Laughter and Tickles: Toward Novel Approaches for Emotion and Behavior Elicitation

Pascal E. Fortin, *Member, IEEE,* and Jeremy R. Cooperstock, *Member, IEEE,*

Abstract—Considerable effort has been invested in the development of effective emotion and behavior recognition techniques. In comparison, little work has been devoted to technologies that can be used to induce specific emotional and behavioral responses, with most such research relying on the presentation of video or images. In this article, we propose a novel technique for the elicitation of emotion based on audio-tactile stimulation. Taking advantage of the relationship between tickling, laughter and emotional states, we conducted an experiment to map the perception of the tickle sensation as a function of vibrotactile stimulation frequency, quantify the effect of hearing laughter stimulus on the perceived intensity of the tactile experience, and assess the potential of the proposed multimodal approach to induce observable mirthful responses. Experimental evidence shows that the perceived intensity of the auditory laughter stimulus has a repeatable scaling effect on the tickle sensation and that the proposed audio-tactile stimulation is a promising approach to laughter elicitation. These findings may inform the design of future multimodal affective interfaces by allowing a more informed prediction of induced emotional and behavioral responses.

Index Terms—laughter, tickling, multimodal interface, emotion-elicitation, physiological signals

1 Introduction

Inducing emotional states in a predictable manner has long remained a challenge, ever since the early days of emotion psychology. As researchers in affective computing require large labeled datasets for their studies, various attempts to address this issue have been considered. For example, the Velten mood induction protocol (MIP) requires the subject to read sequences of sentences out loud, to induce states of elation and depression [1]. Others proposed to use, individually and in combination, music, pictures and film segments, as stimuli to elicit desired affect [2], [3], [4], [5]. Those prior approaches relied mostly on sensory modalities that were associated with, what was thought to be, the main channels through which emotions are interpreted in natural interactions [6]. However, reliance on visual stimulation for elicitation is not always possible. Moreover, outside of controlled laboratory environment, requiring attention to imagery or video may jeopardize users' safety by reducing their environmental awareness. In contrast, the haptic modality, or sense of touch, is rarely overloaded, and recent findings suggest that it plays a crucial role in the communication of distinct emotions [7]. Indeed, prior research assumed that touch was merely intensifying emotional communication occurring through other channels. Further supporting the use of haptics for emotion and behavior elicitation, mediated affective touch was shown to significantly impact economic decision-making [8]. We therefore anticipate that tactile stimulation will play an increasingly important role in upcoming affective, behavioral interfaces and their use in the wild.

Inspired by naturally occurring affective touch interactions, we propose to study the tickling sensation and its applicability to the problem at hand. This particular phenomenon was chosen because of its dominance as a means of interaction in early parent-child relations and its relatively common presence at older ages in the context of intimate relationships. Tickling is also an emotion-rich tactile interaction that has the potential to induce extreme states, from intense visceral pleasure to pain, including complex psychological states such as the feeling of loss of control under an "attacker". In addition, it is one of the few sensory experiences that can trigger body-wide chills and laughter in an exaggerated proportion in comparison to the required stimulus amplitude to induce it. We were drawn to this subject by a desire to understand how auditory stimulation can influence the perceived intensity of tickling, and in particular, to assist the tactile modality in inducing mirthful responses to tickling. To this end, we propose the use of an auditory signal naturally prone to be experienced in combination with the tickle sensation, namely, laughter. This is further motivated by the fact that laughter recordings alone have been used successfully in a variety of contexts to elicit mirthful reactions in listeners [9], [10]. Furthermore, numerous studies have underlined the complex relationship between laughter and internal state of humans, demonstrating the gamut of different emotions that laughter can express (e.g., happiness, anxiety, fear). [11], [12].

Building on our experience with the design of foot-based haptic interfaces, a novel tickling device was designed, differentiating itself from existing apparatuses in its affordance of control over vibration characteristics. This, in turn, allowed for rigorous evaluation of the ability to induce the tickle sensation. Leveraging our custom system and multimodal measurement approaches, we present an experiment addressing the following research questions:

- *Mr. Fortin and Cooperstock are at the Centre for Intelligent Machines, Department of Electrical and Computer Engineering, McGill University, Montreal, Canada.*
  E-mail: jer@cim.mcgill.ca

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- **Q_1:** Is there a relationship between the frequency of a vibrotactile stimulus under the foot and its perceived ticklishness?
- **Q_2:** Does hearing laughter affect the perceived intensity of the tickle sensation?
- **Q_3:** Does the combination of the tickle sensation with laughter increase the occurrence of mirthful responses?

It is anticipated that a deeper understanding of laughter, the tickle sensation, and their interactions, as addressed by these questions, will allow for a more informed design procedure for future affective and behavioral interfaces.

2 RELATED WORK

2.1 Tickling

2.1.1 *Theory and perception*

Stanley and Hall identified the two existing types of tickling reaction: knismesis and gargalesis [13]. They suggested knismesis, to refer to the reaction to a slight touch, similar to the unpleasant sensation of an insect crawling on your skin, while gargalesis refers to a laughing response to a deeper rhythmic tactile stimulation such as the one occurring during the stereotypical context of a parent tickle-playing with his child.

Even though tickling has been an ongoing topic of research during the last century, only recently, researchers started to be interested in the underlying psychophysiological origins of this sensation. Evidence suggests that the knismesis sensation shares neural pathways with pain and itching, as all these percepts cease functioning after the spinothalamic tract is sectioned [14], [15], [16]. However, gargalesis tickling, requiring deep touch, vibration and pressure senses, reportedly takes a different path to the cortex, underlining the possibility that both tickling sensations may be "synthetic senses" resulting from a different integration of multiple mechanoreceptor and nocireceptor signals not relying on the same neural pathways.

Unlike the case of knismesis tickling, it was demonstrated that it is impossible for a mentally healthy individual to self-induce the gargalesis reaction [17], [18], [19], [20]. As proposed by Blakemore et al., every motor command creates an efference copy that is used to generate sensory predictions of motion consequences. That copy allows a comparison of sensory feedback and expectations to be achieved, resulting in attenuation of the sensations associated with self-produced movements [17]. This forward model approach is congruent with evidence from schizophrenic patients, who lack physical self-awareness, and healthy individuals who successfully self-induced the gargalesis reaction using mechanisms to induce delays between the user's movement and the tactile self-stimulation [17], [21]. Harris and Christenfield further demonstrated that a machine may induce a tickling sensation without social context, with the same efficiency as a human experimenter. It is important to underline, however, that they make no mention of whether they observed knismesis or gargalesis reactions and that their stimulation was provided using a cotton swab and/or by hand which may raise doubts about the uniformity of stimulation throughout the experiment [21].

2.1.2 *Tickling interfaces*

Multiple devices with the objective of remotely conveying emotions were developed in the last decade. These interfaces employ a variety of methods and feedback modalities, i.e., pressure, temperature, vibration, etc., to interact affectively with the user [22]. However, when it comes to inducing the tickle sensation, most of the mechanisms are based on the principles of vibrations or laterotactile stimulation.

An example of a vibration-based interface is the "Phantom Slipper", a foot-worn tickling apparatus developed by Kume et al. that reportedly induced a tickle sensation during preliminary user testing [23]. Using a distributed approach, Tsetserukou et al. attempted to remotely convey a multitude of implicit emotion-related interactions such as heart beats and temperature. Their system also elicited explicit touch interaction using the HaptiHug and HaptiTickler. A unique feature of the HaptiTickler is the fact that even though it is based on vibrations, it can render spatiotemporal patterns using its four independent vibration motors located on the ribcage on each side of the body [24]. Avoiding reliance on the custom hardware required by Tsetserukou and Kume, Park et al. developed the "CheekTouch" to elicit bidirectional tickling, using a smartphone with an enhanced case equipped with vibration motors and touch sensors [25]. This system allows the user to tickle and stroke the cheek of its interlocutor by stroking the instrumented case while having a natural conversation. Similarly, the "Kusuguri" by Furukawa et al. used an augmented case. They, however, added complementary visual feedback rendered on the screen to increase the perceived tickle intensity by showing a finger slightly touching the "tickled" user's hand. Although this approach was promising, difficulties in the synchronization of the haptic and visual feedback negatively affected the user experience [26].

