Design and Assessment of the Haptic Creature's Affect Display

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ABSTRACT

The Haptic Creature is a small, animal-like robot we have developed to investigate the role of touch in communicating emotions between humans and robots. This paper presents a study examining how successful our robot is at communicating its emotional state through touch. Results show that, regardless of the human's gender or background with animals, the robot is effective in communicating its state of arousal but less so for valence. Also included are descriptions of the design of the Haptic Creature's emotion model and suggested improvements based on results of the study.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*Haptic I/O, Evaluation / Methodology, Interaction Styles, Input Devices and Strategies, User-Centered Design*; J.4 [**Social and Behavioral Sciences**]: Psychology

General Terms

Human Factors; Design; Experimentation

Keywords

Affective Touch; Socially Interactive Robots; Affect Display; Human-Robot Interaction (HRI); Affect; Haptics; Emotion; Touch; Robot Pets

1. INTRODUCTION

In the Haptic Creature project we are investigating the role of affective touch in the social interaction between human and robot; in particular, the display, recognition, and influence of this form of touch. This knowledge has implications for the role affective touch can play in fostering companionship as well as its application to therapy.

Our approach is to leverage research in human-animal interaction by developing a robotic creature that mimics a small animal, such as a cat or dog, sitting on a person's lap. Dubbed the Haptic Creature (Figure 1), our robot interacts with the human through the modality of touch. An array of touch sensors over its body coupled with an accelerometer allow the robot to sense being touched, while it displays it emotional state through adjusting the stiffness of its ears, modulating its breathing, and presenting a vibrotactile purr.

Figure 1: The Haptic Creature. (Photo: Martin Dee)

In this paper, we report a study which examines the effectiveness of the Haptic Creature to communicate its emotional state to humans when the sole interaction modality is touch. We are particularly interested in seeing if the robot's breathing rate and ear stiffness convey its arousal while the asymmetry of breathing and purring communicate its valence. A secondary goal is to investigate differences in recognition as a result of either gender or prior experience with animals. Finally, we also examine changes in the emotional state of the participant as a result of interacting with the Haptic Creature.

After providing background information in the remainder of this section, we move on in the paper to the design and development of the Haptic Creature's emotional model, including parameters controlling its affect display behavior. The Methods and Results sections then detail our approach to assessing the ability of the robot to communicate its emotional state. Of specific interest is the hybrid nature of the experimental design such that we have a specific metric for overall accuracy as well as deeper details as to how participants perceived the robot's emotional state. We conclude the paper with an extensive discussion of the study results by focusing on specific improvements to the Haptic Creature's affect display behavior.

HRI'11, March 6–9, 2011, Lausanne, Switzerland.

1.1 Affective Touch

Emotion communication is an important aspect of social interaction: individuals can share their internal state with the group; emotions add significance to the interaction; they allow for approval or disapproval; and emotions help to regulate the interaction [5]. The study of human *affect display* — the external manifestation of internal emotional state — has focused mainly on the modalities of vision and audition.

Visually, humans rely on facial expressions to convey emotion [9], so is not surprising that affect display in socially interactive robotics similarly concentrates on facial expression (e.g., [4]). Prosody is the primary parameter of affect display in speech, and this has similarly guided auditory interactive display development (e.g., [24]).

Affective touch has received much less attention, from either psychologists or robot designers. The sense of touch is unique: the skin is the largest organ in the human body; the first sense organ to develop; and it plays a major role in early development [18]. Furthermore, touch is proximal; requiring close or direct, physical contact to sense [12].

Affective touch can be defined as touch that communicates or evokes emotion. Recent studies with humans have shown that touch is capable of communicating distinct emotions [14, 13]. General studies on interpersonal touch, though, have shown various confounding factors such as gender, familiarity, social status, and culture (e.g., [17]). Additionally, these sorts of studies have been found to cause significant levels of participant discomfort (e.g., [28]).

In an attempt to avoid these issues, in the Haptic Creature project we have chosen to draw from models of interaction between human and animal rather than solely between humans in the hope that human-animal touch will be less loaded. This approach leverages the rich patterns of non-verbal communication, especially through touch, that already exist between human and animal [7, 2].

1.2 Related Work

The Haptic Creature lies at the intersection of socially interactive robotics, affective touch, and human-animal interaction. While a comprehensive review of these various domains is beyond the scope of this paper, we draw attention to some other projects that also inhabit this space and have provided important contributions to understanding it. Most notable are the small set of social robots combining touch interaction and animal-like form: Shibata's baby seal, Paro [25]; Stiehl's teddy bear, the Huggable [26]; Saldien and Goris's elephant-like creature, Probo [23]; the dinosaur, Pleo, created by Ugobe [27]; and Sony's dog, Aibo [11]. We cover some of the more significant differentiating factors in relation to these robots. The rationales behind these factors are given more detail in [30].

Perhaps the primary differentiation of the Haptic Creature project is its strong concentration on the modality of touch for affect display. The Huggable is the only other device possessing full-body sensing; Paro and Aibo both have only limited interaction points for touch input; and it is unclear what touch sensing, if any, Probo currently employs. Moreover, each of these other projects focuses much less on touch for affect display originating from robot itself; rather, they rely more on visual and auditory expression.

