Haptic Actuator Design Parameters That Influence Affect and Attention

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Abstract

Most haptic feedback devices to date are designed to be alerts or warnings that capture a user's attention. This can be disruptive or annoying when the user needs to focus on another task of higher importance. We believe that haptic feedback that elicits positive affect can manage attention capture across a wider spectrum than feedback with negative affect. In this study, we explore the affective response to several haptic actuator designs for better management of user attention. We evaluate six parameters that may impact affect: stimulus location on the body, actuation type, actuation intensity, actuation profile, actuator material and actuator geometry. A total of 30 subjects participated in this study (average age 24±3 years). Of the six parameters, we found that actuation profile had the most significant impact on affect. We also found that devices with negative affect were better able to capture the user's attention. Due to the variability in the verbalized preferences among subjects, we propose outfitting all haptic actuators with an intensity control. We anticipate that the results of this study will guide designers in modifying key parameters of haptic devices to appropriately manage user attention.

Keywords: Haptics, affect, attention, vibrotactile feedback, pressure feedback, tactor, pactor, actuator design

Index Terms: H.5.2 [Information Interfaces and Presentation]: User Interfaces—Haptic I/O;

1 Introduction

The recent proliferation of computational capability has led to novel ways of communicating information in a diverse range of applications such as mobile phones, in-car GPS and fly-by-wire aircraft. The use of haptics (the sense of touch and proprioception) has received a great deal of attention as a promising display method for certain kinds of information.

Most haptic feedback devices have been designed to be alerts or warnings in order to capture a user's attention, particularly in safety-critical applications. Examples include in-vehicle vibrotactile feedback systems that warn the driver of impending automobile collisions [7, 8, 9, 12] and wearable vibrotactile belts for airplane pilots that can enhance their situational awareness during low visibility flying conditions [14, 16, 30].

Haptic feedback has also been used to supplement vision and audition to guide muscle movement. The Haptic Radar headband [6] uses vibrotactile actuators ("tactors") to help the wearer detect objects near his head. TactaPack utilizes tactors to provide both spatial and temporal information to physical therapy patients [18]. The Posture Seat uses tactors to coach a seated person into a desired posture [31]. Haptic feedback has also been used to train athletes such as tennis players and swimmers [1, 17], and musicians such as pianists and violinists [13, 15]. In all of these cases, a user's attention is directed towards responding to haptic feedback to complete his primary task.

While multimodal reinforcement using haptics is generally a benefit, the success of haptic warnings and alarms creates an associated downside. When haptic methods are used for non-critical tasks, they may distract the user from a more important task. This was the case in the posture seat cognitive load study [32] where we found that vibrotactile feedback was effective in guiding a user to a desired reference posture but disrupted the user's performance on a typing task.

MacLean advocates placing haptic feedback in the ambience to allow the user more choice in how he allocates attention [19]. This ambient, peripheral feedback would allow the user to attend to his primary task or utilize the presented information at his convenience. For example, the Haptic Car Seat delivers gentle vibrations to the driver to alert him of cars in his blindspot [21]. Instead of forcing the driver to take action, the driver can choose to drive normally or utilize the information to influence his decision to change lanes at that moment.

Our goal is to create haptic devices that can be implemented to modulate attention capture along a spectrum between "ignorable" and "demand action" [20]. In this paper, we will refer to this notion as the *attention capture spectrum*. Along this spectrum, we think that haptic devices that elicit positive affect will be able to modulate attention across a wider spectrum, when compared to those that elicit negative affect.

Affective design (designing for feelings or emotional responses) has been explored across many different disciplines, ranging from marketing [22] to nursing [11] to robotics. In a simulated search-and-rescue mission, Bethel and Murphy found that robots with affective expression were perceived as more friendly and attentive to simulated disaster victims [4]. Yohanan, et. al. explored affective computing through the development of *Hapticat* to render a broad range of user affect with minimal creature features [29]. Haans, et. al. investigated remote social touch mediated by a vibrotactile vest and found that stimulus location on the body significantly impacted affective response [10]. Finally, most relevant to our research is the work by Baumann, et. al. that found that symmetric pressure actuation profiles were more relaxing than asymmetric profiles [2]. Our current study builds upon existing knowledge on affect to investigate whether haptic actuator device designs can elicit positive affect and thus be capable of modulating user response along the attention capture spectrum.

2 Haptic Actuator Design

Mechanoreceptors in the skin are responsive to certain types of stimuli. For example, Pacinian corpuscles, Meissner corpuscles, and hair follicle receptors are sensitive to vibration while Ruffini corpuscles and Merkle discs are sensitive to pressure. Careful design of haptic actuators can selectively stimulate one or more mechanoreceptors to induce a desired sensation or behavioral response. In a study using vibrotactile feedback for seated posture guidance, we found that vibration on the back evoked an attention-getting, "annoyed" response that distracted the person from performing his office task [32]. This led us to believe that devices or

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signals that elicit negative affect may only "demand action." We would like to examine whether a pure pressure stimulus, activating different mechanoreceptors than a vibratory stimulus, might be more apt for modulating attention across the whole spectrum.

In this study we explore the design of pressure actuators, called "pactors," and compare them to vibrotactile "tactors" for affective response, attention capture, and novelty of stimulus. Pactors are comprised of high-torque servo motors attached to cam arms that produce linear displacements at the "contactor head" – the part that comes in contact with the human. The contactor head, which can assume any number of geometries, presses against a person's skin at different speeds and actuation profiles. Although pactors can be actuated repeatedly to produce a tapping sensation, we will only consider simple pressure profiles in this study.

We use the same vibrotactile actuators ("tactors") as the ones developed in [21, 31]. Tactors are comprised of eccentric mass motors mounted on an acrylic plate or rubber pad.