Systems relying on laterotactile stimulation are far less numerous than those based on vibrations. A notable example is "Ants in the pants" by Sato et al. that consists of an augmented sleeve equipped with an array of motor-mounted nylon fibers. This mechanism effectively reproduces the sensation associated with ants crawling up the user's arm [27]. In addition to the tactile component, the system was used with a complementary table-mounted monitor where ants would be seen walking and climbing on the user's hand and under the sleeve. According to the authors and their qualitative results, the use of visual feedback increased the realism of the interaction and the perceived intensity of the stimulus. This clever use of the visual and haptic stimulation avoided the synchronization problems encountered by previous researchers as the insects would become "invisible" as they would crawl up the sleeve. A last tickling interface presented by Knoop et al. is unique due to its actuation mechanism [28]. The tickler is the only device based on shape memory alloys to move bristles resulting in much slower and softer movements in comparison with motor actuation. A formal user study indicated the potential to convey tickling and soft massages among other sensations. This mechanism also presents the advantage of not producing any noticeable sound in contrast with vibration technologies.

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The design of these tickling interfaces, although successful to varying degrees at tickling participants, was not informed by serious scientific evidence but by a priori experiences of the researchers with the phenomenon of tickling. Additionally, most of them featured, as part of the experience, a social component that may have affected the participants' responses. While the results achieved are interesting and promising for tickling interfaces and laughter elicitation, a deeper understanding of the stimulus characteristics responsible for the perception of the tickle sensation still must be acquired. In addition, while most of these devices reported being able to induce the tickling sensation qualitatively, few underwent rigorous evaluation of the extent to which they were able to elicit the sensation in the users.

2.2 Laughter

At this point, it is incumbent upon us to draw an important distinction between laughter and emotion. No consensus currently exists on the physiological and psychological origins of laughter, nor of whether or not it truly represents one's internal emotional state. Indeed, two main opposing points of view exist on the control of emotional expressiveness. Darwin proposed a bottom-up theory explaining that affective behaviors and responses, such as laughter and smiling, are direct consequences of the evolutionary selective processes [29]. This implies that we would be exhibiting hard-wired responses, instantaneously reflecting our internal emotional state. Darwin's theory explains our inherent difficulties at inhibiting the expression of emotions through different motor channels, e.g., facial expressions, posture, and acoustic features. On the other hand, Birdwhistell suggested a top-down model where non-verbal signals are consciously manipulated to convey specific content to other members of a group [30]. Regardless of the underlying theory, experimental evidence support the existence of a relationship between laughter responses and the internal emotional state, justifying its use in the current study [31], [32].

2.2.1 How is laughter expressed?

Although every individual expresses laughter uniquely, there exists components that make this behavior universally recognizable. First, laughter sequences can be segmented into distinct events: the onset, when facial expression abruptly changes, the apex, when the steady vocalization, heavy exhalation and posture modifications may take place, and finally, the offset when the vocalizations have ceased and are slowly fading to a smile [33]. In addition to the time segmentation, acoustic properties of the vocalization [34], [35], whole body movements [13], [29] and facial expressions [36] are conveying key information to ensure the proper detection and interpretation of laughter by other members of the interacting group.

2.2.2 Laughter contagion

Contagious laughter is a phenomenon that is commonly encountered in social contexts and results in a group of people laughing uncontrollably. Not to be confused with the laughing reaction caused by a first abnormally amusing laughter, contagious laughter forms an almost symbiotic link between the members of the group who share this moment and often do not even remember the triggering event that started the escalation. As described by Provine, it is so intense that it "strips away our veneer of culture and language and challenges the shaky hypothesis that we are rational creatures in full control of our behaviour." [9]. The exact sensory channels of the contagious laughter propagation are still to be identified.

Although visual, tactile, auditory and context-dependent cues are all likely important for this event to take place, we hypothesize from the successful historical use of laugh tracks, musical laughing records and laughing boxes in the entertainment industry that its main components reside in the auditory sensory stream [9]. In support of this hypothesis, Neuendorf et al. demonstrated that playing back laughter recordings, while simultaneously reading jokes or viewing humorous videos, elicited significantly stronger laughter and smiling in subjects than when exposed to the same jokes or video content without auditory stimulation [37]. Provine further demonstrated that being part of a group leads to increased intensity of mirthful reaction, even if the constituent members are not actively interacting with each other, e.g., a crowd watching a stand-up comedian [9].

3 Experimental framework

Our investigation is motivated by the previously demonstrated ability of the laughter contagion phenomenon and the promising nature of the tickling sensation in inducing mirthful behaviors. We anticipate that these two modalities could have significant impact on future tactile-enabled mood induction protocols, as well as affective and behavioral interfaces. Specifically, we consider the respective roles of laughter and a light vibrotactile stimulation applied under the arch of the foot, both independently and combined, in the perception of the tickle sensation and elicitation of mirthful responses.

Based on the research questions introduced at the start of this article , we formulated the following hypotheses. These are informed by prior literature, knowledge of the frequency-specific responsiveness of mechanoreceptors in the skin, and prior experience with tickling and laughter.

- **H1**: The tickling sensation intensity will vary significantly across the explored frequency space.
- **H2**: The perceived ticklishness of a vibrotactile stimulus will be positively affected by the simultaneous presentation of laughter, as is observed with other additive multimodal experiences.
- **H3**: The mirthful responses to the combination of vibrotactile stimulus and presentation of laughter will be stronger than to either of the stimuli individually, due to their ecological complementarity.

3.1 Apparatus

The experimental apparatus described in this article and the procedures that were employed are compliant with the TCPS2 Ethical Conduct for Research Involving Humans and were approved by the McGill University Research Ethics

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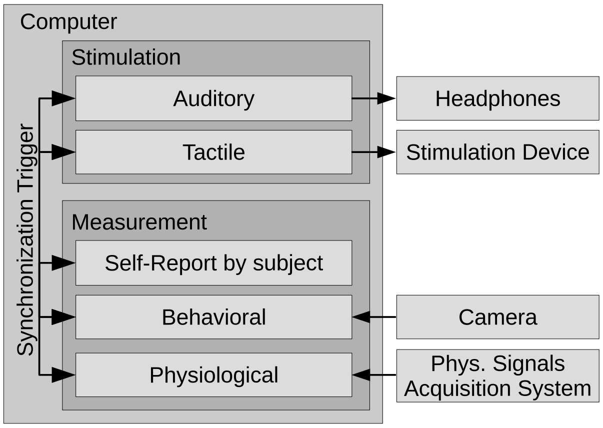

Fig. 1: Overview of the experimental system

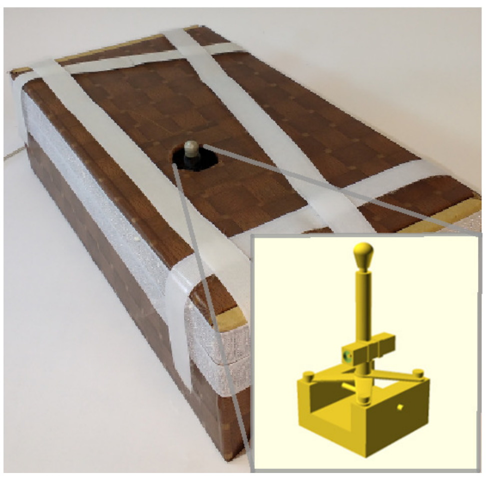

Fig. 2: Custom tickling interface used in the study with foot position visual markers and CAD rendering of the active element of the system.