A second differentiating aspect of the Haptic Creature is the level of zoomorphism. The aforementioned robots all, to varying degrees, have clearly defined features and overall shape. While a goal of the Haptic Creature is that it be recognizable as animal-like, it is consciously designed to have a more minimalistic appearance. This limits the human's expectations while also shifting focus to the interaction rather than the form.

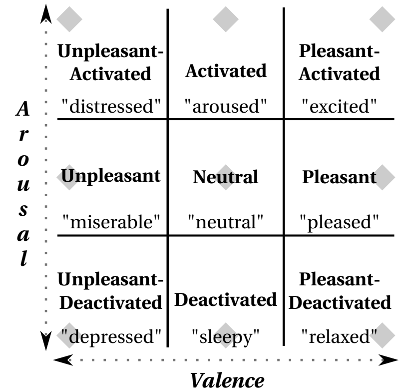


Figure 2: The Haptic Creature's affect space. Quoted names are Russell's emotion labels; diamonds signify locations of the nine "key expressions" that currently define the emotional display.

2. THE HAPTIC CREATURE

The Haptic Creature (Figure 1) is a robot that mimics a small lap animal, such as a pet cat or dog. Its affect display system is composed of body, two ears, and breathing and purring mechanisms. For affect sensing, the robot features touch sensors over its entire body and an internal accelerometer for capturing high-frequency events such as being poked, shaken, or dropped. A more extensive description of the Haptic Creature's mechatronics and computational architecture can be found in [31], while our preliminary approach to gesture sensing is described in [6].

The robot interacts with the world primarily through the modality of touch. That is, it senses the world exclusively through touch and motion, and the intent is the same for its display. However, the nature of some interactions — e.g., breathing — unavoidably produces visual elements as well. Effort has been made to reduce non-touch artifacts wherever possible.

The Haptic Creature regulates its emotional state based on its interpretation of its sensory input. For example, when a human sitting with the robot on her lap gently strokes it, the robot may register this as a pleasing interaction, computationally updating its internal emotional state to reflect happiness. The Haptic Creature then might render this through average-paced, rhythmic breathing that causes its ribcage to press and release against the human's hand, slightly stiffened ears, and a gentle purring vibration.

2.1 Affect Space and Rendering Parameters

The Haptic Creature's emotion model is represented by a two-dimensional affect space adapted from Russell [20, 22] (Figure 2). The horizontal dimension describes the robot's valence — unpleasant vs. pleasant — while the vertical dimension represents the robot's arousal — deactivated vs. activated. Its current emotional state, therefore, is defined by specifying a point in this affect space.

Table 1: Key Expressions: arousal and valence categorization, actuator rendering parameters.

				Ears	Lungs*			Purr Box		
	Key Expression	Arousal	Valence	Volume %	Rate bpm	Bias %	Volume %	Wave	On / Off ms	Amplitude %
U-A:	Unpleasant-Activated	High	Negative	100	70.0	25	30–95	Null	—	—
A:	Activated		Neutral			37				
P-A:	Pleasant-Activated		Positive			50		Sine	728 / 128	0–33
U:	Unpleasant	Medium	Negative	50	42.5	25	20–85	Null	—	—
N:	Neutral		Neutral			37				
P:	Pleasant		Positive			50		Sine	706 / 706	0–26
U-D:	Unpleasant-Deactivated	Low	Negative	0	15.0	25	0–70	Null	—	—
D:	Deactivated		Neutral			37				
P-D:	Pleasant-Deactivated		Positive			50				

* *Rest* parameter, both inhalation and exhalation, always 0 milliseconds.

The manner in which the Haptic Creature displays a particular emotional state is described through a series of *key expressions* located at specific points in the affect space. A key expression provides a detailed description of the behavior in the form of specific values for each actuator's rendering parameters. If the robot's current emotional state does not coincide with a key expression, then the parameters are interpolated from nearby key expression. This interpolation also allows for *tweening* values so that the robot may smoothly transition from one emotional state to another. The individual rendering parameters used to define the behavior for each of the Haptic Creature's actuators will be described here in turn.

Ears. The two ears can be controlled independently of each other in the single dimension of *stiffness*. They vary in firmness in a manner not visually perceptible but can be felt when the human squeezes them. Ear stiffness is specified by means of a *volume* parameter, which ranges from 0% (limp) to 100% (stiff).

Lungs. The Haptic Creature's lungs modulate its manner of breathing through four parameters. *Rate* is defined as breaths-per-minute (bpm). *Bias* controls the symmetry of each breath by specifying the percentage that is dedicated to the inhalation phase, from 0% (all exhale) to 100% (all inhale) — for example, a bias of 25% would allocate 1/4 of each breath to the inhale and 3/4 to the exhale. *Rest* (milliseconds) allows for a pause at the end of inhalation and/or exhalation for each breath, and is defined independently for each. *Volume* defines the minimum and maximum position for each breath.