3 Affect, Attention, and Novelty Indices

The primary aim of the affect study is to explore key design parameters that influence affect. A secondary goal is to determine design parameters that influence attention capture and the perception of novelty. We will start with a broad set of tactor and pactor parameters in the preliminary study and reduce the size of this parameter list so that the affect study (Section 6) may be more tractable.

We will model an "affect index" as a function of the parameters that influence affect:

$$I = f(p_1, p_2, ...p_n). \quad (1)$$

In the simplest case, index I may be a linear combination of the individual parameters. In reality I may also contain terms that capture the interaction effects of the various parameters. The parameters p_i may represent both discrete and continuous variables, such as material type, intensity, radius of curvature, etc. The above equation can also be used to compute the attention and novelty indices.

Given the inherent variability in human cognitive function and the discontinuous nature of discrete parameter choices, it is unlikely that an absolute scale can be used for the affect, attention, and novelty indices. Instead, we propose to measure the relative change in the indices as each parameter is modified. The relative change of the indices will provide insight to haptic device designers. In essence, we are interested in changes in parameters that will yield the greatest ΔI.

4 Parameter List

We will begin by examining the effect of vibratory and pressure feedback on affect while varying body location, stimulus intensity, actuation profile, material and geometry (see Figure 1 for reference). In a preliminary test with 5 subjects, we found that subjects could only distinguish 2 levels of actuation intensity (low and high) and two types of actuation profile (step and ramp). Additionally, subjects could not discern the difference between acrylic and ABS plastic for all geometries, and between ABS and rubber for the hemisphere with the smallest radius of curvature (henceforth called "small R"). Furthermore, the triangular geometry with sharp edges was unacceptably uncomfortable so we omitted it from use. Finally, we found that subjects could only somewhat differentiate between a flat surface and a small R for vibration on the back.

Based on the results of the preliminary test, we narrowed down the levels for each parameter for the affect study to only the ones that were easily discernible, which are presented in Table 1. The specific material-geometry combinations that were discernible during preliminary testing are shown in Figure 1. The dimensions of each contactor head – the piece of the actuator that comes in contact with the human body – are shown in Figure 2. Each of these 14 pactors and tactors varied in actuation intensity (low and high) and

Figure 1: Vibration and pressure actuators used to stimulate the arm and back. Actuator designs vary in actuation type (vibration, pressure), material (hard plastic - acrylic or ABS, soft rubber), and geometry (flat surface, large radius of curvature, medium radius of curvature, and small radius of curvature).

Table 1: Haptic actuator test parameters

Body Site	Act. Type	Intensity	Profile	Material	Geometry
arm	vibration	low	step	plastic	flat
back	pressure	high	ramp	rubber	large R
					medium R
					small R

actuation profile (step and ramp), for a total of 56 combinations to test in the affect study.

The representation of the intensities and profiles implemented for each haptic actuator is shown in Figure 3. Since the tactor is an eccentric mass on a motor, vibration intensity is a function of voltage which increases both frequency and amplitude simultaneously. We commanded the tactors at 40% and 80% of full intensity for the low and high intensities, respectively. The arm pactors created a displacement of 0.25" and 0.40" for low and high intensities, respectively, and the lumbar pactors displaced the back by 0.40" and 0.75".

The choice of body site was motivated by an evaluation of wearable and "environmental" devices – haptic actuators that could be "built in to" the user's existing environment as opposed to being an additional device. We decided to use only the arm for the presentation of stimuli from a wearable haptic device and only the back for the presentation of stimuli from a seat.

5 Equipment and Hardware

Tactors were comprised of miniature pager motors enclosed in a custom ABS housing mounted on the back of a 1.5" x 1.5" x 0.125"

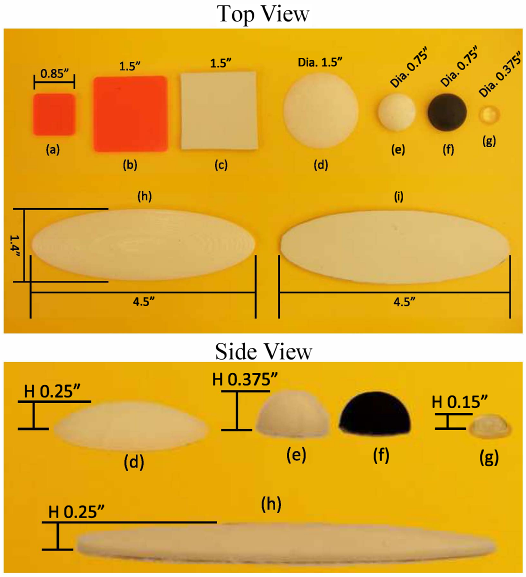


Figure 2: Dimensions of the contactor heads. (a) pactor - acrylic, flat; (b) tactor - acrylic, flat; (c) tactor - rubber, flat; (d) tactor - plastic, large R; (e) tactor and pactor - plastic, medium R; (f) pactor - rubber, medium R; (g) tactor - rubber, small R; (h) pactor - plastic, large R; (i) pactor - rubber, large R.

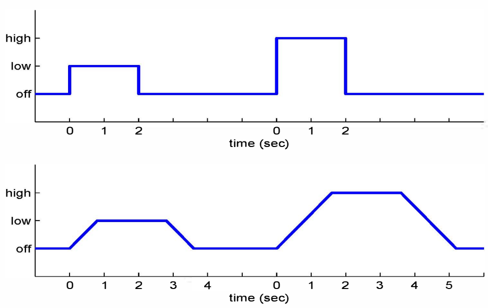


Figure 3: Actuation intensity and profile for the haptic feedback devices. The duration of ramp profiles is longer than that of the step profiles.

acrylic plate or soft rubber pad. The tactors were each controlled by a 3kHz pulse-width modulated (PWM) voltage between 0-3V using a motor controller, which were run from a PC-based servo controller board.

