Effects of Visual Locomotion and Tactile Stimuli Duration on the Emotional Dimensions of the Cutaneous Rabbit Illusion

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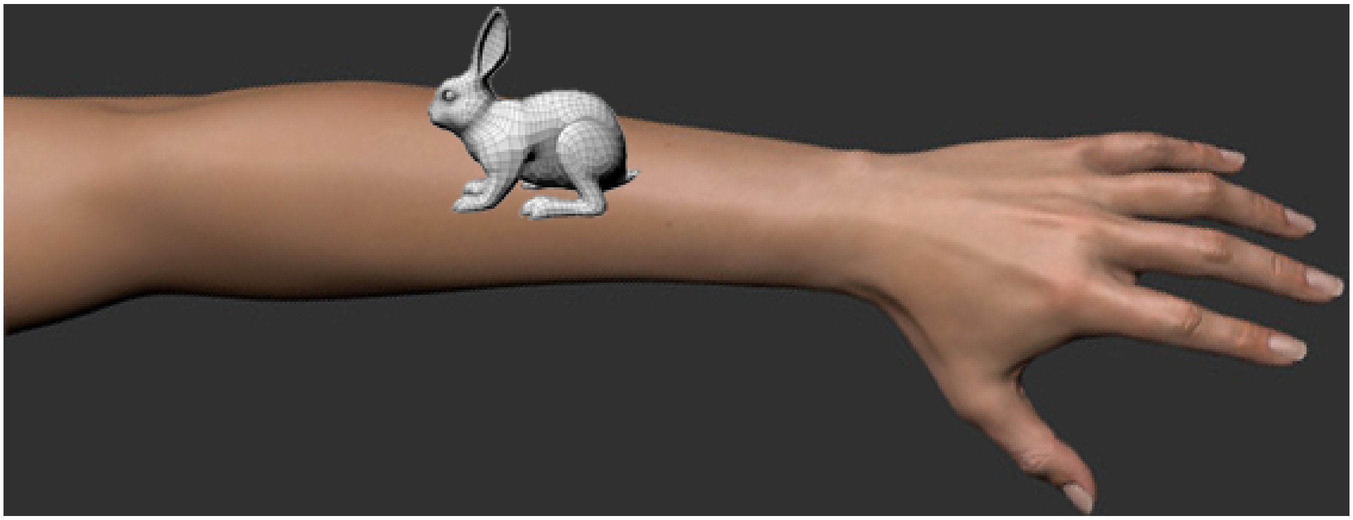

Figure 1: Virtual setup of the cutaneous rabbit illusion.

ABSTRACT

In this study, we assessed the emotional dimensions (valence, arousal, and dominance) of the multimodal visual-cutaneous rabbit effect. Simultaneously to the tactile bursts on the forearm, visual silhouettes of saltatorial animals (rabbit, kangaroo, spider, grasshopper, frog, and flea) were projected on the left arm. Additionally, there were two locomotion conditions: taking-off and landing. The results showed that the valence dimension (happy-unhappy) was only affected by the visual stimuli with no effect of the tactile conditions nor the locomotion phases. Arousal (excited-calm) showed a significant difference for the three tactile conditions with an interaction effect with the locomotion condition. Arousal scores were higher when the taking-off condition was associated with the intermediate duration (24 ms) and when the landing condition was associated with either the shortest duration (12 ms) or the longest duration (48 ms). There was no effect for the dominance dimension. Similar to our previous results, the valence dimension seems to be highly affected by visual information reducing any effect of tactile information, while touch can modulate the arousal dimension. This can be beneficial for designing multimodal interfaces for virtual or augmented reality.

CCS CONCEPTS

• **Human-centered computing** → *Displays and imagers*; **Haptic devices**; **Empirical studies in HCI**; *Mixed / augmented reality*.

KEYWORDS

Cutaneous-Rabbit Illusion, Visuo-tactile Interaction, Mutlimodal Emotions

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1 INTRODUCTION

Our emotions play an important role in our interaction with the world. In real-life situations, they can affect our decision making process leading to drastic changes that can affect positively or negatively our lives [4, 30]. The replication of our world into virtual

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environments has been in human minds as early as 1935; the year Stanley G. Weinbaum published his short novel "Pygmalion Spectacles" that described the first head-mounted display (HMD) [34]. On one hand, we have never been closer to Weinbaum's vision eighty-five years later. The technology progress related to HMDs, from hardware and software perspectives, has been impressive and cutting edge [14, 15, 24]. On the other hand, despite this technological advance, we are still far away from Weinbaum's ultimate vision of an immersive world that not only includes all our five senses, but also provides us with emotional qualia begotten of the virtual experience.