Purr Box. The Haptic Creature's purr box controls the presentation of a modulated vibrotactile purr. *Waveform* determines the type of wave generated: pulse, sawtooth, reverse sawtooth, sine, triangle, or null. *On duration* and *off duration* (milliseconds) define the wave's duty cycle. *Amplitude*, specified as percentages from 0% to 100%, define the wave's minimum and maximum amplitude.

2.2 Affect Display Design

The Haptic Creature's emotional display is currently described by means of nine key expressions located within its affect space (Figure 2): three levels of arousal (*high*, *medium*, and *low*), each matched with three levels of valence (*negative*, *neutral*, and *positive*). Table 1 enumerates the key expressions' settings for each rendering parameter.

Animal models served as the initial reference for the robot's emotion display; however, the goal has never been to create a direct replacement for any particular animal. These models provided a useful starting point for many of the actuator parameter settings, but were tuned through informal user tests where participants provided guided verbal feedback as to their general thoughts on the robot's affect display. Refinements were made that altered the range of expressions or its manner. This procedure was repeated over several iterations.

Subsequently a mini-study with 9 participants was conducted to examine how the robot performed under more experimental conditions. Results and feedback again informed more alterations.

The remainder of this section details the design of the actuator rendering parameters used in the user study profiled in this paper.

Ears. The ears were utilized solely to convey arousal, with stiffness proportional to arousal level: *low* was represented by limp ears and *high* by fully stiffened ones. Both ears always presented the same stiffness.

This approach was intended as a non-visual analog to an animal perking its ears in an alerted state [7]. Most pilot participants understood this concept, although at least one imagined non-stiff ears to connote positive valence.

Lungs. The Haptic Creature's breathing was tuned to convey both arousal and valence.

Arousal was rendered through breathing rate, with faster rates corresponding to *high* arousal. The rates were normalized to those of domestic cats, dogs, and rabbits [19]; however, in cases of extreme arousal their breathing can exceed 100 breaths-per-minute. Piloting allowed us to adjust downward the top rate to a convincing level, while not overtaxing the robot's lung mechanics, to arrive at a range of 15-70bpm.

The valence component of the lung display was determined by the symmetry of breathing: equal durations (50% bias) for inhalation and exhalation corresponded to *positive* valence while a quicker inhalation (down to 25% bias) signified *negative* valence. Domestic animal respiration is actually the opposite: a negative state, such as stress or disease, inhalation will be notably slower. We chose to diverge from the animal model because a quick motion outward by the ribcage striking the human's hand was intended to impart a negative feeling.

Purr Box. The main intent of purring was to convey *positive* valence, as in a cat in a pleased state, though with only the vibratory component. A purr was present in the *pleasant* and *pleasant-activated* conditions. Purring was originally in the *pleasant-deactivated* condition but piloting exposed a confound with arousal: participants consistently ranked the arousal dimension much higher whenever purring was present, especially in the *low* arousal case.

A prototype version of the Haptic Creature [29] was able to convey negative emotions through its purr. Intended to represent the vibration of a growl, it had a staccato-like pulse wave of higher amplitude than its positive valence purr. Though the purr box in both versions are mechanically related, the physical composition of their bodies differ enough such that using similar parameters in the current Haptic Creature did not appear to convey negative valence: both types of purring were interpreted as positive. As a result, it was decided to focus only on using purring for positive emotions for this study; however, plans exist to continue investigating a negative valence purr.

The purr was also tapped to convey arousal, with less priority. An increase in arousal was manifested by a slightly increased amplitude for the purr wave along with a marked decrease in the delay between waves. Too great an amplitude, however, was found unpleasant by pilot participants with smaller body types so the intensity was iteratively tuned to a noticeable range that was not overpowering.

3. METHODS

Our experiment was designed to assess the overall effectiveness of the Haptic Creature's affect display while providing insight towards areas for improvement. Its approach evolved from a succession of pilot studies as briefly described in Section 2.2.

We initially employed Barrett and Russell's affect measure [1], which asks participants to rank twelve emotion adjectives on a five-level Likert scale. This measure proved to be effective at capturing the perceived arousal and valence of the robot; however, the nuances of the data made it difficult to discern if participants were perceiving the specific state intended.

Traditional studies on recognition of emotion in facial expression, on the other hand, administer forced-choice responses from a list of emotion labels. These have the advantage of pinpointing a specific emotion, however, they tend to focus on the distinct nature of the emotion [8].

We developed a hybrid approach that uses both forced-choice emotion labeling as well as assessment of perceived arousal and valence. The intent was to allow coarse grain categorization from the labels while also provide fine grain data from the dimensional responses, with the added advantage that the dual responses provide confirmation of each other.

3.1 Participants

Data from 32 individuals (50% female) were used in the study. Recruited via fliers, online classifieds and mailing lists, each was compensated CAD$10 for their participation. Ages ranged from 19 to 50 ($M = 27.5$, $SD = 9.37$), and all self-identified as native English speakers (81% from North America, 19% from elsewhere). None had previously participated in studies with the Haptic Creature.

3.2 Apparatus

The study was conducted in a soundproof observation studio housing a desk and adjustable office chair. Atop the desk was a 17-inch LCD monitor, a keyboard, and a mouse. All study software, including control of the Haptic Creature, was written in Java and executed on an Intel-based PC running the Gentoo Linux operating system.