Pactors utilized Futaba S3003 and Hitec HS805BB servo motors and custom cam arms. The cam arms incorporated a slot that allowed the pushing mechanism to produce a linear displacement of the contactor head. The amount of displacement was controlled via position feedback inside the servo.

A set of 14 different tactors and pactors were used to stimulate the arm and back, which are shown in Figure 1. Arm tactors and pactors were placed on the medial lateral aspect of the upper arm and were secured in place by a velcro arm strap (Figure 4). The pressure actuators were constrained to linear travel in order to deliver pure pressure to the skin. The back tactor was affixed to the back of a size B Herman Miller Aeron chair approximately 8" above the seat, as shown in Figure 5. The back pactor was embedded in the Aeron lumbar support pillow and was placed approximately 8" above the seat back (Figure 5).

Pactors and tactors were run from the same Lynxmotion servo

Figure 4: Placement of arm actuators. Actuators come in direct contact with the medial lateral aspect of the upper arm and are secured in place by a velcro arm strap.

Figure 5: Placement of back tactor on a size B Herman Miller Aeron chair approximately 8" above the seat. (Left) Back view of seat back showing placement of the vibratory tactor. (Right) Aeron lumbar support pillow with back pactor embedded.

controller board. LabVIEW 2010 was used to communicate with the servo controller board via a serial connection. The entire system was run on a Dell Optiplex GX620 (2.80GHz Pentium 4 processor, 2 GB RAM) with Windows 7. While the existing system makes use of general purpose PC's and software for research purposes, the system could be implemented with a small microcontroller since the bandwidth and computation requirements are modest.

6 Test Procedure

As stated in Section 4, the primary goal of this study was to measure subjects' affective response to various haptic feedback actuators and actuation parameters, while a secondary goal was to determine the impact of these parameters on attention capture and perceived novelty. A total of 56 combinations of the 6 parameters listed in Table 1 were tested. Each stimulus was presented to the test subject for 2-5 seconds, long enough for the subject to perceive the stimulus and formulate a visceral reaction. However, based on feedback from preliminary testing that users were fatigued after one hour of testing, each test subject was only presented a maximum of 44 combinations (randomly selected out of the 56) so that the experiment could be completed within one hour. Test subjects were randomly assigned into one of two groups: Group A received all of the arm stimuli first followed by the back stimuli, while the Group B received all of the back stimuli first followed by the arm stimuli. This was done in order to counterbalance the presentation of stimuli to the arm and back. A randomly generated test sequence was developed for each subject in order to eliminate ordering bias.

Test subjects were instructed to wear short-sleeve shirts since arm actuators needed to be in direct contact with their skin.

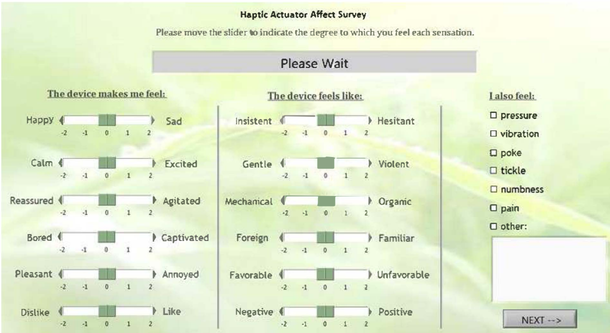


Figure 6: Haptic device affect survey. This survey is completed after each stimulus presentation for a total of 44 trials.

Prior to the start of the test, subjects removed everything from their pockets as cell phone vibrations and even phantom vibrations (e.g. perceived vibrations in the absence of real vibrations) might alter the results of the affect study. Subjects donned noise canceling headphones playing white noise so that sound from the actuators would not influence their perception of the actuators.

Subjects then filled out a short pre-experiment positive and negative affect schedule (PANAS) mood questionnaire to assess their baseline mood [27, 28]. We adopted a standard 4-point scale PANAS questionnaire typically used in psychology experiments to assess mood [26]. Questions include "I feel calm," "I feel secure," "I feel tense," etc. Test subjects were instructed to spend only about 2 minutes answering this survey.

Next, subjects were presented examples of pressure and vibration stimuli on the arm and back in order to familiarize them with the sensations. The definitions of the adjectives in the affect survey shown in Figure 6 were explained to the test subjects. This familiarization phase lasted less than 5 minutes.

The bulk of the experiment was the affect test. A randomized test sequence was generated for each subject. For each trial, a haptic actuator was selected (based on the test sequence) and a stimulus was presented to the subject's body. When the stimulus was active, the text "Please Wait" appeared on the screen. When the text cleared, the subject moved the sliders shown in Figure 6 to indicate how he felt about the stimulus. When he submitted the survey, a new stimulus was presented. The subject repeated this process up to 44 times. At the end of the trials, or at the end of one hour, whichever came first, the subject answered a post-experiment PANAS questionnaire, which was the same as the one administered in the pre-test.

We developed an affect survey that was modeled after the self-assessment manikin (SAM) tool [3, 5] in order to tailor to our needs and used some of the same antonym-pair descriptors as the ones used in [2]. The SAM tool is a pictorial survey that helps researchers plot a test subject's affect on the 2D or 3D affect grid comprising of "valence," "arousal," and "dominance" dimensions [24, 25]. Since our affect survey was a departure from the SAM tool, we opted to analyze affect as one lumped affect index (Equation 1).

The survey questions were designed such that, out of the 12 antonym pairs, 6 measured affect, 4 measured attention capture, and 2 measured novelty of the stimulus (Table 2). Test subjects could select additional words such as poke, tickle, numbness, etc. that further described their sensation. They could also enter other sensations in the free response text box.

At the conclusion of the experiment, test subjects were asked in an informal interview about their preferences for a specific type of feedback and for their overall impressions of the actuators and actuation profiles.