One obstacle that several users face to reach some sort of emotional qualia is the lack of tangible interaction. Hence, the growing need in creating new haptic technologies to enhance the user's immersion. Yet, it is not enough to focus on only improving the quality of the mechanical stimulation, it is also crucial to understand how the haptic device could trigger emotions while interacting with the virtual world. Moreover, it is important to focus on the right kind of emotions. Similar to emotions one comes across in our daily interaction with the "real" world, where fear, surprise, comfort, and sadness are encountered; virtual interactions should allow similar affective demonstrations. However, the intensity of these emotions needs to be monitored and controlled properly in a virtual setting. Since strong emotions often modify humans' physiological responses, a drastic emotional change during the virtual interaction could lead to emotional distress and be potentially dangerous for the user [6, 12, 21]. Take the extreme case of a zombie apocalypse game, where the user can see themselves being eating by a zombie. It would certainly provide some excitement to the player but it would be less enjoyable to feel the physical sensation of being eaten by a zombie.

As haptic researchers, the general goal of our research is 1) to understand how a tactile supplementation is perceived emotionally by the user by evaluating to what extent certain sensations are accepted or rejected, and 2) to provide design principles and guidelines to engineers and designers to help them integrate this technology appropriately in a way it is accepted by the user and becomes fully part of the multimodal interface. A more specific goal related to this study is to understand how the cutaneous saltation (aka. cutaneous rabbit-illusion) affects and is, in turn, affected by visual stimulation.In an ongoing research related to the affective cutaneous-rabbit illusion, our previous work showed that the valence dimension is mainly affected by the visual stimulus offsetting the effect of any tactile stimulation, specifically if this visual stimulus is considered unpleasant. Our research also showed that the arousal and dominance dimensions can be modulated by the tactile stimulation depending on the nature of the visual stimulation [35]. Additionally, we showed that the numerosity of visual stimuli affects the emotional dimensions; with fewer items (3 items) associated with higher rating values on the emotional scale [36].

In the current study, we modified the initial setup by using projected images of saltatorial animals (animals that jump) on the stimulated arm to increase the association between the visual images and the tactile sensations. Based on multisensory integration principles, the integration is more likely when the stimuli are closer in space and time [20, 23, 31]. The purpose was to determine the preeminence of the visual and tactile modalities on the three emotional dimensions and provide guidelines accordingly.

Figure 2: The visual saltatorial locomotion: left: aerial to aerial: taking off condition; right: touchdown to touchdown: landing condition.

An additional emphasis was made on the dynamic nature of the images by focusing on the starting action. Since we are using saltatorial silhouettes, the focus was either on the aerial phase of the visual locomotion or on touchdown of the saltation (see Fig. 2). We expect that trials that start with an animal jumping would have higher emotional values, suggesting an acceleration effect, compared to ones starting in a touchdown position.

2 THE CUTANEOUS-RABBIT ILLUSION

The first description of the Cutaneous-Rabbit Illusion dates back to 1972 by Frank Geldard and Carl Sherrick [11]. It is also known as cutaneous saltation of the cutaneous-rabbit effect (CRE). When participants received equidistant tactile stimuli on a low acuity skin area such a forearm, they reported a distributed sensation across the whole area despite that the stimulation was only delivered on specific locations. The tactile illusion has been described by participants as a tiny rabbit hopping on the arm, hence its name.

There are multiple variations of the CRE [7, 9, 13, 33] for multiple applications [16, 18, 19, 25, 32], but we are limiting the explanation to the one used in this study, which is the most common version [27]. As shown in Fig. 3, nine bursts are delivered at three equidistant locations on the forearm for a total recommended duration between 300 and 500 ms, a time interval where the illusion is the strongest [26]. Each location receives three successive bursts. In our experiment, each burst lasted 12, 24, or 48 ms with an Inter-Burst Interval (IBI) of 24 ms resulting in a total time duration between 300 and 624 ms (Table 1).

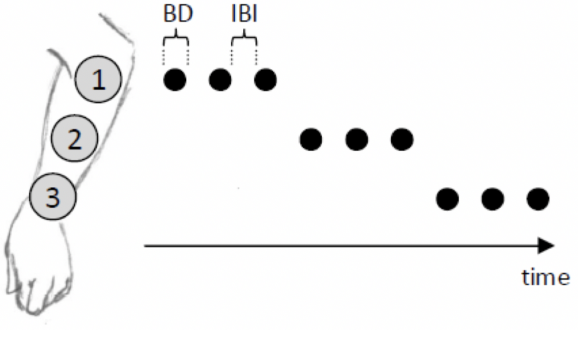


Figure 3: The actuators position on the forearm and the stimulation pattern (from [26]).