Figure 3: Participant interacting with Haptic Creature during study.

Participants sat in the chair and faced the monitor on the desk. The mouse was placed on the side that they self-identified as their mouse hand. The Haptic Creature was situated in their lap with its backside initially facing the participant's non-mouse hand; however, participants were allowed to adjust its position as they saw fit throughout the study. Participants wore ear muffs to mask any extraneous sounds that may be generated by the robot (Figure 3).

3.3 Stimuli

The Haptic Creature presented nine different emotional renderings in the study, which corresponded directly with the nine key expressions of the affect display design. These stimuli were chosen because they provide good separation by displaying minimum, maximum, and average states for both arousal and valence.

3.4 Response Format

Participants were asked to provide two categories of responses each time they assessed the robot's emotional state: (1) a particular emotion label (i.e. word), and (2) perceived valence and arousal levels; and to choose a confidence score for each response from a five-level Likert scale ranging from "not at all confident (guessed)" to "very confident".

Participants chose one of sixteen emotion labels from a provided list (Table 2). Six options were Ekman's basic emotions [8]: *afraid*, *angry*, *disgusted*, *happy*, *sad*, and *surprised*. Nine were from Russell's circumplex model of affect [20, 1] and Affect Grid [22]: *aroused*, *depressed*, *distressed*, *excited*, *miserable*, *neutral*, *pleased*, *relaxed*, and *sleepy*. The emotion words were presented in alphabetized order with a final option, *none of these* to address shortcomings of forced-choice responses for perceived emotions [21, 10].

Table 2: Emotion label list.

Afraid*	Angry*	Aroused	Depressed
Disgusted*	Distressed	Excited	Happy*
Miserable	Neutral	Pleased	Relaxed
Sad*	Sleepy	Surprised*	None Of These†

Unmarked labels are from Russell; *from Ekman; †avoids artificial agreement.

The decision to include both Ekman and Russell emotion labels was to increase the overall richness of available choices by combining words from research on distinct emotions (Ekman) with those from research on the dimensional nature of emotions (Russell).

To identify their perception of the robot's valence and arousal, participants made selections on a seven-level version of Lang's Self-Assessment Manikin (SAM) rating scales [16]. Instructions for using the SAM scales were adapted from Bradley and Lang (2007) [3]; however, the order of each scale was reversed such that the valence scale was labeled "Unhappy versus Happy" and the arousal scale was labeled "Calm versus Excited". The SAM images were from PXLab [15] and measured $69x74$ pixels. To increase visibility of the facial expressions, we used portrait versions of the valence images rather than more traditional full figure.

The SAM format proved more efficient to administer compared to our original use of the Barrett-Russell measure, and its pictorial representation of affect avoided confusion with the emotional labeling response.

3.5 Procedure

The entire study took approximately one hour to complete. This section presents details of the various steps in the study.

Instructions. Instructions provided an overview of the research being conducted; an explanation of the Haptic Creature and information on interacting with it; and the study protocol, including a detailed explanation of the response format.

Practice Session. During a short (approximately three minutes) familiarization session, all nine stimuli were demonstrated in different random order for each participant. Each stimulus was presented for 20 seconds with a visually displayed countdown timer. Participants were instructed to interact with the Haptic Creature but were not asked to assess its emotional state.

Assessing Haptic Creature Affect. The main portion of the study consisted of the Haptic Creature rendering the nine simulated emotional states and, for each, the participant recording his or her emotion label and arousal/valence SAM scale assessments. No time restriction was imposed, and the robot displayed its current emotional state until a response was recorded.

Stimuli were presented in three sets with each set consisting of the nine stimuli repeated two times. Thus, each unique stimulus appeared six times for a total of 54 trials — 9 stimuli x 2 repetitions x 3 sets. The order of stimuli in each set was randomized differently for each participant, and a two minute rest break came between sets.

Reporting Participant Affect. Before the initial set and upon completion of each set the participant reported his or her own current emotional state. Responses were collected by means of the SAM scales, but no emotion word choices were presented.

Post-Study Questionnaire. A questionnaire collected participant demographic information, background with various animal types, general feedback on the Haptic Creature, and strategies employed in assessing its emotional state. Participants ranked their experience interacting with a variety of animal types on a five-level scale: *none*, *up to 1 year*, *2–3 years*, *4–5 years*, and *more than 5 years*.

Table 3: Frequency of emotion label chosen for each condition.

Condition		Condition		Condition	
Label	%	Label	%	Label	%
U-A		A		P-A	
Distressed[2]	**70**	Distressed[2]	56	Distressed[2]	43
Excited	10	Excited	17	**Excited**	**28**
Aroused	8	**Aroused**	**15**	Aroused	12
Surprised	7	Pleased[3]	6	Pleased[3]	11
U*		N		P	
Distressed[2]	23	**Neutral**	**25**	**Pleased**[3]	**44**
Pleased[3]	18	Pleased[3]	24	Distressed[2]	26
Aroused	16	Distressed	14	Aroused	9
Neutral	15	Aroused	13	Excited	6
Excited	9	Relaxed	8		
U-D		D		P-D	
Sleepy	33	**Sleepy**	**42**	Sleepy	49
Relaxed	31	Relaxed	30	**Relaxed**	**31**
Depressed[1]	**14**	Depressed[1]	17	Depressed[1]	10
Neutral	11	Neutral	7		

Labels in boldface represent expected choice for respective condition. Only frequencies greater than 5% are listed. [1] *Depressed* includes *Sad*. [2] *Distressed* includes *Afraid*, *Angry*, and *Disgusted*. [3] *Pleased* includes *Happy*. *The expected label for *Unpleasant* was *Miserable* (2%).