Board (REB# 432-0416). This section presents the different systems employed for stimulus presentation and the interfaces used to actively and passively acquire subjects' responses to stimulation.

3.1.1 Stimulation system

A novel tickling apparatus was developed, shown in Figure 2, consisting of a single end effector, driven by a vibration actuator attached to a lever, enclosed in a vinyl-coated enclosure on which participants could rest their foot. In contrast with the devices described in Section 2.1.2, our system was engineered to allow the most control over vibration parameters and potential stimulation location. To do so, we capitalize on the nearly constant frequency response and wide acceleration range over the 10 to 1000 Hz frequency range provided by the Tactile Labs haptuator Mark II vibration actuator. Constant vibration amplitude was ensured for the frequencies of interest by designing a multi-band equalizer, informed by no-load end effector acceleration measurements, acquired using an ADXL325 accelerometer at a 2 kHz sampling rate by a National Instruments NI-USB-6218 USB data acquisition card.

To ensure that participants were comfortable and that the stimulation was rendered at the same location throughout the experiment, four Velcro bands were placed on the enclosure to outline the foot (see Figure 2). Using the Velcro outlines made it possible to reposition the foot in its initial placement if it moved during experimentation and after extended pauses. This approach was favored over constraining the subject on the device since physical constraints may have negatively affected naturally occurring behavioral responses.

The stimulation system employs a custom Matlab script, leveraging capabilities of the data acquisition toolbox to render both the auditory and vibration signals using the left and right channels of a laptop audio output (Asus K501U with Conexant HD sound card), at a sampling rate of 44.1 kHz. To ensure uniformity of experimental conditions across participants, vibration stimuli were rendered using a $\pm$2g no-load calibrated amplitude, and all auditory stimuli were delivered to participants using the same pair of Sony MDR-ZX310 over-ear headphones at 50% system volume settings. The perceived loudness of the auditory stimuli was not validated using aurally accurate binaural measurement tools.

3.1.2 Measurement systems and approaches

Three complementary measurement approaches were used for the multimodal assessment of participants' responses, as illustrated in Figure 1. These included a video recording of the participant during the experiment, self-reported values, and acquisition of physiological signals. Video recording provided direct access to observations of natural mirthful behaviors induced by the experimental stimuli [38]. Self-reports provided insights into the subjective sensory experience and emotions of the participants while physiological measurements were relied upon as ground truth [39].

Self ratings: All subjective ratings during the experiment were provided by participants using an optical two-button computer mouse. For this purpose, two self-reporting interfaces were designed to allow user input. The first, presented in Figure 3, was used to assess participant perception of induced arousal and valence of a stimulus using the Affective Slider (AS) proposed by Betella and Verschure [40]. This approach was favored over the Self-Assessment Manikin Scale (SAM), and the Differential Emotion Scale (DES) for its reported ease of use and ability to accurately reflect the subject's emotional state based on the partial arousal-valence-dominance model [41]. The AS instrument was implemented as instructed by its designers and integrated in a Matlab UI followed by an assessment of perceived intensity of the laughter recording (PLI). PLI was evaluated using a discrete seven-point scale, using verbal anchors to signify the extreme values (1–"Not Laughing at all" to 7–"Laughing Hysterically").

The second self-reporting instrument relied on a single virtual slider with verbal anchors, as shown in Figure 4. This tool was used to report the ticklishness of a stimulus after its presentation. Self-rating through this interface was favored over oral reporting as used by Harris and Christenfield [38] to minimize the interactions between the subject and researcher during the experiment. Furthermore, a slider allowed a more nuanced rating than discrete numerical

Fig. 3: Auditory excerpt rating interface

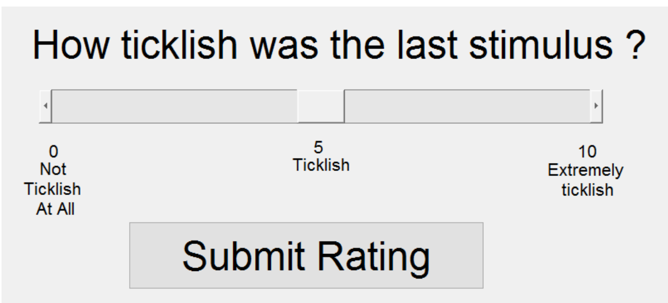

Fig. 4: Audio-tactile stimulus rating interface

scales, allowing participants to better express the relative differences that they might perceive between two stimuli.

Behavioral assessment: Behavioral assessment was carried out by video recording the facial expressions of the participants for the duration of the experiment. The video was captured by the built-in webcam of the laptop at a frame rate of 30 fps and a resolution of 320×240 pixels. These recordings were automatically segmented using a synchronized time stamp and were analyzed by the principal investigator, who was blind to the stimulus being rendered during each segment, according to a five-point behavioral scale proposed by Harris and Christenfield (0 = No apparent response, 1 = voiceless smile, 2 = laughter, 3 = twisting and wiggling in response to the stimulus and 4 = subjects pulls limb away from tickling device) [21], [38]. In the context of this study, the transition from the voiceless smile (1) to laughter (2) code occurred from the moment the smiling was accompanied by visually apparent saccadic exhalations.

Physiological measurements: The capacity of the autonomic nervous system (ANS) to reflect emotional state of the participants and responses to stimuli has been demonstrated by previous literature [39], [42], [43]. Salimpoor et al. demonstrated that a small set of physiological signals provided sufficient indicators to detect the “chills” induced by music. They also concluded that although moderate enjoyment of music does not result in significant changes to the biosignals, a considerable increase in enjoyment will necessarily affect physiological indications of arousal [39]. It is hypothesized that both of these principles apply equally to the tickle sensation, which produces similar body-wide and intense physiological reactions such as the music-induced “chills”.

In the current experiments, physiological measurements were acquired using a ProComp Infiniti from Thought Technology Ltd. All sensors requiring skin contact were installed on the non-dominant hand. Skin conductance sensor electrodes were secured on the distal phalanx of the digitus secundus and digitus annularis. Heart rate (HR) was computed using a blood volume pulse (BVP) sensor attached using a finger clip to the distal phalanx of the digitus medius. Skin temperature was measured at the distal phalanx of the thumb. Finally, abdominal respiration amplitude and rate were measured using a respiratory belt sensor. All sensors were sampled at 256 Hz. Table 1 presents a summary of the sensors used and Figure 5b depicts the sensor placement on the hand.

TABLE 1: Physiological signal sensors used in the experiment

Sensor ID	Description
SA9309M	Skin conductance (SC)
SA9310M	Skin temperature (SKT)
SA9308M	Blood volume pulse (BVP)
SA9311M	Abdominal respiration

Segmentation of the physiological signals was achieved using the synchronized time stamps. Before running any statistical analysis, SC signals were convolved with a Butterworth low-pass filter to remove movement artifacts and noise while conserving their physiologically relevant properties [39]. Although Salimpoor et al. suggested filtering the raw respiration signal, the presence of high-frequency components potentially related to laughter or sudden heavy exhalations are desirable to our study. Visual inspection of the acquired data indicated that raw skin temperature was unaffected by movement artifacts. Excerpts where SC level demonstrated significant DC drift, caused by an accumulation of charge at the electrode-skin interface [39], were linearly detrended by subtracting a first-order polynomial regression from the signal of the excerpt. To account for variability of the subjects’ normal physiological state, pre-experiment baseline measurements were subtracted from the within-excerpt measurements, reflecting relative changes due to treatment conditions. The remaining segments were visually inspected and rejected on a case-by-case basis according to the characteristics of the waveform. These two data quality approaches resulted in the rejection of 13% of all physiological signal segments. Mean values were computed within subjects for all excerpts and then filtered for outliers exceeding two standard deviations from the within-excerpt mean.

