.001**
	Vibration	-2.342	0.353	-6.626	< **.001**
Sound	Sound+Vib	-2.010	0.340	-5.916	< **.001**
	Vibration	0.824	0.315	2.612	0.145
Sound+Vib	Vibration	2.834	0.483	5.871	< **.001**

Table 7: Post Hoc Comparisons - Modality for Heart Rate with Bonferroni corrections.

Sound and Vibration, see Table 7. The marginal means for State can be seen in Table 8 and show increased mean vales for the stressed state compared to the calm state.

			95% CI	
State	Marginal Mean	SE	Lower	Upper
Calm	78.646	2.303	73.590	83.701
Stressed	81.582	2.303	76.526	86.638

Table 8: Marginal Means - State for Heart Rate of Experiment 2.

Post hoc tests for the interaction can be seen in Table 9 and are less easily summarised. There are many statistically significant differences between the modality-state combinations, apart from Stressed-N/A with all the Calm variations with feedback, as well as the Calm-Sound with the other Calm variations with feedback and Stressed-Sound with both Calm-Sound+Vibration and Stressed-Vibration which all showed no significant differences.

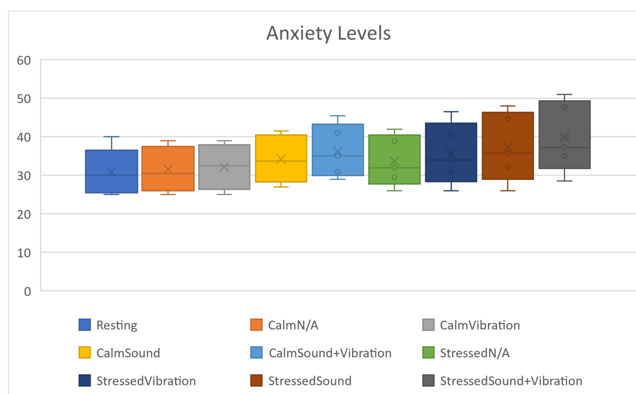


Figure 8: Anxiety Levels for all Modalities of Experiment 2: showing the mean anxiety levels over all participants for each modality, where the coloured box highlights the first and third quartile of the data, with the median being depicted as the coloured line within the box with the x-marking and the whiskers showing the minimum and maximum values.

4.4.2 Anxiety Levels. The reported state anxiety levels for all conditions can be seen in Figure 8. Results of the repeated measures

		MeanDiff	SE	t	p_{bonf}
None,Calm	None,Stress	-2.405	0.603	-3.987	**0.012**
	Sound,Calm	-3.076	0.542	-5.671	< **.001**
	Sound,Stress	-5.661	0.675	-8.391	< **.001**
	S+Vib,Calm	-4.210	0.542	-7.763	< **.001**
	S+Vib,Stress	-8.546	0.675	-12.667	< **.001**
	Vib,Calm	-2.335	0.542	-4.305	**0.002**
	Vib,Stress	-4.754	0.675	-7.047	< **.001**
None,Stress	Sound,Calm	-0.671	0.675	-0.995	1.000
	Sound,Stress	-3.256	0.542	-6.004	< **.001**
	S+Vib,Calm	-1.806	0.675	-2.676	0.302
	S+Vib,Stress	-6.141	0.542	-11.322	< **.001**
	Vib,Calm	0.070	0.675	0.103	1.000
	Vib,Stressed	-2.349	0.542	-4.331	**0.002**
Sound,Calm	Sound,Stress	-2.585	0.603	-4.286	**0.006**
	S+Vib,Calm	-1.134	0.542	-2.092	1.000
	S+Vib,Stress	-5.470	0.675	-8.108	< **.001**
	Vib,Calm	0.741	0.542	1.366	1.000
	Vib,Stress	-1.678	0.675	-2.487	0.482
Sound,Stress	S+Vib,Calm	1.451	0.675	2.151	1.000
	S+Vib,Stress	-2.885	0.542	-5.318	< **.001**
	Vib,Calm	3.326	0.675	4.930	< **.001**
	Vib,Stress	0.907	0.542	1.673	1.000
S+Vib,Calm	S+Vib,Stress	-4.335	0.603	-7.188	< **.001**
	Vib,Calm	1.875	0.542	3.457	**0.028**
	Vib,Stress	-0.544	0.675	-0.806	1.000
S+Vib,Stress	Vib,Calm	6.211	0.675	9.206	< **.001**
	Vib,Stress	3.792	0.542	6.991	< **.001**
Vib,Calm	Vib,Stress	-2.419	0.603	-4.011	**0.012**

Table 9: Post Hoc Comparisons - Modality * State for Heart Rate of Experiment 2.