4. RESULTS

We first present results related to the ability of the Haptic Creature to successfully communicate specific intended emotions as demonstrated by (a) participants' choice of emotion words as best descriptors of particular states, and (b) their ratings of valence and arousal. We then describe our data with regards to participants' self-reported affect states and implied changes thereof.

4.1 Recognition Scoring

As presented in Section 3.4, for each emotion presented by the Haptic Creature participants made a forced-choice response from among sixteen emotion labels. Russell's emotion labels are dimensional in nature so have direct mappings to the stimuli presented (Figure 2). Ekman's labels, on the other hand, do not have a direct mapping but may overlap with Russell's labels. To address this, the perceived arousal and valence ratings were analyzed for each label choice. Labels where both the arousal and valence did not statistically differ were considered equivalent.

The result was that Ekman's *sad* was found to be equivalent with Russell's *depressed*; Ekman's *afraid*, *angry*, and *disgusted* were found to be equivalent with Russell's *distressed*; and Ekman's *happy* was found to be equivalent with Russell's *pleased* — only Ekman's *surprised* was not found to be equivalent with any other emotion labels. Figure 4 displays the mean perceived arousal and valence ratings broken down by each emotion label choice.

A recognition score was then computed by counting all the occurrences when an emotion label choice matched the intended emotion presented by the Haptic Creature. This score, in turn, was converted to a percentage.

Table 4: Perceived arousal homogeneous subsets.

		Subset for $\alpha = .05$				
Condition	N	1	2	3	4	5
P-D	192	1.43				
D		1.55				
U-D		1.67				
N			3.77			
P			4.04	4.04		
U				4.09		
A					5.39	
U-A					5.67	5.67
P-A						5.75
Sig		.34	.18	1.00	.15	1.00

Subsets 2 & 3 overlap at 4.04. Subsets 4 & 5 overlap at 5.67.

Table 5: Perceived valence homogeneous subsets.

		Subset for $\alpha = .05$		
Condition	N	1	2	3
U-A	192	2.67		
A			3.35	
P-A				4.05
U				4.11
U-D				4.24
N				4.33
D				4.38
P				4.50
P-D				4.54
Sig		1.00	1.00	.06

Overall recognition scores for the 32 participants ranged from 17% to 52% (M = 30%, SD = 10%). A 2x3 between-groups ANOVA was conducted to examine differences in recognition scores between gender and experience with animals. There was no statistically significant interaction effect, $F(2, 26) = 1.11$, $p = .35$, $\eta_p^2 = .08$. Both the main effect for gender, $F(1, 26) = .57$, $p = .46$, $\eta_p^2 = .02$, and the main effect for animal experience, $F(2, 26) = .01$, $p = .99$, $\eta_p^2 = .00$, were not statistically significant.

The animal experience factor was computed through the animal background information gathered in the post-study questionnaire as described in Section 3.5. The relevant animal types for the present analysis were cats, dogs, and rabbits because they most closely resemble the morphology and interaction of the Haptic Creature. The ratings of the three animal types were summed, and participants were then ranked into one of three experience categories: *low* (3–6), *moderate* (7–11), and *extensive* (12-15).

In addition to participants' recognition scores, the frequency of emotion label choices was examined for each stimulus presented. These results are summarized in Table 3.

4.2 Perceived Arousal and Valence Ratings

Participants also ranked the perceived arousal and valence for each rendering presented by the Haptic Creature. Figure 5 charts the means for each by condition. These data were evaluated by means of one-way repeated measures ANOVA for the condition factor. Through post hoc analysis, we examined any resultant homogeneous subsets.

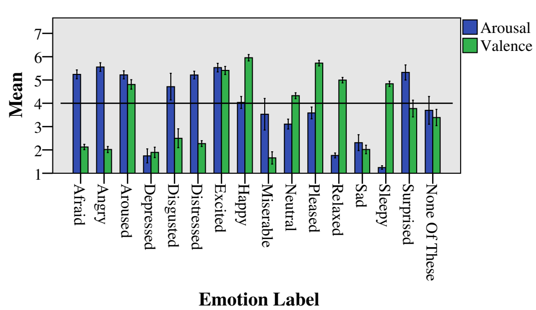


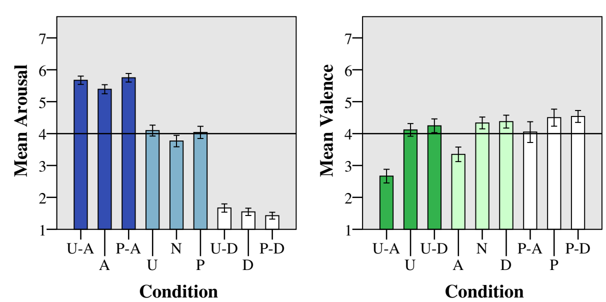
Figure 4: Mean perceived arousal and valence ratings by emotion label chosen.