3.1.3 Pre-experiment mood assessment

To quantify potential emotionally induced biases among participants, we adopt the 7-point Brief Mood Introspection Scale (BMIS) proposed by Mayer and Gaschke to assess the direct experience of mood. Although the scale contains only 16 adjectives from 8 mood states (happy, loving, calm, energetic, fearful/anxious, angry, tired and sad), its reliability was demonstrated in comparison to the Mood-State Introspection Scale (MIS) and the Russel Adjective Scale, both of which require significantly longer completion time [44].

3.2 Experimental Protocol

Since the experimental protocol is shared, with minor exceptions, for experiment phases I and II, a general description is first presented, with details specific to each phase in Sections 4.1.2 and 5.1.2 respectively.

Participants were welcomed with a brief information session and presented with the stimulation and measurement methods. After having read, understood and signed the consent form, participants completed a brief pretest questionnaire to report their gender, age, dominant foot, and self-reported general ticklishness. The BMIS test was then provided and completed. To ensure consistency and avoid researcher bias, any questions related to vocabulary were answered using the definitions provided by the Merriam-Webster online dictionary.

The experimenter proceeded to attach physiological sensors to the participants' non-dominant hand, as described in Section 3.1.2. As can be observed in Figure 5, a comfortable office chair was then adjusted to provide an approximate 90° knee bend when the bare right foot was resting on the stimulation apparatus. The foot was positioned so the end effector was resting at the center of the inner arch. To maintain approximately equal contact pressure across participants, the height of the end effector was adjusted by first lowering it to the minimum, then raising it until the participant would report feeling the tip, and then raising it further by 1.4 mm (2 turns of a 0.7 mm coarse pitch M4 bolt).

To ensure maximum attention to the stimulus, care was taken to minimize potential sources of distraction. Although the experiment was conducted in a large laboratory room located on a moderately busy floor, ambient sound was not considered to be a concern since participants wore headphones through which either the auditory stimulus or pink noise was played at a volume sufficient to mask background sound. Participants were asked to close their eyes and open them only when prompted by an audible "beep" to rate the stimulus. Before beginning the stimulation, they were informed that the researcher would be sitting on a chair outside of their field of view, and would be the only other person in the room during the experiment.

Excluding the initial information session and signature of the consent form, the total duration of the experiment was approximately 30 minutes, with the exception of one participant whose session extended to approximately 45 minutes.

3.3 Stimuli presentation

The stimulus presentation approach employed for both phases of the experiment began with a two-minute pre-stimulation period to allow for the acquisition of baseline physiological signals [45], followed by a sequence of stimuli and pauses, as illustrated in Figure 6. A 5 s pause was allowed between the stimulation and the self-reporting period to ensure that mirthful reactions were not interrupted by the prompt, indicating the need to report. This short pause, the rating time and a supplementary delay were included to ensure a pause of at least 15 s between the end of a stimulus and the onset of the next as suggested by the PsychLab guide [1]. The order in which stimuli were presented to the participant was randomized, ensuring that same stimulus or stimulus pair was not rendered twice sequentially. Although all phases of the experiment used this stimulation-report-pause sequence, the nature of the stimuli varied, as described in further detail in Sections 4.1 and 5.1.

(a) (b)

Fig. 5: Experimental setup: (a) experimental scene and (b) physiological sensors placement on the subject's non-dominant hand

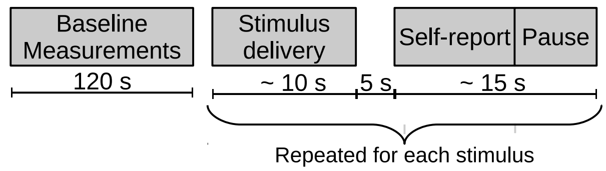

Fig. 6: Time line presentation of the experimental procedure

3.4 Participants

A total of 10 subjects (4 male, 6 female) participated ($\overline{x}$= 20.9 years old, σ=3.14 years) in both phases of the experiment, conducted sequentially in a single session. Participants were healthy undergraduate and graduate students of McGill University from different faculties, recruited through internal mailing lists and social networks. No participants reported known health conditions or being under medication known to potentially affect their tactile sensitivity. In addition, participants were pre-screened to ensure that none were suffering from gelatophobia: the fear of being laughed at. Participants enrolled on a voluntary basis and received a monetary compensation of $10 (CAD) for their time.

4 Phase I: Response to laughter recordings

In order to disambiguate between the effects of laughter and tickling stimulation, the first experimental phase al-

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TABLE 2: Selected auditory excerpts, their duration, the gender of the laughing person and finally the reported mean perceived laughing intensity. Presented mean PLI is computed from samples collected during the pilot.

Filename	Duration (s)	Gender	Mean PLI
1_368300_379309.wav	11	F	2.33
20_468385_477132.wav	8.75	F	4.67
6_109888_121850.wav	11.96	M	7
waterfall.wav	10	N/A	N/A

lowed the gathering of participants' responses to laughter stimulation alone. Additionally, it served as a validation for the selected auditory stimuli set and reproduced the results of previous studies regarding the behavioral, physiological and affective responses to presentation of laughter recordings.

4.1 Methodology

4.1.1 Stimuli

The auditory stimuli consisted of three selected laughter recordings taken from the AVLaughterCycle database [46]. This particular database is known for its high-quality recordings and reliance on natural laughter, as opposed to forced laughter executed by actors, as presented in the PinoyLaughter [47] and the MMLI databases [48]. All 1001 laughter excerpts present in the database were listened to, analyzed and screened based on the following set of criteria: duration, gender and perceived laughter intensity (PLI). A stimulus duration of approximately 10 seconds was selected as it allowed for a clear representation of the onset, apex and offset phases of the laughter burst. Therefore, all excerpts that were below 8 and over 12 seconds were automatically filtered out, removing a significant amount of heavy exhaling recordings, which were deemed unrepresentative of laughter. For the final selection of auditory stimuli, PLI was evaluated by five lab members on a seven-point Likert scale (1–not laughing at all to 7–laughing hysterically). For this assessment, recordings were presented sequentially using a pair of Sony MDR-ZX310 over-ear headphones in a quiet laboratory space and rated using the same interface employed in the final experiment (see Figure 3). A recorded laughter gender ratio of 50% was desired to avoid or reduce the likelihood of interaction with the participant's gender but ended up being $1/3$ male and $2/3$ female, due to constraints imposed by the duration, the need for variability in the PLI of the recordings, and the desire to maintain a reasonable duration of the experiment.

Table 2 presents the chosen auditory excerpts and their properties. Using the mean PLI acquired during the pilot, the following labels were attributed to each auditory stimulus: low intensity laughter (LL), medium laughter (ML) and intense laughter (IL). A fourth stimulus, consisting of a recording of a waterfall was used as a control auditory stimulation (CS). It was selected for its neutral valence and arousal rating, as reported by Weninger et al. and Schuller et al. [49], [50].

4.1.2 Procedure

Once participants were positioned as specified in Section 3.2, they were presented with an example laughter recording, and the interface used to rate its valence, arousal and PLI (see Figure 3). The example excerpt was not part of the experimental stimuli and was chosen for its medium to low PLI to avoid within-subject contagion effect. Following the exposition to and rating of the example stimulus pair, a 2-minute period was allowed for baseline measurements of the physiological signals. Then, the stimulation-report-pause sequence took place as presented in Section 3.3.