Table 2: Grouping of adjectives to measure plesantness, attention capture, and novelty

Affect	Attention	Novelty
Happy/Sad	Calm/Excited	Mechanical/Organic
Reassured/Agitated	Bored/Captivated	Foreign/Familiar
Pleasant/Annoyed	Insistent/Hesitant	
Dislike/Like	Gentle/Violent	
Favorable/Unfavorable		
Negative/Positive		

7 Results

This section presents the trends and statistical analyses between the actuator parameters and affect, attention, and novelty. The affect, attention, and novelty indices range from -2 to +2. The PANAS mood index ranges from -1 to +1. We define statistical significance to be $p < 0.05$. All statistical analyses were carried out in STATA 11.

A total of 30 subjects (14 males, 16 females) participated in the experiment. The average age was 24±3 years. The average weight, height, upper arm length, and medial upper arm circumference were 65.9±12.1kg, 167±32cm, 27±3.1cm, and 30±3.2cm, respectively. All test subjects reported at least some amount of experience with haptic actuators, with a few people reporting extensive experience.

7.1 Parameters that significantly influence affect

Linear regression models were run on each of the parameters as well as their interactions to determine their effects on affect. The statistically significant changes in the affect index from baseline are summarized in Table 3. The baseline case was taken to be arm vibration at low intensity with a step input using flat plastic, which had a baseline affect index I of -0.140.

When all of the parameters were treated as independent, then body site, actuation intensity, actuation profile, material, and geometry exhibited a statistically significant impact on affect. Moving the body site from arm to back changed the affect index by -0.130. Increasing the intensity from low to high changed the affect index by -0.158. Changing the profile from step to ramp input increased the affect index by 0.305, etc. (Table 3)

When we took into account two-way interaction effects in the linear regression analysis, we found four instances yielding statistically significant results, and these are reported in Table 3. While actuation type was not significant in the single variable analysis, it became significant in the two-way interaction effects. As such, we included it in the table.

Table 3: Parameters and interactions between parameters that result in significant changes in affect. [1] Actuation profile became a significant variable in the two-way interaction analyses.

Stimulus change	Δ Affect	p-value
arm →back	-0.130	0.001
vibration→pressure[1]	+0.187	0.000
intensity low→high	-0.158	0.000
step→ramp	+0.305	0.000
plastic→rubber	+0.108	0.020
flat→smallR	+0.160	0.004
arm→back & vibration→pressure	-0.278	0.000
arm→back & low→high	-0.269	0.001
arm→back & step→ramp	+0.240	0.002
vibration→pressure & step→ramp	+0.262	0.001
arm→back & vibration→pressure & step→ramp	+0.351	0.022

Table 4: Parameters and interactions between parameters that result in significant changes in attention

Stimulus change	Δ Attention	p-value
arm→back	+0.214	0.000
vibration→pressure	-0.240	0.000
intensity low→high	+0.325	0.000
step→ramp	-0.389	0.000
flat→smallR	-0.215	0.000
arm→back & vibration→pressure	+0.315	0.000
arm→back & low→high	+0.291	0.000
vibration→pressure & low→high	+0.239	0.001
vibration→pressure & step→ramp	-0.409	0.000

When we performed a linear regression with up to three-way interactions, only the interaction among body site, actuation type, and profile was significant. The four-way interaction analysis yielded no statistically significant results.

7.2 Parameters that significantly influence attention

The same set of linear regression analyses were run for attention as for affect. When all of the parameters were treated as independent, body site, actuation type, intensity, profile, and geometry had a statistically significant influence over attention. These are the same parameters that significantly impacted affect with the exception of actuator material.

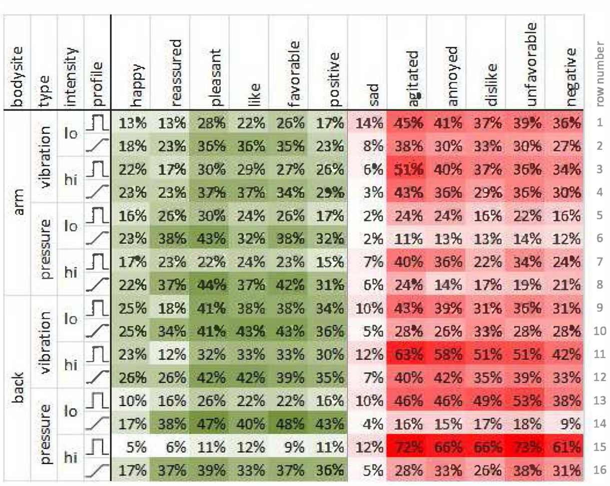
Taking into account two-way interaction effects, we found that the interaction between body site and actuation type, between body site and intensity, between actuation type and intensity, and between actuation type and profile were also statistically significant. Unlike the results for affect, the interaction between body site and actuation profile was not statistically significant in affecting attention ($p = 0.060$).

The three-way and four-way interaction linear regression results did not achieve statistical significance. The variables and interactions that cause significant attention changes are listed in Table 4. An increase in the attention index signifies greater attention capture.

7.3 Parameters that significantly influence novelty

The same set of linear regression analyses as affect and attention were performed for novelty. When all of the parameters were treated as independent, body site, actuation type, intensity, profile, and geometry showed statistically significant influences on novelty. These were the same parameters that significantly affected attention.