Table 1: Duration of the stimulation based on BD variations

Condition	BD	IBI	Total Duration
T12	12 ms	24 ms	300 ms
T24	24 ms	24 ms	408 ms
T48	48 ms	24 ms	624 ms

3 EVALUATION STUDY

3.1 Participants

Twenty-three participants (14 female and 9 male) who participated in this study were right-handed students from Bentley University. Their age varied between 18 and 26 years. They all signed a consent form before their participation and they received a class credit for their participation. The experiment protocol was approved by the Institutional Review Board of Bentley University.

3.2 Setup and Materials

The experimental setup (see Fig. 4) consisted of a sleeve with three C-2 tactors (Engineering Acoustics Inc. [1]) attached to the left forearm. A white screen was then displayed on the forearm to allow the projection of the images. The white screen, a rectangular cover of 33 x 17.78 cm (W x L), was put on the forearm and attached to the desk through Velcro. A mini projector was attached through a custom-made support to the desk to allow an accurate projection on the white screen. The timing and the projection of the stimuli were controlled using Psychtoolbox, a toolbox for psychophysical experiments using MATLAB [2].

3.3 Stimuli

The CRE consisted of nine bursts in three equally-distant locations on the left forearm from left to right (elbow to wrist). An optimum frequency vibration of 250Hz with 0.8 mm amplitude was used for each burst. The duration of each burst was set at 12 ms, 24 ms, or 48 ms, referring to three tactile conditions T12, T24, and, T48 respectively. Simultaneous to the tactile sensations, visual silhouettes of six saltatorial animals (rabbit, kangaroo, spider, grasshopper, frog, and flea) were projected on the left arm (see Fig. 5), i.e. for each tactile burst, a black silhouette appeared on the same location of the burst with the same duration resulting into 9 flashing images on three locations on the forearm. Additionally, there were two locomotion conditions: taking-off (location 1: jumping silhouette, location 2: landing silhouette, location 3: jumping silhouette) and landing (location 1: landing silhouette, location 2: jumping silhouette, location 3: landing silhouette). An example of a trial is represented in Fig. 6.

The main task for participants was to rate the multimodal experience using the Self-Assessment Manikin (SAM) that uses a 9-point graphic scale, depicting cartoon characters expressing three emotion elements: pleasure, arousal and dominance (PAD) shown in Fig. 7. SAM was developed by Bradley and Lang in 1994 [5] and is based on the PAD emotion model of Mehrabian [22].

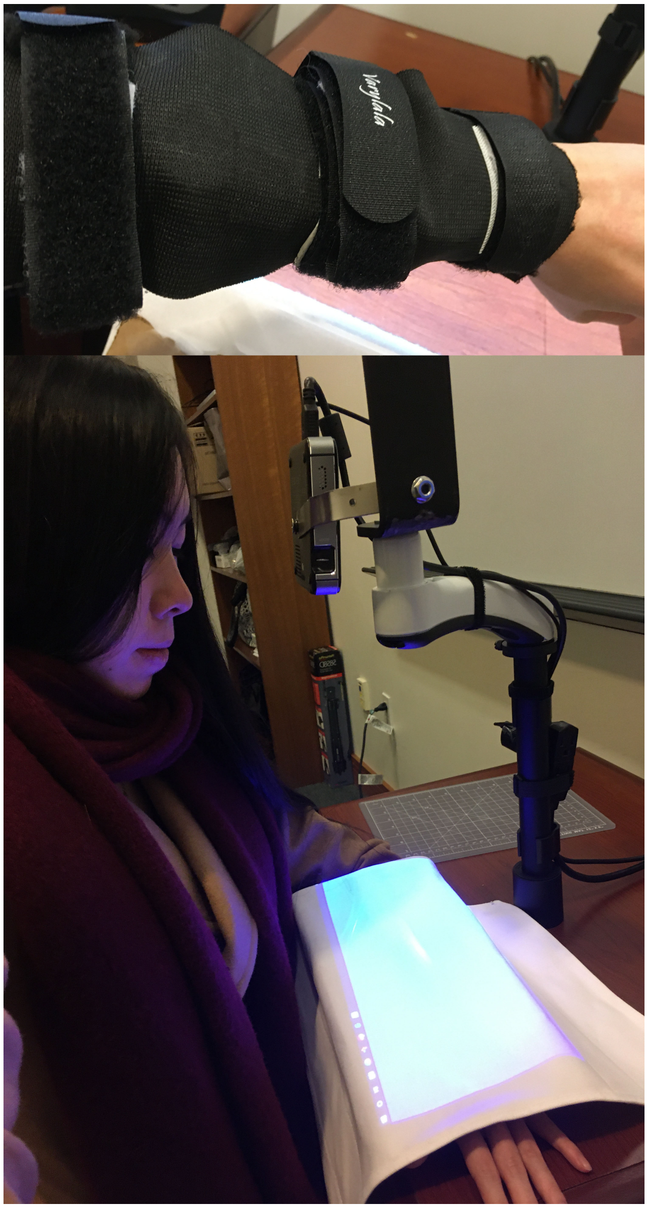


Figure 4: Top: The sleeve made of straps and Velcro to hold the three actuators against the skin. Bottom: Participant looking at the projected screen on her left arm.