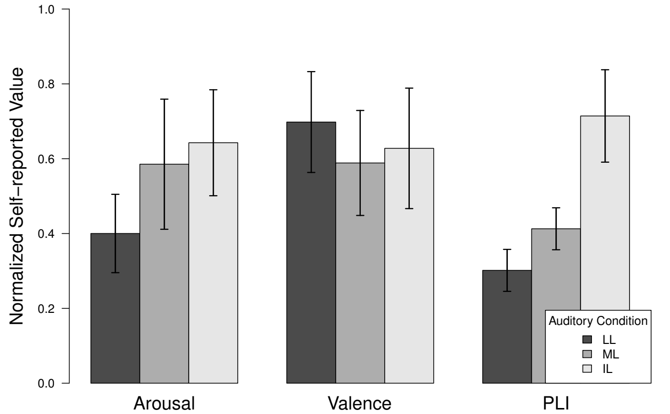

Fig. 7: Normalized self-reported values of arousal, valence and perceived laughter intensity (PLI) for the three auditory conditions (LL, ML and IL). Error bars represent the 95% confidence interval on the mean (1.96 standard error from the mean).

4.2 Results

4.2.1 Self-Ratings

A one-way repeated measures ANOVA was used to investigate the effects of laughter recording on self-reported arousal, valence and intensity. As shown in Figure 7, both self-reported arousal and laughter intensity were significantly affected by the laughter excerpt (F(3,80)=8.598, p<.01 and F(3,80)=32.909, p<.0001) while valence was not significantly affected (p>0.05). A Tukey HSD test demonstrated that both intense laughter (IL) and medium laughter (ML) recordings were perceived as significantly more arousing than the low intensity laughter (LL) excerpt (z=3.029 p<.01 and z=3.967 p<.001). Additionally, IL was perceived as more intense than both ML ($z_{IL-ML} = 5.729$ p<.001) and LL ($z_{IL-LL} = 7.839$ p<.001), while the difference between ML and LL was not significant ($z_{ML-LL} = 2.111$ p>.05).

Taking into account the subjectivity of self-ratings, the rank-order correlation coefficient was used to test for potential correlation between subjects' ratings and their reported pre-experiment mood. No significant monotonic correlation was observed between any combination of BMIS mood axes and values reported by participants.

4.2.2 Behavioral Assessment

Analysis of facial expressions from video recordings was performed following the coding approach described in Section 3.1.2. Table 3 presents a summary of the participants' responses to the auditory excerpts. Considering the auditory nature of the stimulation, no observations of responses,

TABLE 3: Summary of behavioral assessment by laughter recording and response

	Response observation count		
	0	1	2
Laughter Recording	No Response	Voiceless Smile	Laughter
LL	8 (80%)	2 (20%)	0 (0%)
ML	7 (70%)	3 (30%)	0 (0%)
IL	4 (40%)	2 (20%)	4 (40%)

coded as "3-twisting and wiggling in response to the stimulus" and "4-subjects pulls limb away from tickling device", were made. Thus, the table only includes the first three ordinal elements.

Additionally, a Spearman's rank-order correlation test was run to determine if a relationship existed between subjects' reactions and their self-reported arousal, valence, and perceived laughter intensity. A moderate negative correlation was observed between reported arousal and the behavioral evaluation of stimuli ($r=-0.386$, $p<.05$) while no significant correlations were observed for valence and PLI ($p>0.05$).

To gather further insight regarding the responses, post-hoc Spearman's correlation tests were used to explore the potential correlation between the participants' mood prior to the experiment and their facial expressions during stimulation. Positive monotonic correlations were observed between the participants' initial mood, reflected by the unpleasant-pleasant axis ($r=0.62$, $p<.001$), the tired-positive axis ($r=0.41$, $p<.05$) and their behavioral responses.

4.2.3 Physiological Signals

A within-subjects one-way ANOVA was used to assess the main effect of auditory stimulation on observed mean and standard deviation (SD) of relative within-excerpt heart rate, skin conductance, skin temperature and respiration rate. Baseline measurements were also included in the analysis to provide a control condition for comparison. Significant effect of auditory stimulus on physiological signals were observed on heart rate SD ($F(3,80)=12.69$, $p<.0001$), respiration rate mean ($F(3,80)=8.18$, $p<.001$), mean skin conductance ($F(3,80)=27.39$, $p<.0001$), and skin temperature mean ($F(3,80)=78.19$, $p<.0001$) and SD ($F(3,80)=4.12$, $p<.0001$).

A Tukey HSD multiple comparison test showed that the heart rate SD was significantly lower when presented with any laughter conditions than during the baseline but did not significantly vary between the auditory conditions ($z_{LL-CS}=-3.981$ $p_{LL-CS}<.001$, $z_{ML-CS}=-4.312$ $p_{ML-CS}<.001$, $z_{IL-CS}=-3.915$ $p_{IL-CS}<.001$).

Only the intense laughter stimulus created a significant increase in mean respiration rate ($z=4.495$, $p<0.001$), likely due to the effect of higher frequency series associated with the expression of laughter.

Additionally, event-related skin conductance responses and decreases in skin temperatures were observed across all stimulation condition. Within the laughter stimuli, only intense laughter was found to exhibit a significantly lower temperature drop than low intensity laughter ($z=-3.026$, $p<0.05$).

A post-hoc Spearman's correlation test was run to evaluate monotonic correlation between subjects' physiological signals and self-reported arousal, valence, perceived laughter intensity (PLI), and coded behavioral assessment. A summary of the results is presented in Table 4.

4.3 Discussion

Phase I of the experiment was not intended to directly address our research questions. Instead, it was meant to measure baseline responses to unimodal laughter stimulation and validate the choices of laughter excerpts in their ability to induce meaningful physiological and behavioral responses.

As we expected, the self-reported perception of recorded laughter intensity was positively rank order correlated with reported arousal ($r=0.41$, $p<.05$) while the reported valence did not vary significantly across conditions. We hypothesize that the lack of social context surrounding the stimulation prevented significant effects on the perceived pleasantness of the stimulation. This observation highlights the importance of context awareness in the use of mood induction procedures. Previous evidence showing a decrease in pleasantness associated with hearing a relatively long sequence of laughter was not observed in our case [51]. We expect that the use of different alternating laughter stimuli attenuated the effect to a state of non-significance. In addition, a repeated measures ANOVA conducted on all subjective ratings revealed that no statistically significant difference was attributed to the presentation order within the same auditory stimulation condition ($p>.05$).

Counterintuitively, the self-reports of arousal, valence and PLI did not significantly vary with the subject's reported mood, obtained by means of the BMIS questionnaire. However, observations show that participants whose initial mood was scored higher on the unpleasant-pleasant and the tired-positive dimensions expressed more mirthful reactions to the hearing of laughter. These findings are in agreement with a naive conception of laughter, i.e., you are more likely to exhibit mirthful reactions and signs of enjoyment if you are in a positive mood or mindset. However, they contradict findings of Devereux and Ginsburg who observed no correlation between pre-experiment mood assessment and the laughter reactions of participants [52]. The results therefore support the hypothesis that the pretreatment emotional state and/or mood is more significant than the stimulus in predicting laughter responses of subjects. It is noteworthy that the reports of perceived laughter intensity by participants were in complete rank-order agreement with the results acquired during preliminary testing with lab members, supporting the validity of our selection process for laughter recordings.