Running a linear regression with interactions, we found that only the two-way interactions between body site and actuation type, between body site and intensity, and between actuation type and actuation profile significantly impacted the novelty index. The variables and interactions that caused significant novelty changes are listed in Table 5. An increase in the novelty index implies that the stimulus felt more unfamiliar and mechanical to the test subject.



bodysite	type	intensity	profile	happy	reassured	pleasant	like	favorable	positive	sad	agitated	annoyed	dislike	unfavorable	negative	row number
arm	vibration	lo	⎍	13%	13%	28%	22%	26%	17%	14%	45%	41%	37%	39%	36%	1
			⟋	18%	23%	36%	36%	35%	23%	8%	38%	30%	33%	30%	27%	2
		hi	⎍	22%	17%	30%	29%	27%	26%	6%	51%	40%	37%	36%	34%	3
			⟋	23%	23%	37%	37%	34%	29%	3%	43%	36%	29%	36%	30%	4
	pressure	lo	⎍	16%	26%	30%	24%	26%	17%	2%	24%	24%	16%	22%	16%	5
			⟋	23%	38%	43%	32%	38%	32%	2%	11%	13%	13%	14%	12%	6
		hi	⎍	17%	23%	22%	24%	23%	15%	7%	40%	36%	22%	34%	24%	7
			⟋	22%	37%	44%	37%	42%	31%	6%	24%	14%	17%	19%	21%	8
back	vibration	lo	⎍	25%	18%	41%	38%	38%	34%	10%	43%	39%	31%	36%	31%	9
			⟋	25%	34%	41%	43%	43%	36%	5%	28%	26%	33%	28%	28%	10
		hi	⎍	23%	12%	32%	33%	33%	30%	12%	63%	58%	51%	51%	42%	11
			⟋	26%	26%	42%	42%	39%	35%	7%	40%	42%	35%	39%	33%	12
	pressure	lo	⎍	10%	16%	26%	22%	22%	16%	10%	46%	46%	49%	53%	38%	13
			⟋	17%	38%	47%	40%	48%	43%	4%	16%	15%	17%	18%	9%	14
		hi	⎍	5%	6%	11%	12%	9%	11%	12%	72%	66%	66%	73%	61%	15
			⟋	17%	37%	39%	33%	37%	36%	5%	28%	33%	26%	38%	31%	16

Figure 7: Matrix of haptic actuator parameters and their corresponding affect ratings. Numbers show percent of subjects who selected a certain adjective for each combination of test parameters.

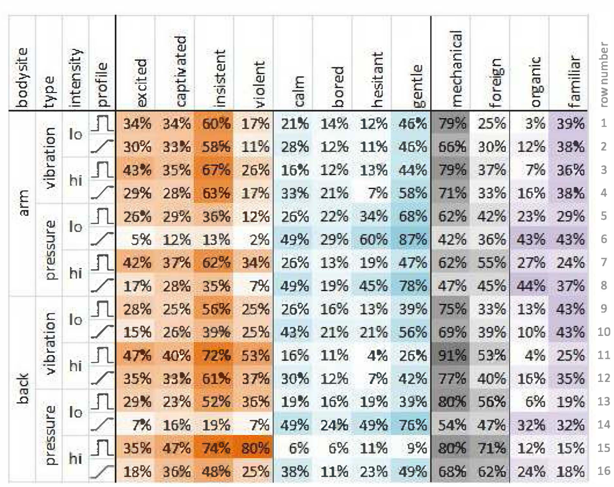
Table 5: Parameters and interactions between parameters that result in significant changes in novelty

Stimulus change	Δ Novelty	p-value
arm→back	+0.264	0.000
vibration→pressure	-0.126	0.018
intensity low→high	+0.164	0.000
step→ramp	-0.262	0.000
flat→smallR	-0.211	0.001
arm→back & vibration→pressure	+0.257	0.005
arm→back & low→high	+0.215	0.018
vibration→pressure & low→high	-0.283	0.002

7.4 Preferences for specific parameter combinations

The matrix of actuator parameters, their corresponding affect, attention capture, and novelty is shown in Figures 7 and 8. For simplicity, the material and geometry parameters were omitted from this matrix since subjects did not show sensitivity to material or geometry.

Looking at Figure 7, it is apparent that the majority of test subjects disliked the high intensity pressure applied to the back with the step input (row 15, dark red). Over half of the subjects also disliked the high intensity step input vibrations on the back. However, close to half of the subjects preferred the ramp profiles for both pressure and vibration on the back, and the ramp profile for pressure on the arm (dark green rows). About a third of the subjects found vibrations on the arm to be pleasant while another third felt the exact opposite about arm vibrations. Generally subjects did not



bodysite	type	intensity	profile	excited	captivated	insistent	violent	calm	bored	hesitant	gentle	mechanical	foreign	organic	familiar	row number
arm	vibration	lo	⎍	34%	34%	60%	17%	21%	14%	12%	46%	79%	25%	3%	39%	1
			⟋	30%	33%	58%	11%	28%	12%	11%	46%	66%	30%	12%	38%	2
		hi	⎍	43%	35%	67%	26%	16%	12%	13%	44%	79%	37%	7%	36%	3
			⟋	29%	28%	63%	17%	33%	21%	7%	58%	71%	33%	16%	38%	4
	pressure	lo	⎍	26%	29%	36%	12%	26%	22%	34%	68%	62%	42%	23%	29%	5
			⟋	5%	12%	13%	2%	49%	29%	60%	87%	42%	36%	43%	43%	6
		hi	⎍	42%	37%	62%	34%	26%	13%	19%	47%	62%	55%	27%	24%	7
			⟋	17%	28%	35%	7%	49%	19%	45%	78%	47%	45%	44%	37%	8
back	vibration	lo	⎍	28%	25%	56%	25%	26%	16%	13%	39%	75%	33%	13%	43%	9
			⟋	15%	26%	39%	25%	43%	21%	21%	56%	69%	39%	10%	43%	10
		hi	⎍	47%	40%	72%	53%	16%	11%	4%	26%	91%	53%	4%	25%	11
			⟋	35%	33%	61%	37%	30%	12%	7%	42%	77%	40%	16%	35%	12
	pressure	lo	⎍	29%	23%	52%	36%	19%	16%	19%	39%	80%	56%	6%	19%	13
			⟋	7%	16%	19%	7%	49%	24%	49%	76%	54%	47%	32%	32%	14
		hi	⎍	35%	47%	74%	80%	6%	6%	11%	9%	80%	71%	12%	15%	15
			⟋	18%	36%	48%	25%	38%	11%	23%	49%	68%	62%	24%	18%	16

Figure 8: Matrix of haptic actuator parameters and their corresponding attention and novelty ratings. Numbers show percent of subjects who selected a certain adjective for each combination of test parameters.

feel sadness from the haptic stimuli.