3.4 Procedure

After signing the consent form, participants set on an adjustable height seat in a manner their forearm was comfortably positioned in parallel with the table edge. After putting the sleeve on, the white screen was adjusted and the projector was turned on. After introducing and explaining the SAM scale and test the system with six non-recorded trials, participants were instructed to verbally rate their feeling about the tactile stimulation by selecting 1 if they felt completely happy/excited/controlled, 9 if they felet completely unhappy/calm/in control, and 5 if they felt completely neutral,

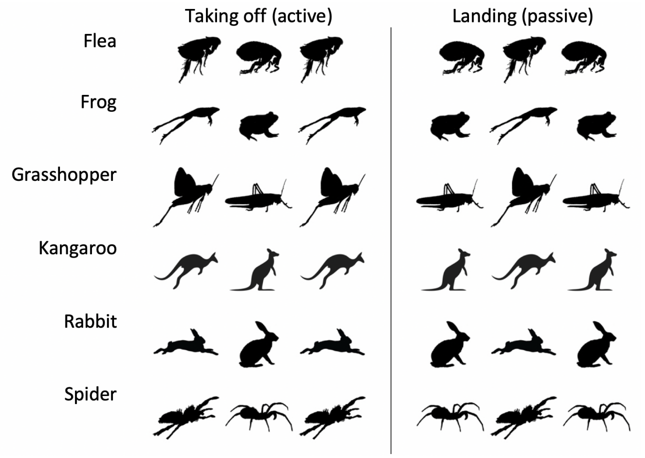


Figure 5: The six saltatorial animals depicted in the two conditions: taking off and landing.

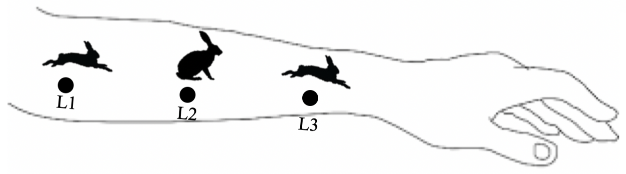


Figure 6: The animal (here the rabbit in the taking off condition) appears on the arm simultaneously with the tactile conditions: three successive taps on three locations: L1, L2, and L3.

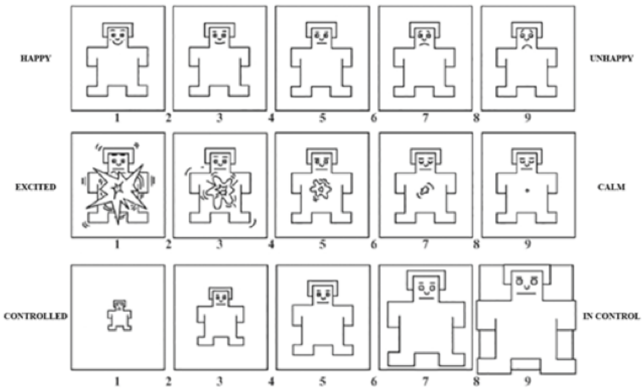


Figure 7: The Self-Assessment Manikin Scale: a 9-point scale for valence (top), arousal (middle), dominance (bottom).

neither happy or sad/neither excited or calm/ neither in control or controlled. All participants completed 144 trials (6 animals * 3 tactile durations * 2 locomotion phases * 4 repetitions).

For each trial, participants pressed a button to go to the next trial. A trial consists of one multimodal CRE that can last between 300 and 624 ms (Table 1) with the SAM scale displayed just afterwards to allow participants to provide their verbal response, which was recorded by the experimenter. A post-survey questionnaire was given to the participants at the end of the experiment asking them to describe the tactile sensation (drawing on an image of a forearm), report any phobia, and evaluate the strength of the animal and tactile sensation using a 5-point scale with 1 being weak and 5 being strong.