ANOVA can be seen in Table 10 and showed significant differences for both Modality and State, but not their interaction. *Post hoc*

	Corr.	Sum of^2	df	Mean^2	F	p
Modality	G-G	419.719	1.441	291.348	73.031	< **.001**
Residual	G-G	63.219	15.847	3.989		
State	None	273.375	1.000	273.375	38.770	< **.001**
Residual	None	77.563	11.000	7.051		
Mod*State	None	7.813	3.000	2.604	1.790	0.168
Residual	None	48.000	33.000	1.455		

Table 10: Repeated Measures ANOVA on Anxiety Levels in Experiment 2; Mauchly's Test revealed that sphericity was violated for Modality and Greenhouse-Geisser (G-G) corrections were applied.

tests with Bonferroni corrections for Modality showed significant differences between all modalities, see Table 11. Investigation of the marginal means, see Table 12 showed an increase of reported anxiety from no feedback to vibration, then sound and lastly the combination of sound and vibration. The variable State showed significant differences and the marginal means, see Table 13, showed an increase in anxiety from the calm to the stressed state.

		MeanDiff	SE	t	p_{bonf}
None	Sound	-3.375	0.444	-7.595	< **.001**
	Sound+Vib	-5.563	0.596	-9.333	< **.001**
	Vibration	-1.438	0.306	-4.692	**0.004**
Sound	Sound+Vib	-2.188	0.258	-8.489	< **.001**
	Vibration	1.938	0.243	7.988	< **.001**
Sound+Vib	Vibration	4.125	0.431	9.563	< **.001**

Table 11: Post Hoc Comparisons - Modality for Anxiety Levels with Bonferroni corrections.

			95% CI	
Modality	Marginal Mean	SE	Lower	Upper
None	32.563	1.760	28.706	36.419
Vibration	34.000	1.760	30.144	37.856
Sound	35.938	1.760	32.081	39.794
Sound+Vibration	38.125	1.760	34.269	41.981

Table 12: Marginal Means - Modality of Anxiety Levels for Experiment 2.

			95% CI	
State	Marginal Mean	SE	Lower	Upper
Calm	33.469	1.764	29.608	37.330
Stressed	36.844	1.764	32.983	40.705

Table 13: Marginal Means - State of Anxiety Levels for Experiment 2.

4.5 Limitations

While both sample size and age variation were increased for this experiment compared to the first, they were still not representative of the population and all participants were again students, on the younger side and all right-handed. We did not investigate differences in hand side in this experiment, but it cannot be assumed that there are no differences for people of different handedness. The choice of apparatus and study elements could, again, have an unintended effect on the results that we were not aware of, but the trends in results between studies may also highlight the generalisability of the effects of heartbeat cues between apparatus.

4.6 Experiment 2 Discussion

For this second experiment, we found more clear trends in state anxiety than heart rate. There was a clear difference in reported state anxiety levels between the calm and stressed state, which we would expect and reflects that the measures taken to calm and stress participants were successful. In addition, we could observe a clear hierarchy of modalities which impacted state anxiety levels, with each modality showing a statistically significant difference to the others. The absence of heartbeat cues led to the least anxiety, followed by vibration, then sound and lastly the combination of sound and vibration with the biggest increase in anxiety as shown in the marginal means. This contrasts results from prior work [19] for presentation of slow heartbeat, where sound did not have any influence on stress levels but vibration did, while it mirrors results by Iodice et al. [10] who showed that auditory presentation of a fast heartbeat can have an influence on emotions (in their case perceived effort). These results can help design cues to elevate emotions, with different levels being achievable with using either a single or two modalities at the same time.