Interestingly, over half of all subjects felt the haptic stimuli were insistent and mechanical (dark orange and dark grey columns, respectively, in Figure 8), suggesting that different designs would need to be pursued to make haptic actuators feel more organic and familiar. Finally, pressure and vibration on the arm seemed to be more familiar and gentle than pressure and vibration on the back.

7.5 Correlations between affect, attention, and novelty

We noticed that for almost all test subjects there was an overall negative correlation between affect and attention (average $R = -0.50 \pm 0.33$, min$= -0.89$, max $= +0.38$). In other words, a stimulus that was perceived as unfavorable captured the user's attention better. An example of one subject's plot of the affect and attention indices for the arm and back body sites over the course of the experiment is shown in Figure 9.

Similarly, we found a negative correlation between novelty and affect (average $R = -0.51 \pm 0.20$, min $= -0.82$, max $= -0.02$) and a positive correlation between novelty and attention (average $R = 0.39 \pm 0.23$, min $= -0.22$, max $= +0.76$). Stimuli that were perceived as novel (foreign, mechanical) were usually scored lower in affect than stimuli that were familiar and organic. Stimuli that were perceived as novel were positively correlated with attention; new stimuli tend to capture a user's attention better than familiar stimuli.

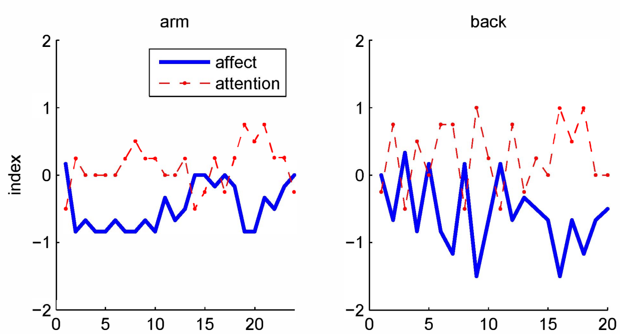


Figure 9: Plot of one subject's affect and attention data to illustrate the direct negative correlation between affect and attention. Trial numbers for the arm and back are displayed on the x-axes.

7.6 Correlations between pre-experiment mood, affect, and post-experiment mood

We utilized the PANAS mood questionnaire to investigate trends in subjects' current mood and their affective response to the haptic actuators. We found that all test subjects exhibited a neutral to positive baseline mood at the beginning of the study (average mood index 0.234±0.051, min=0.103, max=0.325 on a scale of -1 to +1). However by the end of the study there was a statistically significant negative shift in their mood ($p = 0.01$) as subjects felt less "calm" and "pleasant" by the end of the experiment, as evidenced by their individual PANAS adjective ratings. The average post-experiment mood index was 0.181±0.098, with a range of -0.020 to +0.309.

Anecdotal evidence from post-experiment interviews suggest that this mood shift could be a result of a number of reasons, such as "boredom with test" and general "dislike of listening to white noise for an hour," and may not necessarily be caused by the haptic actuators. This negative mood shift is consistent with Salminen's finding that test conditions (naturalistic vs. lab setting) impacted affect, with greater negative affect derived from the lab setting [23].

7.7 Correlations between biographical, physiological data and affect, attention, novelty

We collected information about each test subject's age, gender, height, weight, arm length, and arm circumference. When analyzed as independent variables, we found no correlation between each of the variables and affect, attention, and novelty, with only one exception: weight was positively correlated with affect (R=+0.354). We also found that only the interaction between age and gender in two-way interaction analyses resulted in a statistically significant affect on affect (p=0.004); females tended to give higher affect ratings of the devices than males but older females gave lower affect ratings than younger males.

7.8 Anecdotes

In the post-experiment interview, subjects shared with us their overall impressions of and preferences for the haptic actuators. Sixteen out of 30 subjects preferred vibrations on the back and were annoyed by pressure on the back. Meanwhile 7 subjects preferred just the opposite. Additionally 8 subjects liked pressure on the arm but not vibration on the arm, and 5 preferred the opposite.

We found a similar bimodal distribution for stimulus intensity and actuation profile. Five people consistently preferred low intensity profiles while 5 consistently liked high intensity profiles. Three subjects consistently preferred the step profile while another 3 consistently preferred the ramp profile. The remaining subjects did not exhibit a consistent preference for intensity and profile.

Six of the test subjects mentioned that the long duration of the vibration stimuli were unfavorable and preferred shorter duration bursts. The onset of the vibration stimuli excited or captivated them, but the three-second or longer stimulus length was too long and "annoyed" or "agitated" them.

Twenty-six out of 30 subjects could not consciously discern the different materials and geometries contacting their skin. Only one person felt the edge of the flat plastic actuator against their arm. Another subject noted a "cold" sensation from the flat plastic actuator contacting their arm. The two others preferred the soft rubbery material to the hard plastic material.

Finally, additional words that were used to describe the haptic actuators included "poke," "finger touch," "tap," and "natural" for the pactors acting on the arm and the back, and "itchy," "insect-like," "massage-like," and "cell phone-like" for vibrations on the arm and back. One subject also thought the vibrations on the back felt "friendly."

8 Discussion and Conclusion

In this study we varied six different parameters - location of stimulation, feedback actuation type, actuation intensity, profile, material, and geometry, and measured subjects' responses to combinations of these parameters. Looking at Table 3 it appears that actuation profile exhibited the greatest change in the affect index among the independent parameters while actuator material had the smallest statistically significant change. Table 4 shows that actuation profile is also the most influential parameter for attention capture. We are encouraged by these results because a parameter such as material or actuation type is essentially fixed after the device is designed whereas the profile and intensity are inherently adjustable in real time.