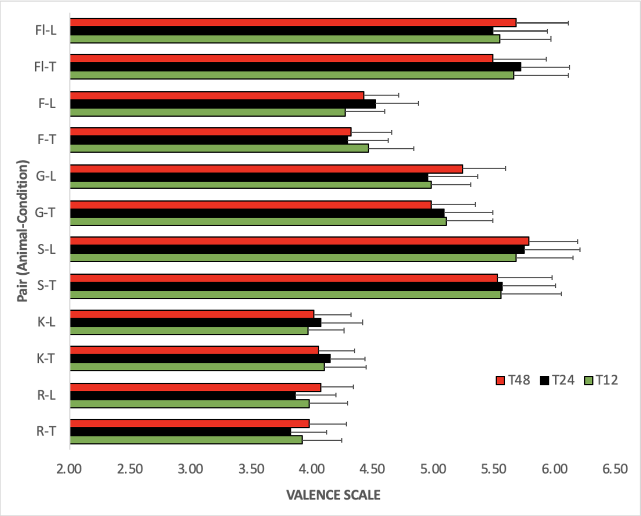


Figure 8: Valence scale for each pair animal-locomotion for the three tactile conditions: T12, T24, AND T48.

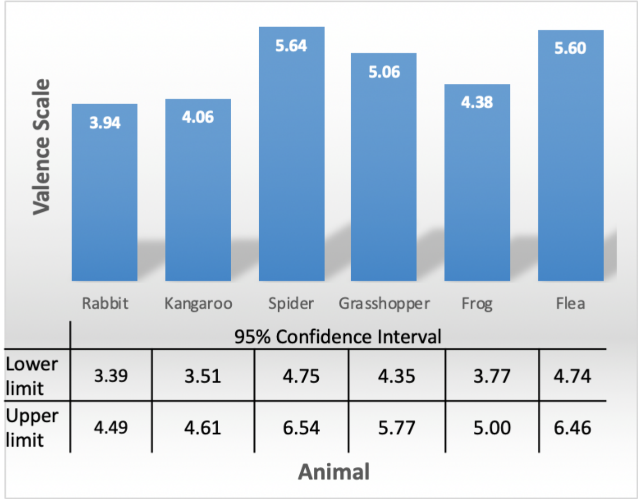
4 RESULTS

4.1 Data Analysis

A three-way repeated measured ANOVA with the factors Animal, Tactile, and Locomotion was performed on the Valence, Arousal, and Dominance scores. Test of normality and sphericity were checked and a Greenhouse-Geisser correction was applied when sphericity was violated. Post-hoc analysis was performed using the non-parametric Dunn's Multiple Comparison Test with Bonferroni correction (the obtained p-values are multiplied by the number of tests being carried out to give the adjusted p-values) [8]. There was also no significant difference of gender.

4.2 Valence

Figure 8 displays the valence scores obtained for each animal-locomotion pair for the three tactile conditions. The three-way ANOVA showed a significant effect of the factor animal [F(1.76, 38.81) = 19.35, $p < .001$]. No interaction effect nor additional single factor effect were found. Regardless of the locomotion or the duration of the tactile stimuli, post-hoc analysis showed significant difference ($p < .05$) between rabbit vs. spider and flea and kangaroo vs. spider and flea. As shown on Fig. 9, Rabbit and Kangaroo scored lower on the scale (more pleasant) than Spider and Flea (less pleasant). This significance was corroborated by confidence intervals at 95% confidence level showing no overlap in participants' responses for these animals.



	Rabbit	Kangaroo	Spider	Grasshopper	Frog	Flea
	95% Confidence Interval					
Lower limit	3.39	3.51	4.75	4.35	3.77	4.74
Upper limit	4.49	4.61	6.54	5.77	5.00	6.46

Figure 9: Valence scale for each animal. The table below displays the confidence interval at 95% level.

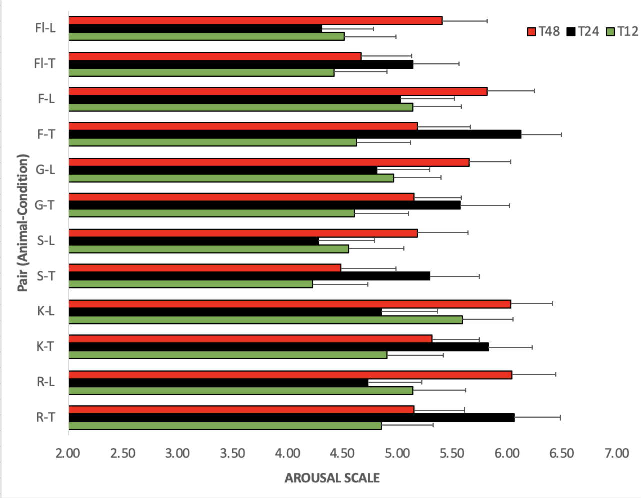


Figure 10: Arousal scale for each pair animal-locomotion for the three tactile conditions: T12, T24, AND T48.