For arousal, the one-way repeated measures ANOVA with Greenhouse-Geisser correction for violations of sphericity yielded a statistically significant difference among the nine conditions, $F(6.37, 1216.87) = 839.29$, $p < .0005$, $\eta_p^2 = .82$. Multiple comparisons via Tukey's HSD computed five homogeneous subsets as shown in Table 4. The expected outcome, however, was for three: one for each level of arousal.

Inspection of the table reveals that subset 1 contains all the *low* arousal conditions; while subsets 2–3 contain all *medium* conditions and overlap on *pleasant*; and subsets 4–5 contain all *high* conditions and overlap on *unpleasant-activated*.

We computed the effect size for the non-overlapping conditions of subsets 2–3 ($d = .27$) and subsets 4–5 ($d = .38$). Both produce "small" effect sizes, implying a statistical but not a practical difference. Therefore, we consider subsets 2–3 to be one as we also consider subsets 4–5.

For valence, the one-way repeated measures ANOVA with Greenhouse-Geisser correction for violations of sphericity also yielded a statistically significant difference among the nine conditions, $F(5.79, 1105.63) = 29.62$, $p < .0005$, $\eta_p^2 = .13$. Multiple comparisons via Tukey's HSD computed the expected outcome of three homogeneous subsets (Table 5); however, they do not represent one for each level of valence. The only discernible pattern from table is that the first three conditions are *high* arousal conditions, not at all related to valence conditions.



(a) Dark bars are *high* arousal conditions, light are *medium*, and white are *low*.

(b) Dark bars are *negative* valence conditions, light are *neutral*, and white are *positive*.

Figure 5: Mean ratings for (a) perceived arousal and (b) perceived valence.

Table 6: Participant arousal and valence self-reports at specified times.

Time	N	Arousal M	Arousal SD	η^2	Valence M	Valence SD	η^2
Baseline	32	3.88	1.36	—	5.16	.99	—
After Set1		3.22*	1.45	.17	4.88	.98	.08
After Set2		3.03*	1.26	.35	4.78	.91	.13
After Set3		3.09*	1.35	.28	4.78*	1.01	.17

*Statistically significant difference ($p < .05$) from baseline.

4.3 Participant Affect State

Participants also reported their own emotional state four times during the study. Separate one-way repeated measures ANOVA for arousal, $F(3, 93) = 6.12$, $p = .00$, $\eta_p^2 = .17$, and for valence, $F(3, 93) = 3.10$, $p = .03$, $\eta_p^2 = .09$, both found a statistically significant difference among these four self-assessments. Multiple comparisons adjusted via the Holm-Bonferroni method were conducted between the baseline measurement and each subsequent report. The means, standard deviations, effect sizes, and statistically significant differences are presented in Table 6.

5. GENERAL DISCUSSION

The goal of this study was to investigate how well the Haptic Creature communicates its emotional state through touch. In specific, do the current settings for its rendering parameters represent their intended affective state.

The overall results suggest that the robot is capable of communicating its level of arousal but less effective at conveying valence. Details of these results provide information on ways to appropriately modify rendering parameters in order to improve the robot's overall ability to communicate.

Emotion Label Selections. An examination of Table 3 shows the Haptic Creature correctly communicated four of nine conditions: *unpleasant-activated* (70%), *pleased* (44%), *deactivated* (42%), and *neutral* (25%). The least successful condition was *unpleasant* as its emotion label, *miserable*, occurred only 2%. This has always been the most difficult for pilot participants to discern, and this also seems to be the case in the present study. The perceived valence and arousal for *miserable* in Figure 5 appears valid for when the label was chosen; however, it was not chosen very often.

Effectiveness of Conveying Arousal. Visual inspection of the robot's perceived arousal in Figure 5(a) shows a clear stair-step pattern from conditions of *high* activation down to those of *low* activation. The statistical analysis in Section 4.2 also confirms there are three homogeneous groups corresponding to the three arousal states.

Breathing rate and ear stiffness were the main features meant to vary with arousal while being held constant along the valence axis. It appears that the settings for actuator rendering parameters related to arousal represented their intended affect state.

Ambiguity in Communicating Valence. Figure 5(b), on the other hand, does not reveal the same stair step pattern as for the perceived valence. We expected low ratings for *negative* valence conditions increasing up to those of *positive* valence. This ambiguity is similarly evident in the emotion label selections where, regardless of the condition's valence, *distressed* dominates the *high* activation states and *sleepy* dominates the *low* activation ones (Table 3).

Breathing's Contribution to Valence. Breathing symmetry was one feature intended to convey valence. In the post-study questionnaire 71% of participants rated breathing symmetry as something they consciously used to assess the Haptic Creature's emotional state while, in contrast, breathing rate and depth ranked 100% and 94% respectively. Furthermore, structured open-ended questions allowed participants to explain how they differentiated levels for arousal and valence. As expected, breathing rate predominated the answers for arousal. Surprisingly, however, it also appeared frequently in responses to valence: some mentioned fast breathing as *positive* valence but others felt it was *negative*.