The evaluation of heart rate showed a less clear picture with many interactions between Modality and State. A deeper look revealed that the Stressed state without feedback was not different from any of the Calm conditions with feedback. This could indicate that the stress induction method and the addition of fast heartbeat feedback could have a similar effect on the heartbeat. Similarly, Calm Sound+Vibration did not show statistically significant differences to Calm Sound, Stressed Sound and Stressed Vibration: arguably the most stressful modality combination in the lesser stressful state (according to the anxiety level evaluation) showed no significant difference with the slightly less stressful modality in the calmer state and both other feedback providing modalities in the stressful state. This would indicate that effect on user heart rate of calm and stressed state is not as clear, mirroring what we see in Figure 7, where we can see that the stressed state increase *starts* on a lower level than where the calm state increase *ends*, similar to the Calm single modality levels. This overlap seems to show itself within these interactions. In addition, we can see in these interactions that the differences in heart rate between the modalities Sound and Vibration seem to not be as clear cut as we have seen for anxiety levels (mirroring the results of the post hoc tests for Modality).

5 GENERAL DISCUSSION

Results of both experiments showed a clear increasing influence of the presentation of fast heartbeat as vibration and sound on heart rate and anxiety levels. Both the fixed presentation of 120bpm (as vibration) and the adapted increase of 30% of the participants collected resting heart rate (as both sound and vibration) were successfully used to increase the anxiety levels and heart rate of participants. Two different types of mathematical tests and calming videos were effectively used to, respectively, stress or calm participants (either to return to a calm baseline or to initiate a calm state during task completion). The hand which the vibrotactile cues was presented to did not have any influence on the heart rate, but a very small impact on anxiety levels, where the presentation on the dominant hand led to slightly higher reported anxiety.

In Experiment 1, in which only vibration was compared to no feedback, the increase in anxiety level and heart rate was easily observable. However, while differences between Sound and Vibration and their combination presented themselves clear cut in terms of anxiety levels for both calm and stressed state in Experiment 2 and the heart rate clearly increased when feedback was provided, their influence on heart rate in combination with the effects of the calm and stressed state were less clear. The higher stressful calm conditions seem to overlap with the lower stressful conditions in the stressed state in terms of impact on heart rate. Future work could investigate if a more stressful task could overcome this.

6 FUTURE APPLICABILITY OF FAST HEARTBEAT CUES

Prior work has predominately focused on calming applications using slow vibrotactile and auditory heartbeat cues [3, 7], but a more complete understanding of the physiological and psychological impact of fast heartbeat cues opens the doors for a more holistic range of experiences that interface designers can use. Heart rate was elevated in both stressed and calm states, which further broadens the use-cases of fast heartbeat both to applications that do not induce any prior stress as well as applications that purposefully induce stress. Possible emotionally neutral applications include facilitating immersive simulations of exercise or work training by emulating effort, rousing users with increased feelings of alertness before a task, or facilitating future studies of interoceptive processing [10]. By contrast, designers of horror and thriller media can seek to leverage fast heartbeat to heighten audience feelings of fear, anxiety, excitement and dread and further immerse them in experiences such as films, games or virtual rides. As early as 2001, horror video-games such as *Silent Hill 2*[6] have been using vibrotactile heartbeat feedback this way. An empirical understanding of these cues and their impact on users informs effective, intentive, and careful application of them in future experiences. Finally, as presenting fast heartbeat increases user anxiety, future work must always exercise ethical caution and consent to avoid any harms to vulnerable users. For example, perception of physiological signals like an elevated heart rate can worsen ongoing anxiety symptoms for socially anxious people [15].

7 CONCLUSIONS

We conducted two experiments to investigate the influence of the presentation of a fast heartbeat as vibration on the wrist and sound on heart rate and anxiety levels of participants, both in stressed and calm situations. This research complements prior work which largely evaluated the calming effect of slow heartbeat or only evaluated the impact of fast heartbeat presentation on subjective measures. We observed a clear increase in heart rate and anxiety levels, where especially for the anxiety levels the different modalities showed a clear hierarchy. Our results provide opportunities to embed the different findings of prior work for only one of the modalities and can help researchers decide on the mode of presentation of fast heartbeat to elicit a specific level of anxiety increase.

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