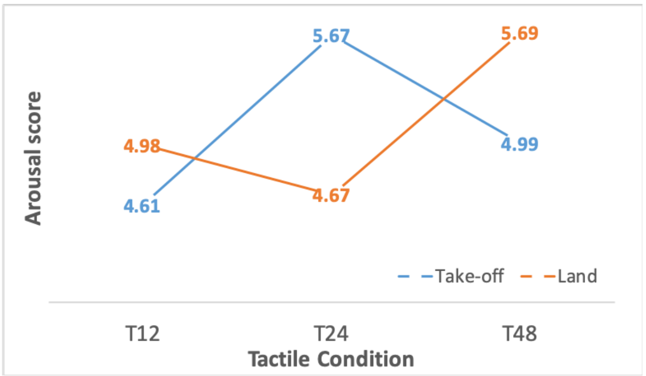


Figure 11: Interaction plot of Locomotion (take-off, landing) and Tactile (T12, T24, T48).

4.3 Arousal

The repeated measured ANOVA showed a significant effect of the factor Animal [F(1.99, 41.71) = 5.91, p <.001, the factor Tactile [F(1.23, 25.82) = 12.36, p <.001], and an interaction effect Tactile x Locomotion [F(1.14, 24) = 9.7, p <.001. To break down the interaction effect, pairwise comparisons were performed on all pairs. All scores for the taking-off condition scored higher than the landing condition when associated with the intermediate duration (24 ms). This trend was significant for all animals.

The opposite tendency was observed for the shortest duration T12 and the longest duration T48, as scores for the landing condition were higher than scores for the taking-off condition (see Fig. 10 and Fig. 11 for the interaction plot). For T12, this difference between the two locomotions was significant (p. <.05) for kangaroo, spider, and frog. For T48, the significant difference was observed for rabbit, kangaroo, spider, and flea.

4.4 Dominance

Fig. 12 summarizes the dominance score. No significant effect was found for this emotional dimension. The central tendency of all scores was around 5, which is the neutral position.

4.5 Circumplex Affective Model

Since the dominance dimension did not show any significant tendency, we examined the valence-arousal relationship using the circumplex model [28]. As depicted on Fig. 13, for pleasant animals (rabbit, kangaroo, frog), all similar pairs fell within the same segment. For example, all 24-landing pairs are in the happy segment; while the 24-take-off pairs are in the relaxed segment. Similarly, for unpleasant animals (flea, spider), the 24-take-off pairs are in the depressed piece while the 24-land combinations are in the angry segment.

A reversed trend was observed for the 48 ms duration, as displayed in Table 2, where landing conditions were judged depressed and taking-off conditions were leaning towards the angry emotions. Grasshopper seems to be a neutral stimulus for almost all participants and its scores tend to gravitate around the center (purple color).

4.6 Post-survey

Ten participants out of twenty-three reported animal phobias varying from insects and spiders to small animals. When asked to describe the tactile stimulation by drawing it on a sketch of an arm, thirteen participants described it as localized sensations at three spots suggesting that the illusion was weak for these participants. Among the ten remaining participants: two participants described the hoping sensation, two described it as a moving sensations from left to right, two reported circular propagations at three spots, and four participants described the sensations as propagating perpendicularly to the arm.

Finally, participants were also asked to rate the strength of the tactile sensation for each animal on a 5-point scale, with 5 being the

Table 2: Duration of the stimulation based on BD variations.

Emotion: pleasant animals (rabbit, kangaroo, frog)	pairs	Emotion: unpleasant animals (flea, spider)	pairs
Relaxed	24T, 48L	Depressed	24T, 48L
Content	12L, 48T	Angry	12T/L, 24L, 48T
Happy	12T, 24L		

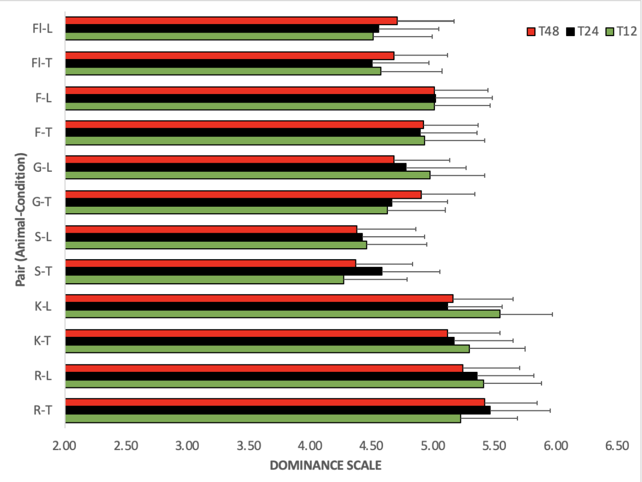


Figure 12: Dominance scale for each pair animal-locomotion for the three tactile conditions: T12, T24, AND T48.