In accordance with the auditory perception literature, the choice of auditory excerpt affected physiological responses of the participants, reflecting activity of the autonomic nervous system [53]. Our results are in agreement with the findings of Averill, who measured physiological responses of subjects under various emotional states [54]. In both cases, participants exhibited significant increase in skin conductance and reduction of skin temperature levels as the

TABLE 4: Spearman's correlation coefficients computed between subjects' physiological signals and self-reported arousal, valence, perceived laughter intensity (PLI) and behavioral assessment. (p< 0.5*)

	Heart Rate		Respiration Rate		Skin Cond.		Skin Temp.	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Arousal	0.049	0.055	0.037	**-0.394***	0.162	-0.365	**-0.414***	**0.442***
Valence	-0.083	-0.080	**-0.392***	0.127	0.158	0.139	-0.358	-0.268
PLI	0.177	-0.252	0.234	0.118	-0.024	-0.008	0.012	-0.068
Behavioral (Camera)	0.007	0.046	**0.507***	**0.615***	-0.047	0.118	0.135	-0.281

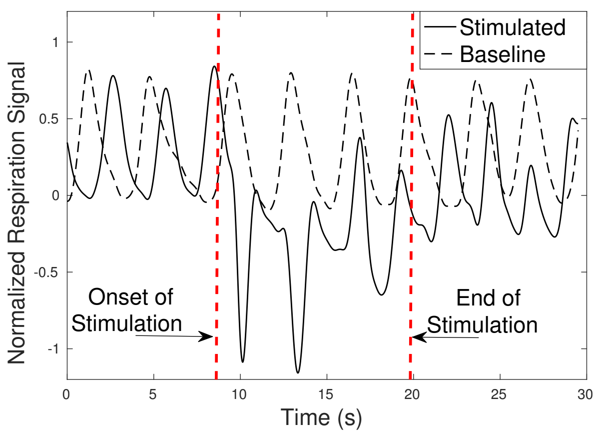

Fig. 8: Sample of participant 1's respiration signal in baseline and observed laughter state, as determined from recorded facial expressions.

self-reported arousal increased. Furthermore, we hypothesize, from the significant effect of stimulation condition on within-excerpt respiration rate, and the significant strong correlation between behavioral assessment and respiration rate, that these variations are due to mirthful reactions of the subjects. A noticeable difference in the pattern can be observed in the reactive case (see Figure 8), interrupting the regular breathing rhythm with an incomplete inhalation followed by sudden exhalation segments, before returning to regular breathing pattern.

The first phase of the experiment allowed us to obtain base measurements of the ability of the selected laughter recording to induce mirthful reactions. Of the ten participants, four did not demonstrate any behavioral evidence of pleasure or joy during stimulation, two exhibited at most a voiceless smile, while the remaining four participants laughed only when presented with the intense laughter condition. This low rate of very intense response may be due to the fact that the participants were not screened for their mood, sense of humor, etc., as some other studies have done in the past. It is hypothesized that by not screening participants in such a manner, our study is more representative of the general population, and allows us to quantify more effectively the correlation between self-reports of general ticklishness, behavioral and physiological responses to the tickle sensation.

5 Phase II - Response to laughter recordings and tickling

The second phase of the experiment aimed to quantify the key elements required to address the research questions: how vibration frequency affects the intensity of the perceived tickle sensation, how intensity of a vibration-induced tickle is affected by auditory stimulation, and the ability of the proposed multimodal approach to elicit laughter.

5.1 Methodology

5.1.1 Stimuli

The auditory stimulus set was composed of the same excerpts employed in Phase I of the study. It consisted of three laughter recordings of varying perceived laughter intensity (PLI) accompanied by a neutral arousal-valence-rated recording of a waterfall (LL, ML, IL and CS respectively).

The tactile stimuli, delivered through our custom stimulation interface, consisted of four unique vibration signals rendered at the center of the inner arch of the right foot, tangentially to the skin, without regard to the reported dominant foot of the participant. This choice of stimulation site was motivated by the results of Kennedy and Inglis, who found no or a negligible presence of fast-acting and slow-acting mechanoreceptors in that region, thus reducing the ability of participants to differentiate between frequencies [55]. This site, due to its geometry, would also allow the integration of vibrotactile actuators and accompanying circuitry into a possible insole or instrumented shoe implementation of the system. The four sinusoidal vibration frequencies: 10, 70, 100 and 200 Hz were chosen based on their ability to induce tickle sensations to various degrees. This was determined during a pilot study involving ten lab members who were asked to rate the ticklishness of ten frequencies using the same experimental framework as the present study. Five of these lab members later participated in the determination of the PLIs, but were not otherwise involved in the experiment. Table 5 presents the association between the reported ticklishness, vibration stimulus frequency, and associated condition labels used for the remainder of this article.

Using a full-factorial, within-subject experiment design resulted in a total of sixteen different audio-tactile stimulus pairs. Considering the subjectivity of ticklishness and the ambiguous nature of self-assessment, each stimulus pair was presented three times to each participant in random order, distributed throughout the experiment, ensuring that the same pair was never rendered twice sequentially.

5.1.2 Procedure

Since both phases of the experiment were held during the same session, the participants were already familiar with the research objectives and instructions, and were already wearing the physiological sensors.

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TABLE 5: Association of vibration frequency to ticklishness

Frequency (Hz)	Ticklishness	Condition Label
10	Low	**LT**
70	High	**HT**
100	Medium	**MT**
200	Very Low	**VLT**

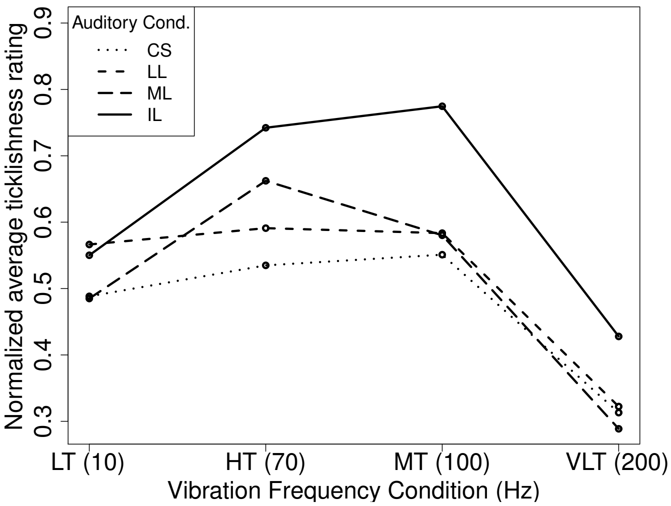

Fig. 9: Normalized self-reported ticklishness for each frequency and auditory condition type. Error bars were omitted for legibility.

Presentation of stimuli followed the convention presented in Section 3.3. However, considering the duration of the experiment session and the desensitizing nature of the tactile stimulation, participants were asked to take 2-minute pauses after every twelve stimulations (three pauses in total), to ensure their comfort and allow for adequate resensitization of the foot.

5.2 Results

5.2.1 Self ratings

To confirm the observable scaling effect of laughter on ticklishess, illustrated in Figure 9, a conventional one-way repeated measures analysis of variance was employed. The results demonstrate a significant effect of aggregated auditory conditions on the perceived tickle sensation intensity ($F(1,18)=6.841$, $p<.05$).

Of direct relevance to our first research question, a two-way repeated measures ANOVA was employed to quantify the effect of auditory and vibrotactile stimulation conditions on self-reported ticklishness. Significant main effects of both tactile ($F(3,320)=38.866$, $p<.0001$) and auditory ($F(3,320)=9.020$, $p<.0001$) stimulation conditions were observed with no significant interaction ($p>0.05$). Mean within-subject normalized self-report of the perceived tickle sensation intensity are presented in Figure 9, allowing a visualization of the trend associated with tactile stimulation, and the scaling effect of the auditory stimulation conditions.

Using a Spearman's test to explore rank-order correlation between the reported initial mood state and the self-reported perceived ticklishness, showed no significant correlation with any of the mood dimensions ($r_{ArousalCalm}$ =0.08, $r_{NegRelax}$ =0.03, $r_{PleasantUnpleasant}$ =-0.04, $r_{TiredPos}$ =-0.02, all $p>.05$).