Inspection of the perceived valence in Figure 5(b) shows a decrease in all *high* arousal states — bars 1, 4, and 7 — when the breathing rate was fastest, and a similar pattern can be seen in the first three conditions of Table 5. This implies *negative* valence may have been inferred from rapid breathing. This aligns with models of domestic animal breathing where increased respiration rates can imply sickness or distress; however, it is also noted that it can be the result of excitement or exercise [19].

Depth was one additional breathing factor mentioned by participants as conveying valence. For this study, however, the Haptic Creature's depth of breathing changed based on arousal: the amount of displacement remained constant at around 70%-75% but both the minimum and maximum amplitude increased as arousal increased. Participants appear instead to have been using depth as cue for valence, with some suggesting shallow implied *negative* and deep conveyed *positive* valence.

These responses provide useful insight for modifications to actuator rendering parameters to improve the robot's affect display, particularly in respect to valence. Leveraging breathing rate for not only arousal is one approach. Using depth of breathing to convey valence rather than arousal is another possible modification.

In addition, since participants did indicate breathing symmetry as something they considered, the related parameters can be adjusted. The current approach to symmetry always biases faster inhalation over exhalation when breathing is asymmetric. It is possible, however, to also do the opposite, where the inhale of a breath is slower than its exhalation. This approach could augment the current one by widening the expressive range for breathing symmetry. Any modifications to rate, depth, or symmetry of breath would, of course, require further evaluation as to their effectiveness.

Finally, as noted in Table 1, the *rest* parameter was currently unused. This is yet another parameter that could be manipulated to affect the valence component.

Purring's Contribution to Valence. Purring was another mechanism the Haptic Creature used to display its emotional state. Its main goal was to convey valence though, where present, the purring also varied with arousal. In particular, purring was rendered only in the *pleasant* and *pleasant-activated* conditions of this study. Inspection of Table 3 for these two conditions indicate that purring was effective in conveying the *pleasant* state but not *pleasant-activated*. In addition, *distressed* prevailed in the latter condition yet was also frequent in *pleasant*.

Questionnaire responses reflect that some participants considered the purr, since it was vibrotactile rather than audible, to connote shaking or shivering. This is especially apparent in the *pleasant-activated* condition as some felt as if the purr was too strong; they noted that the increase in the intensity of the purr corresponded to an increase in excitement but also noted that if it was too strong it implied unhappy or fearful emotions.

This was a surprising result since, as discussed in Section 2.2, pilot participants rarely found any purr to imply *negative* valence, even ones intentionally designed as such. Nonetheless, shaking or shivering provides a very useful metaphor from which to develop *negative* valence purring.

No Influence by Gender or Animal Experience. While the primary goal of this study was to examine the Haptic Creature's effectiveness in communicating its emotional state, the study also investigated differences in recognition as a result of gender or prior experience with animals. The latter case in particular stems from the thought that humans with greater experience with animals might fare better (or, perhaps, worse) when assessing the robot's emotional state. As the results in Section 4.1 show, however, there were no statistically significant differences noted for either gender or animal experience.

Interaction Decreases Participant Arousal. One of the broader goals of the Haptic Creature project is to investigate the influence of affective touch. Future studies will examine this more directly; however, this study afforded a chance to begin examining the question by asking participants to rate their own affective state at various points. Most notable, results in Section 4.3 show a statistically significant decrease in arousal with large effect size. It should be noted, however, that there was no control group — all those reporting interacted directly with an active Haptic Creature — so the results at this point can not completely confirm the changes were a direct result of interacting with the robot.

6. REFERENCES

[1] L. F. Barrett and J. A. Russell. Independence and bipolarity in the structure of current affect. *Journal of Personality and Social Psychology*, 74(4):967–984, April 1998.

[2] A. Beck and A. H. Katcher. *Between Pets and People: The Importance of Animal Companionship*. Purdue University Press, West Lafayette, Indiana, USA, 1996.

[3] M. M. Bradley and P. J. Lang. The international affective picture system (IAPS) in the study of emotion and attention. In J. A. Coan and J. J. Allen, editors, *Handbook of Emotion Elicitation and Assessment*, Series in Affective Science, chapter 2, pages 29–46. Oxford University Press, 2007.

[4] C. L. Breazeal. *Designing Sociable Robots*. MIT Press, Cambridge, Massachusetts, USA, 2002.

[5] J. J. Campos, D. L. Mumme, R. Kermoian, and R. G. Campos. A functionalist perspective on the nature of emotion. *Monographs of the Society for Research in Child Development*, 59(2/3):284–303, 1994.

[6] J. Chang, K. MacLean, and S. Yohanan. Gesture recognition in the haptic creature. In A. Kappers, J. van Erp, W. B. Tiest, and F. van der Helm, editors, *Haptics: Generating and Perceiving Tangible Sensations - EuroHaptics 2010*, volume 6191 of *Lecture Notes in Computer Science*, pages 385–391. Springer Berlin / Heidelberg, 2010.