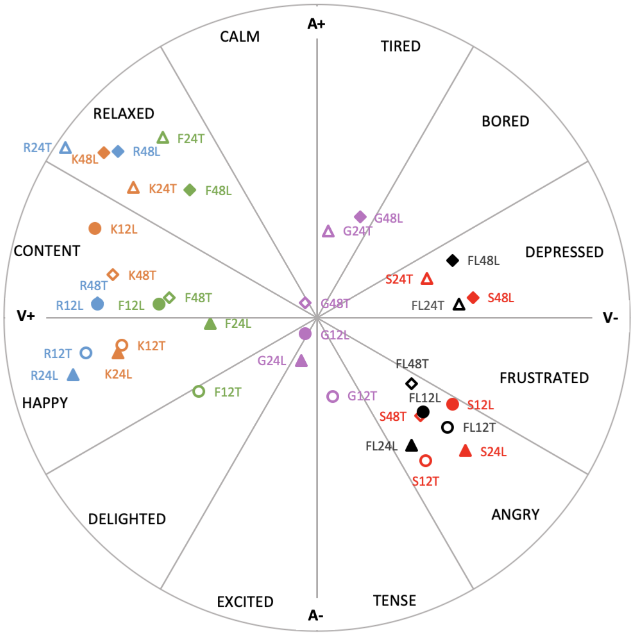


Figure 13: the valence (V)-arousal (A) circumplex: the + represents higher values on the scale, the - refers to the lower values. Each color represents an animal (blue:rabbit, orange, kangaroo, green: frog, purple: grasshopper, red; spider, black: flea). Each shape represents a tactile condition (circle: T12, triangle: T24, diamond: T48). The landing condition is represented by filled shapes, the taking-off conditions are empty shapes.

strongest and 1 the weakest. Fig. 14 displays the scores that varies between 3 and 3.83 across animals. The flea and the spider scored slightly higher, but this difference was not significant within and between-participants (phobia vs non-phobia, and illusion vs. non illusion).

5 DISCUSSION AND CONCLUSIONS

The results showed a significant effect for valence and arousal scores. For valence, the visual representation of the animal was strong enough to offset any effect of the locomotion or tactile sensation, suggesting a dominance of vision for the pleasurable dimension. This corroborates in part our previous results where we found that visual valence scored higher for unpleasant visual stimuli regardless of the duration of the tactile sensations [35]. A similar conclusion was reached by Sampath et al. [3] using stimulation on the hand and different haptic technology (Electroactive Polymer Actuator).

In sum, whether the visual stimulus is pleasant or unpleasant, the valence dimension seems to be visually affected, which could suggest that any tactile sensation could do the trick and improve the multimodal experience if the timing and the location of the tactile stimulation match the visual stimulation. On one hand this is good news for designers as there is no need to invest in expensive technology during testing. On the other hand, it would represent challenges if the focus of testing is on the haptic technology itself and the purpose is to distinguish small nuances between the different tactile sensations during a visual interaction. The best in this case is to use unimodal conditions either as control conditions or as a stand-alone experiment.

Rather than focusing on Valence as one single dimension, it would be beneficial to take a holistic approach by considering simultaneously the arousal dimension. Noting that for the arousal dimension, an interaction effect between the locomotion and the duration of the tactile stimuli was found. Taken together, the circumplex model in Fig. 13 illustrates an interesting trend. Since the visual locomotion is action focused, it is not surprising that the arousal dimension is the one affected as seeing something or someone jumping brings additional excitement to the viewer.

More specifically, the intermediate tactile sensation T24, when associated with the taking-off condition (which can be seen as two

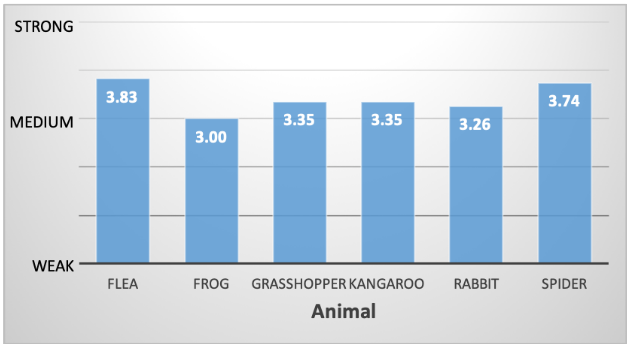


Figure 14: Average score for the strength of the tactile sensation for each animal.