TABLE 6: Spearman rank-order coefficients, and associated p-values, between behavioral assessment and self-reports of ticklishness, self-assessed general ticklishness and the four mood dimension scores obtained with the BMIS questionnaire.

	r	p-value
ticklishness self-ratings	.02	.72
general ticklishness	**.46**	**0.01**
arousal-calm	**-.12**	**<.001**
negative-relaxed	**-.41**	**<.001**
unpleasant-pleasant	**.69**	**<.001**
tired-positive	**.25**	**<.001**

The self-assessed general ticklishness obtained in the pretest questionnaire showed a weak monotonic correlation with the self-reported ticklishness of stimuli ($r=0.31$, $p<.001$). Similarly, a weak monotonic correlation was observed between the self-reported stimulus ticklishness and the participants' ratings of perceived stimulus laughter intensity, as obtained in Phase I of the experiment ($r=0.196$, $p<.001$).

5.2.2 Behavioral assessment

Of the ten participants, four did not show any sign of mirth over the course of the experiment, three exhibited at most a voiceless smile, and the remaining three participants demonstrated laughter.

Behavioral responses of the participants during multimodal stimulation were analyzed using a two-way repeated measures ANOVA. No significant effects of laughter recording, vibration frequency condition, or interactions were observed ($p>.05$). While the tactile stimulation by itself, under the auditory control condition, induced smiling responses in 17% of its presentations, it did not successfully induce gargalesis reactions. Additionally, the behavioral assessment showed meaningful rank-order correlation with the different mood dimensions as well as the pre-experiment general ticklishness self-report (see Table 6). Self-ratings of stimulus ticklishness did not exhibit significant correlation with the behavioral assessment, suggesting a discrepancy between the reported and expressed sensation.

The behavioral assessment did not show signs of rank-order correlation with the valence of the reported laughter recordings and PLI, obtained during Phase I ($r_{valence}$ =0.05, r_{PLI} =0.06, both $p>.05$). However, they exhibit a weak negative monotonic correlation with the self-reported arousal ($r=-0.326$, $p<.001$).

5.2.3 Physiological measurements

A two-way repeated measures ANOVA was used to assess auditory and tactile stimulation effects on within-excerpt individual physiological signals, i.e., heart rate, respiration rate, skin conductance and skin temperature. Statistical details and results of the analysis are presented in Table 7. Significant main effects of both auditory and tactile stimulation condition were found on heart rate SD, respiration rate mean and SD, and skin conductance mean. In addition, significant main effects of the tactile stimulation condition were observed on skin temperature mean. No significant interaction between auditory and tactile modality was observed for any of the physiological signals.

To assess the potential relation between observed physiological responses and self-reported ticklishness of each stimulus, Spearman's rank-order correlation test was performed. The majority of significant correlations were very weak ($0<r<0.19$) or weak ($0.20<r<0.39$) (see Table 8). The same Spearman test was applied to evaluate the correlation between the physiological signals and the behavioral responses of participants, captured using a camera. For this latter test, moderate negative correlation was observed in the case of within-excerpt mean heart rate value, while very weak to weak correlation was observed for the other physiological signals (see Table 8).

For identification of physiological changes specific to the tickle sensation alone, post-hoc Spearman rank-order correlation tests were computed between physiological signals and the self-reported sensation. The data used for this specific test included the multimodal stimulus conditions but excluded data points where behavioral coding exceeded a "voiceless smile". The objective was to remove the potential effect of expressed laughter on the physiological signals. Statistically significant monotonic correlation was observed between behavioral responses and mean heart rate ($r=0.185$, $p<.001$), mean skin conductance ($r=-0.137$, $p<.05$) and SD ($r=0.265$, $p<.001$), and mean skin temperature ($r=-0.159$, $p<.01$) and SD ($r=0.16$, $p<.01$).

5.3 Discussion

5.3.1 Research Question 1

Our first research hypothesis, stating that a repeatable relationship exists between the frequency of a vibrotactile signal and its perceived ticklishness is tentatively confirmed by our observations. Indeed, self-reported intensity of the tickle sensation under each stimulation condition (see Figure 9) demonstrates a clear relationship between vibration frequency under the foot and the perception of this emotion-rich sensation. Due to the frequency step size between each vibrotactile conditions, it is impossible to pick the single point at which the percept is maximized. However, it is possible to assume with moderate confidence that it lies within the 70 to 100 Hz interval. It is equally important to note that as far as our experimental protocol is concerned, these conclusions are limited to the arch of the foot, which, as noted earlier, has a low concentration of mechanoreceptors [55]. Therefore, applying the same stimuli to a more tactually discriminative region, even remaining in known ticklish zones, would likely modify the perceived sensation.

Since this study presents the first quantification of perceived ticklishness as a function of vibration frequency, and given the highly subjective nature of self-reporting the sensation, we wanted to ensure that subjects were not responding to more basic parameters of the stimulus. To this end, we accounted for the perceived amplitude of vibration through the pre-experiment calibration. Furthermore, we note that the bell-shaped curve observed in Figure 9 does not appear in previous frequency perception experiments under the feet. Instead, these reported a decreasing relationship between perception and frequency for the 10–500 Hz frequency band, with peaks at the active frequencies for particular mechanoreceptors [56], [57]. This discrepancy of results suggests that although the two vibrotactile parameters of amplitude and frequency are likely related, participants were not basing their self-reports using these parameters, but instead, on the desired tickling sensation.

5.3.2 Research Question 2

Our second research question relates to the potential scaling effects of the auditory stimulation, in this case laughter, on the self-reported intensity of the tickle sensation. Our hypothesis was confirmed as the simultaneous hearing of laughter was observed to have a significant scaling effect on the perception of ticklishness. The observed amplifying effect was found to be positively correlated with the perceived laughter intensity (PLI) and reported arousal of the recordings, assessed during the experiment.

Hence, while we are convinced of its scaling abilities, further analysis would be required to determine what features of the auditory stimulation was responsible for the observed effect. Assuming the underlying cause stems from laughter-specific features, a potential reductionist explanation could be drawn from the conditioning theory. Indeed, since the majority of our tickling experiences are accompanied by laughter from the tickler and/or observers, an association between the intensity of the tactile sensation and the auditory stimulation could have developed over time and exposure. However, while we are inclined to attribute the amplification effect to laughter-specific effects, the scaling effect could also be due purely to hardwired interaction between the tactile experience and the acoustic features of the auditory stimulation [29], [39], [58]. The recruitment of more participants would equally provide insightful data and increase the significance of the results.

5.3.3 Research Question 3

During experiment phase II, neither the influence of the tactile nor auditory stimulation on the behavioral responses of participants was found to be statistically significant. This result was unexpected, as phase I and prior experiments on the topic already demonstrated the significant contribution of laughter recordings to the elicitation of mirthful responses. This result contradicts our third hypothesis that the combined tickle sensation and sound of laughter would generate more mirthful reactions in subjects. Anecdotally, the tactile stimulation, under the control auditory condition, induced smiling responses in 17% of the cases where it was presented but did not successfully induce gargalesis reactions. We hypothesize that this lack of direct effect of tickling on mirthful responses may be due to the perceived intensity of the tickle sensation induced by the system. Indeed, behavioral responses suggest that these sensations were not intense, failing to provoke withdrawal reactions as was observed in the literature [21]. This may have been caused by the limitations of the single-point stimulation that was used, in contrast to a feather or cotton swab

TABLE 7: Statistical details associated with two-way repeated measures ANOVAs investigating the effects of auditory and tactile stimulation on physiological signals. Statistically significant results (p<.05) are in bold. The label, *Int.*, refers to the audio-tactile interaction term. For legibility, degrees of freedom ($\mathrm{df}_{Tactile} = 3$, $\mathrm{df}_{Auditory} = 3$, $\mathrm{df}_{Interaction} = 9$ and $\mathrm{df}_{WithinSubject} = 320$) are omitted from the table.