The statistically significant effect of actuation type on attention, where changing from vibration to pressure decreased the attention capture index by 0.240 points, confirmed our assumption in the posture seat cognitive load study [32] that vibration is attention-demanding and that pressure is less intrusive. When designing haptic devices for ambient feedback, it may be preferable to utilize pressure rather than vibration. However, the interaction effect between actuation type and actuation profile actually decreased the attention index by 0.409 points, suggesting that haptic device designers should primarily manipulate the actuation profile parameter to achieve the desired attentional salience.

Interestingly there was a negative correlation between affect and attention for almost all subjects, meaning that devices with negative affect were better able to capture a user's attention. This result suggested that devices that feel more pleasant might be attended to at the user's convenience.

We also found a positive correlation between attention and novelty, and a weak negative correlation between affect and novelty. These trends implied that negative or unfamiliar sensations tended to capture attention better than positive or familiar sensations. It is recommended that haptic device designers manipulate actuation parameters to induce familiar sensations such as finger poke, palm touch, or massage in order to achieve positive affect, effectively shifting towards the "ignorable" side of the attention spectrum.

Finally, while test results showed parameters with consistent significant effects on affect, we found inconsistencies with the subjects' verbal interview responses. Some people preferred high intensity vibrations on their back while others disliked them. Similarly some people preferred low intensity pressure on the arm while others preferred high intensity pressure. While the numerical data shows that no "volume" control is needed, anecdotal evidence shows that people have highly variable preferences and that haptic device designers should incorporate an intensity control to allow users to adjust to their desired intensity level.

In conclusion, the key findings from this study are the following:

- There is a negative correlation between affect and attention; devices that have negative affect generate positive attention capture.
- Actuation profile most significantly impacted affect and attention. Other parameters with statistically significant effects on affect and attention include: body site, actuation type, actuation intensity, and actuator geometry (changing from flat to smallR). Haptic device designers should choose the body site and physical implementation of the actuator based on their application constraints, and dynamically control actuation profile and intensity to modulate affect and attention capture.
- Some of the two-way interaction effects among the parameters tested, such as the interaction between body site and actuation intensity, were also significant. Designers should therefore take into consideration the potential interaction effects between the parameters that they choose.
- Preferences for haptic feedback intensity varied by test subject. One easy way to address this variability is to incorporate an adjustable intensity control to allow users to customize the feedback to their liking.

We mentioned in the introduction that we live in an era of information overload and haptic alarms that distract a user from his primary task only contribute to the problem. Our longer term goal is to develop "ambient" haptic devices [19] that deliver meaningful information to the user in a non-distracting way. This requires knowing which parameters are important in managing user attention across the full attention spectrum as defined by Matthews [20]. The aim of this paper is to evaluate a user's affective response to various design parameters of haptic actuators. The results of this study will ultimately serve to guide device designers in choosing parameters that will effectively modulate a user's attention.

9 Limitations

Many interesting results surfaced from this study yet we would like to acknowledge several limitations. First, humans are highly variable in their feelings and preferences, which may be linked to their age, gender, body dimensions, haptic sensitivities, present mood, past experiences, culture, upbringing, etc. Differences in these variables may dramatically impact the affect and attention results, which we did not seek to explore in this study. Thus we should be cautious in trying to generalize the results from the 30 participants to a larger, more diverse population. Further work may be required to investigate, for example, age, past experiences, and cultural associations with the perception of certain haptic stimuli.

Second, the materials chosen for this study did not differ enough in durometer and thermal conductivity. Most test subjects could not tell the difference between the acrylic and ABS plastic and rubber that were placed against their skin. Only one subject noted a temperature difference between the acrylic plate and the other materials. In the future we may wish to test with more contrasting materials such as rubber and metal.

Finally, it may be more desirable to run a simpler, more targeted study with up to 3 variables instead of the current study with 6 variables. It was difficult to isolate the root cause of the interaction effects with so many variables.

10 Future Work

This study uncovered many interesting findings while at the same time raised many questions that we want to consider for our future work.

First, we want to characterize the just-noticeable difference (JND) in actuation parameters for pressure and vibration feedback. We hypothesize that stimulus changes above this JND threshold will result in positive attention capture, and the degree of attention capture can be modulated by presenting a stimulus farther or closer to the JND threshold. Ultimately we would like to determine the parameters that can be used to span the whole attention spectrum.

Second, we wish to explore the effects of positive affect haptic actuators on task performance. As we have shown in [32], vibrotactile actuators can be disruptive to primary task performance and more ambient feedback may be needed if the primary task is to be completed effectively. We postulate that using devices with positive affect, coupled with actuating these devices just above the JND threshold, will result in pleasant and detectable feedback providing information that can be processed in the periphery. Similar to a person standing behind you while you're working, this peripheral information can be acknowledged but should not distract you from your primary task.

Finally, it would be interesting to investigate whether the peripheral haptic sense can be "trained" to detect certain sensations and ignore others. We know that humans are sensitive to haptic changes – a tap on the shoulder, a cell phone vibrating in the pocket, etc. – but can these sensations be learned to be processed in the background even at the onset? Additionally, it would be interesting to create or reverse any ingrained negative cultural or experiential associations with certain haptic stimuli to elicit only positive affective response and thus negative (low) attention capture.

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References

[1] M. Bachlin, K. Forster, and G. Troster. Swimmaster: a wearable assistant for swimmer. *Ubicomp '09: Proceedings of the 11th International Conference on Ubiquitous Computing*, pages 215–224, 2009.

[2] M. A. Baumann, K. E. MacLean, T. W. Hazelton, and A. McKay. Emulating human attention-getting practices with wearable haptics.

In *In Proceedings of IEEE Haptic Symposium (HAPTICS '10)*, pages 149–156. IEEE Press, March 2010.