hops), was classified relaxing for pleasant stimuli and depressing for unpleasant stimuli. The same observation can be made for the longest tactile condition when associated with the landing condition (which can be visually described as one hop). Additionally, more excitement (content and happy) was observed for pleasant stimuli and more angriness for unpleasant stimuli when associated with the shorter and intermediate durations (T12 and T24) in the landing condition and the longest duration (T48) in the taking-off condition (see Fig. 2). A plausible explanation is the tactile-locomotion combination provide a distortion of time that can contract or dilate the perception of the tactile stimulation depending on the presented pair. Alternating stimulus' duration in multimodal situations have been observed between the visual and tactile modalities in previous work [10, 17] where watching a moving object expands the duration of a tactile stimulus. Because we did not ask explicitly participant to judge the duration of the stimulation, this explanation would require experimental validation in the future with similar conditions.

The next step for this work is to progress from a projected setting to a VR setting (see Fig. 1), but before doing so, a further investigation of the stimulus location, the participants' interaction, and PAD model would benefit the virtual implementation. Previous research showed that stimuli located on the upper part of the screen have higher valence than the ones on the bottom part of the screen [29] when participants are allowed to interact with the object. Because our images were located on the center of the screen, it would be interesting to investigate up-bottom-up and bottom-up-bottom paradigms. If deemed possible, participants would have to interact with the virtual animals as they are approaching on the arm.

Finally, after using this paradigm in three different studies, including the one in this manuscript, we pose the following predictions and hypotheses on this type of multimodal affective interaction: (see Table 3) within a multimodal context (both tactile and visual), several consequences are possible.

Take for example scenario 7, a VR situation where the user feels unhappy, excited, and controlled (i.e. being bitten by a zombie). This scenario could put the user in a defensive and even dangerous emotional state if a haptic feedback is used, as it could trigger strong emotions that would change their physiological responses. Seeing your avatar being eaten is unpleasant enough, adding haptic feedback would bring the interaction to another level that could not be comfortable for the player. On the contrary, in scenario 8 (i.e. seeing someone else being bitten), the tactile input would affect negatively both valence and arousal dimensions without affecting negatively the dominance dimension, which is related to the social context and in this specific case a haptic feedback would enhance the game without putting the user into an intense distress.

The emotional social context (SC) is an important variable during a virtual interaction. Contrary to a movie theatre, where the user's presence is physically detached, in the VR/AR, the user is often in situations of first-person view (FOV) that enhances the sense of presence and social interaction. An excited and controlled user in a VR/AR setup could trigger the wrong kind of emotions within the virtual world that can leave the participant with emotional distress and anxiety. Creating the right kind of emotions is important within the virtual world. This first step is to investigate these different scenarios in depth using haptic feedback within a virtual context.

An additional manipulation of the haptic feedback would allow us to alter the emotion by changing the intensity of the burst themselves (50%, 75%, 100%) to enhance or reduce specific emotional states. Based on our previous research, a decreasing intensity would have a relaxing or calming effect, while an increasing intensity would produce a defensive reaction. It is important to keep in mind that additional factors can affect this manipulation such as the funneling illusion, which is the opposite of saltation. Instead of a distributed sensation, two adjacent bursts are combined into one single sensation.

Finally, emotion classification remains a contested issue, as multiple models and several measures are available and they are rarely without any flaws. Although most of the dimensional models incorporate valence and arousal, only few include the intensity dimension. We opted for the PAD model of emotion because it is one of the rare models that incorporates the dominance dimension, which can be important in a VR social context during the interaction with multiple senses. Since the dominance dimension did not have an effect, the circumflex model was more appropriate to display the relationship between valence and arousal. As for the affect measure, we opted for SAM scale -which is based on the PAD model- because it is widely used, has the advantage of being non-verbal, is fast to administer after each trial, and has been supported by strong experimental validation and generalization.

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Table 3: Duration of the stimulation based on BD variations.

Scenario #	Valence	Arousal	Dominance	Possible Emotional State
Scenario 1	Happy	Calm	Controlled	Calm or worried state (depends on the SC)
Scenario 2	Happy	Calm	In-control	Calm state
Scenario 3	Happy	Excited	Controlled	Appetitive or nescient state (SC)
Scenario 4	Happy	Excited	In-control	Appetitive state
Scenario 5	Unhappy	Calm	Controlled	Neutral or defensive state (SC)
Scenario 6	Unhappy	Calm	In-control	Neutral state
Scenario 7	Unhappy	Excited	Controlled	Defensive and dangerous state
Scenario 8	Unhappy	Excited	In-control	Defensive state

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