		Heart Rate		Resp. Rate		Skin Cond.		Skin Temp.	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Tactile	F-stat	1.404	92.72	6.801	31.05	90.91	5.415	7.744	1.407
	p-value	.23	<.001	<.001	<.001	<.001	<.001	<.001	.23
Audio	F-stat	0.416	70.14	6.383	26.93	71.97	1.522	0.979	0.680
	p-value	<.001	<.001	<.001	<.001	<.001	.21	.40	.56
Int.	F-stat	1.566	1.560	1.285	0.362	0.675	1.188	1.056	0.718
	p-value	.11	.11	.23	.97	.76	.29	.40	.72

TABLE 8: Summary of Spearman's rank order coefficients evaluating monotonic correlation between subjects' physiological signals and self-reported ticklishness of a stimulus and camera-based assessment of facial expressions. ($p < 0.5$*,$p < 0.01$**)

	Heart Rate		Resp. Rate		Skin Cond.		Skin Temp.	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Self-Report	**0.12***	-0.00	0.05	0.07	**-0.14****	**0.11***	**-0.15****	-0.04
Facial expressions	**-0.51****	**-0.31****	0.09	**0.20****	**0.13****	-0.05	**0.15****	**-0.14****

being dragged on the skin, in previous tickling-related experiments. The expressive responses were instead found to be more closely dictated by the pre-experiment mood of the participants. The observed rank-order correlation coefficients (from Tables 4 and 8) indicate that the initial mood assessment on the unpleasant-pleasant dimensions is a better predictor of successful laughter elicitation in the multimodal than in the auditory only stimulation context.

It should be noted that the experimental context may have affected the observations of naturally occurring laughter. Even though the stimuli were inspired by human-human interactions, their removal from the ecologically valid context involving direct social interaction may have affected the way they were interpreted by participants. Indeed, the observation and elicitation of natural laughter has been an ongoing challenge for researchers due to overt and covert inhibition of emotional expressions by participants. Furthermore, there is a possibility that what was coded as mirthful responses using video recordings may have been visually equivalent responses invoked by different internal emotional states such as nervousness, anxiety and fear.

5.3.4 Further Discussion

Of interest to our work is a distinction of the roles played by the subjects' expression of laughter from the effects of tickling on observed physiological responses. In this regard, Table 8 provides a comparison of the rank-order correlation between physiological signals and self-reports of stimulus ticklishness in the case of observed laughter responses. Similar results are summarized in Section 5.2.3 for the case in which no facial expression responses are observed. A brief inspection of the results under the expressive and non-expressive cases outlines that situations in which laughter was not expressed did not exhibit all of the physiological changes observed when the response was accompanied by mirthful expressions. As could be anticipated, in the case of expressed laughter, the behavioral responses were significantly reflected the respiration related signals (as seen in Figure 8). On the other hand, the knismesis tickle sensation was hardly distinguishable from physiological responses observed during arbitrary startling stimuli: a positive event-related skin conductance response, drop in skin temperature and a sudden acceleration of the subject's heart rate. However, similarly to the music induced "chills", it is hypothesized that more obvious physiological variations could be observed given a stronger induction of the complex somatosensory experience [39].

Following the guidance of Perneger [59], we did not apply p-value correction methods, since the results presented do not pertain to the block acceptation or rejection of a single research hypothesis, and the majority of the tests were planned before data collection. In addition, there exists no consensus as to which correction method is appropriate, nor how such corrections should be applied, with the field of affective computing.

6 Conclusion and Future Work

In an effort to explore novel emotion-elicitation approaches, this study investigated the relationship between a laughter stimulus and the perception of the tickling sensation. Leveraging the capabilities of our custom vibration rendering device and a combination of traditional self-reports, facial expression analysis and physiological measurements, we presented the first evidence linking vibration frequency to the perception of the tickle sensation. Furthermore, our observations suggest that a significant scaling effect on the perceived ticklishness of the tactile stimulation is experienced when participants are simultaneously exposed to laughter recordings. While laughter recordings alone achieved good performance at eliciting mirthful reactions, our results suggest, contrary to our initial hypothesis, that the addition of the tactile modality did not significantly increase observed occurrences of laughter. The lack of a social context during the experiment may have negatively impacted the expression of mirthful responses. Moreover,

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while tickling is an emotion-rich tactile interaction, it is not universally associated with mirthful experiences. Under certain circumstances, it may have a negating effect on the laughter stimulus. Whether these observations were due to the limited tickling ability of the rendering system, a true non-additivity of laughter and tickling or a lack of social context is left as a question for future experimentation.

This first study on the combined use of laughter recordings and the tickle sensation attempted to address key questions that can inform the design of future affective interfaces, by providing a better understanding of the relationship between delivered stimulus and expected perceived intensity of emotion-rich tactile feedback. We recognize that tickling is a complex phenomenon, which is impacted by many other factors than vibration frequency alone. Due to the small sample size and the few publications on tickling and laughter, the authors wish to emphasize the exploratory nature of the results obtained, and hope that this study will encourage others to replicate the experiments, further exploring the questions it raises. A dedicated study on the physiological responses to tickling would be necessary to fully quantify its effects on the autonomic nervous system, and to differentiate between the casual tactile stimulus and the more complex tickle sensation itself. Such findings would complement previous neurophysiological findings [60], [61] and close the loop for this affective touch interaction by allowing the detection of successful sensation elicitation. Nevertheless, the findings reported in this article represent an important incremental step towards an understanding of ANS responses to emotion-rich tactile feedback.

Finally, there is an open question as to the range of contexts in which it is both feasible and appropriate to employ such tickle-inducing strategies to modify the affective state of a user. In terms of technological feasibility, existing haptic shoe and insole technologies could theoretically be used as rendering platforms, similar to the "phantom slippers", to elicit the tickling sensation and potentially induce mirthful behaviors [23]. As suggested by our results, the choice of actuation mechanism integrated in such systems would be crucial to its effectiveness at inducing the tickle sensation under the foot. Indeed, linear reasonant actuators (LRA), unlike eccentric rotation mass (ERM) and voice-coil actuators, cannot vibrate with reasonable amplitude in the frequency band of interest.[2] In addition, the novel use of laughter playback to augment the perceived intensity of such stimulus could be harnessed to provide perceptually equivalent sensations using less energy. It is also hypothesized that the proposed audio-tactile approach could be more effective than picture and video based MIP in the wild as its reliance on haptics to convey emotion-rich sensations offloads the visual sense, allowing full environmental awareness.

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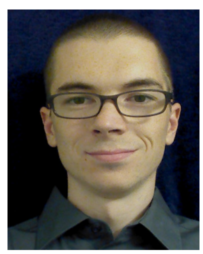
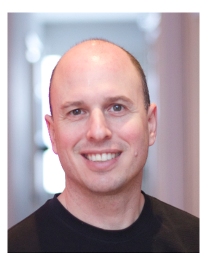


Pascal E. Fortin received the bachelor of engineering degree in electrical engineering from University du Quebec a Chicoutimi. He is currently a PhD candidate in electrical engineering at McGill University's Shared Reality Lab. His research interests include affective computing, physiological signals processing and human-computer interactions. He is a student member of the Centre for Interdisciplinary Research in Music Media and Technology and IEEE.



Jeremy R. Cooperstock is an associate professor in the department of Electrical and Computer Engineering, a member of the Centre for Intelligent Machines, and a founding member of the Centre for Interdisciplinary Research in Music Media and Technology at McGill University. He directs the Shared Reality Lab, which focuses on computer mediation to facilitate high-fidelity human communication and the synthesis of perceptually engaging, multimodal, immersive environments. Cooperstock's work on the Ultra-Videoconferencing system was recognized by an award for Most Innovative Use of New Technology from ACM/IEEE Supercomputing (2005) and a Distinction Award from the Audio Engineering Society (2001). The research he supervised on the Autour project earned the Hochhausen Research Award from the Canadian National Institute for the Blind (2013) and an Impact Award from the Canadian Internet Registry Association (2012), and his Real-Time Emergency Response project won the Gold Prize (brainstorm round) of the Mozilla Ignite Challenge (2012).