[3] C. Bethel, J. Burke, R. Murphy, and K. Salomon. Psychophysiological experimental design for use in human-robot interaction studies. In *International Symposium on Collaborative Technologies and Systems, CTS 2007*, pages 99 –105, May 2007.

[4] C. L. Bethel and R. R. Murphy. Non-facial and non-verbal affective expression for appearance-constrained robots used in victim management. *PALADYN Journal of Behavioral Robotics*, 1(4):219–230, 2010.

[5] M. M. Bradley and P. J. Lang. Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavioral Therapy and Experimental Psychiatry*, 25:49–59, 1994.

[6] A. Cassinelli, C. Reynolds, and M. Ishikawa. Augmenting spatial awareness with Haptic Radar, October 11 - 14 2006.

[7] M. Enriquez, O. Afonin, B. Yager, and K. Maclean. A pneumatic tactile alerting system for the driving environment, 2001.

[8] S. Fels, R. Hausch, and A. Tang. Investigation of haptic feedback in the driver seat. *Proceedings of the IEEE ITSC 2006 Intelligent Transportation Systems Conference*, pages 584–589, 2006.

[9] G. M. Fitch, R. J. Kiefer, J. M. Hankey, and B. M. Kleiner. Toward developing an approach for alerting drivers to the direction of a crash threat. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 49(4):710–720, 2007.

[10] A. Haans, C. de Nood, and W. A. IJsselsteijn. Investigating response similarities between real and mediated social touch: A first test. *Proceedings of the ACM Conference on Human Factors in Computing Systems (2007)*, pages 2405–2410, 2007.

[11] D. Heylen, M. Vissers, R. op den Akker, and A. Nijholt. Affective feedback in a tutoring system for procedural tasks. *ISCA Workshop on Affective Dialogue Systems*, page 244253, 2004.

[12] C. Ho, H. Z. Tan, and C. Spence. Using spatial vibrotactile cues to direct visual attention in driving scenes. *Transportation Research Part F: Traffic Psychology and Behaviour*, 8(6):397–412, 2005.

[13] K. Huang, E.-L. Do, and T. Starner. PianoTouch: A wearable haptic piano instruction system for passive learning of piano skills, 2008.

[14] C. Jansen, A. Wennemers, W. Vos, and E. Groen. FlyTact: A tactile display improves a helicopter pilot's landing performance in degraded visual environments. *6th EuroHaptics International Conference*, 5024:867–875, 2008.

[15] R. M. Johnson, J. van der Linden, and Y. Rogers. Musicjacket: the efficacy of real-time vibrotactile feedback for learning to play the violin. In *CHI EA '10: Proceedings of the 28th International Conference on Human Factors in Computing Systems*, pages 3475–3480. ACM, 2010.

[16] L. A. Jones, M. Nakamura, and B. Lockyer. Development of a tactile vest. *IEEE Computer Society 12th International Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems (HAPTICS 2004)*, pages 82–89, 2004.

[17] J. Lieberman and C. Breazeal. Development of a wearable vibrotactile feedback suit for accelerated human motor learning. *IEEE International Conference on Robotics and Automation*, pages 4001–4006, 2007.

[18] R. W. Lindeman, Y. Yanagida, K. Hosaka, and S. Abe. The TactaPack: A wireless sensor/actuator package for physical therapy applications. *14th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*, pages 337–341, 2006.

[19] K. E. MacLean. Putting haptics into the ambience. *IEEE Transactions on Haptics*, 2(3):123–135, 2009.

[20] T. Matthews, A. K. Key, J. Mankoff, S. Carter, and T. Rattenbury. A toolkit for managing user attention in peripheral displays. In *Proceedings of the 17th annual ACM symposium on User interface Software and Technology*, pages 247 – 256. ACM, 2004.

[21] J. Morrell and K. Wasilewski. Design and evaluation of a vibrotactile seat to improve spatial awareness while driving. *IEEE Haptics Symposium*, pages 281–288, March 25-26, 2010.

[22] J. Peck and J. Wiggins. It just feels good: Customers' affective response to touch and its influence on persuasion. *Journal of Marketing*, 70(October 2006):56–59, 2006.

[23] K. Salminen, V. Surakka, J. Rantala, J. Lylykangas, P. Laitinen, and R. Raisamo. Emotional responses to haptic stimuli in laboratory versus travelling by bus contexts. *Proceedings of the 3rd International Conference on Affective Computing and Intelligent Interaction, ACII 2009*, pages 387–393, September 10-12, 2009.

[24] C. Swindells, K. E. MacLean, K. S. Booth, and M. Meitner. Exploring affective design for physical controls. *CHI 2007 Proceedings on Emotion & Empathy*, April 28-May 3, 2007.

[25] C. Swindells, K. E. MacLean, K. S. Booth, and M. Meitner. A case-study of affect measurement tools for physical user interface design. *Proceedings of Graphics Interface, Canadian Human-Computer Communications Society, GI2006*, June 2006.

[26] TheChangeGroup. `https://changegroupcounseling.com/stai/`.

[27] T. A. Watson D, Clark L. Development and validation of brief measure of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology*, 54(6):1063–1070, 1988.

[28] T. A. Watson D, Clark L. The PANAS-X manual for the positive and negative affect schedule - expanded form. `http://ir.uiowa.edu/psychology_pubs/11/`, 1999.

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

[30] J. J. Young, H. Z. Tan, and R. Gray. Validity of haptic cues and its effect on priming visual spatial attention. *11th International Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*, pages 166–170, 2003.

[31] Y. J. Zheng and J. B. Morrell. A vibrotactile feedback approach to posture guidance. *IEEE Haptics Symposium*, pages 351–358, 2010.

[32] Y. J. Zheng and J. B. Morrell. Cognitive load assessment of a vibrotactile posture feedback chair. *Proceedings of the Human Factors and Ergonomics Society 54th Annual Meeting*, pages 1214–1218, September 2010.