[7] C. Darwin. *The Expression of the Emotions in Man and Animals*. John Murray, London, England, 1872.

[8] P. Ekman. Are there basic emotions? *Psychological Review*, 99(3):550–553, July 1992.

[9] P. Ekman and W. V. Friesen. Constants across cultures in the face and emotion. *Journal of Personality and Social Psychology*, 17(2):124–129, February 1971.

[10] M. G. Frank and J. Stennett. The forced-choice paradigm and the perception of facial expressions of emotion. *Journal of Personality and Social Psychology*, 80(1):75–85, January 2001.

[11] M. Fujita and H. Kitano. Development of an autonomous quadruped robot for robot entertainment. *Autonomous Robots*, 5(1):7–18, March 1998.

[12] M. A. Heller and W. Schiff, editors. *The Psychology of Touch*. L. Erlbaum, Hillsdale, New Jersey, USA, 1991.

[13] M. J. Hertenstein, R. Holmes, M. McCullough, and D. Keltner. The communication of emotion via touch. *Emotion*, 9(4):566–573, August 2009.

[14] M. J. Hertenstein, D. Keltner, B. App, B. A. Bulleit, and A. R. Jaskolka. Touch communicates distinct emotions. *Emotion*, 6(3):528–533, August 2006.

[15] H. Irtel. PXLab: The psychological experiments laboratory [online]. http://www.pxlab.de, 2007. Mannheim (Germany): University of Mannheim.

[16] P. J. Lang. Behavioral treatment and bio-behavioral assessment: Computer applications. In J. B. Sidowski, J. H. Johnson, and T. W. Williams, editors, *Technology in Mental Health Care Delivery Systems*, pages 129–139. Ablex, Norwood, New Jersey, U.S.A., 1980.

[17] B. Major and R. Heslin. Perceptions of cross-sex and same-sex nonreciprocal touch: It is better to give than to receive. *Journal of Nonverbal Behavior*, 6(3):148–162, March 1982.

[18] A. Montagu. *Touching: The Human Significance of the Skin*. Perennial Library, New York, New York, USA, 1986.

[19] W. O. Reece. *Functional Anatomy and Physiology of Domestic Animals*. Wiley-Blackwell, Ames, Iowa, U.S.A., 4th edition, 2009.

[20] J. A. Russell. A circumplex model of affect. *Journal of Personality and Social Psychology*, 39(6):1161–1178, December 1980.

[21] J. A. Russell. Is there universal recognition of emotion from facial expression? A review of the cross-cultural studies. *Psychological Bulletin*, 115(1):102–141, January 1994.

[22] J. A. Russell, A. Weiss, and G. A. Mendelsohn. Affect Grid: A single-item scale of pleasure and arousal. *Journal of Personality and Social Psychology*, 57(3):493–502, September 1989.

[23] J. Saldien, K. Goris, S. Yilmazyildiz, W. Verhelst, and D. Lefeber. On the design of the huggable robot probo. *Journal of Physical Agents*, 2(2):3–11, June 2008.

[24] M. Scheutz, P. Schermerhorn, J. Kramer, and D. Anderson. First steps toward natural human-like hri. *Autonomous Robots*, 22(4):411–423, May 2007.

[25] T. Shibata, T. Mitsui, K. Wada, A. Touda, T. Kumasaka, K. Tagami, and K. Tanie. Mental commit robot and its application to therapy of children. In *Advanced Intelligent Mechatronics, 2001. Proceedings. 2001 IEEE/ASME International Conference on*, volume 2, pages 1053–1058. IEEE/ASME, July 2001.

[26] W. D. Stiehl, J. Lieberman, C. Breazeal, L. Basel, L. Lalla, and M. Wolf. Design of a therapeutic robotic companion for relational, affective touch. In *Robot and Human Interactive Communication, 2005. ROMAN 2005. IEEE International Workshop on*, pages 408–415, August 2005.

[27] Ugobe. Pleoworld - the home of pleo, the robotic baby dinosaur from ugobe life forms. http://www.pleoworld.com/, December 2007.

[28] D. N. Walker. A dyadic interaction model for nonverbal touching behavior in encounter groups. *Small Group Research*, 6(3):308–324, August 1975.

[29] S. Yohanan, M. Chan, J. Hopkins, H. Sun, and K. MacLean. Hapticat: Exploration of affective touch. In *ICMI '05: Proceedings of the 7th International Conference on Multimodal Interfaces*, pages 222–229, New York, New York, USA, October 2005. ACM Press.

[30] S. Yohanan and K. MacLean. The haptic creature project: Social human-robot interaction through affective touch. In *Proceedings of the AISB 2008 Symposium on the Reign of Catz & Dogs: The Second AISB Symposium on the Role of Virtual Creatures in a Computerised Society*, volume 1, pages 7–11, April 2008.

[31] S. Yohanan and K. E. MacLean. A tool to study affective touch: Goals & design of the haptic creature. In *CHI '09: Proceedings of the 27th International Conference Extended Abstracts on Human Factors in Computing Systems*, pages 4153–4158, New York, New York, U.S.A., 2009. ACM.