Differences in Haptic and Visual Perception of Expressive 1DoF Motion

Elyse D. Z. Chase
Stanford University
Stanford, CA, USA
elysec@stanford.edu

Sean Follmer
Stanford University
Stanford, CA, USA
sfollmer@stanford.edu

ABSTRACT

Humans can perceive motion through a variety of different modalities. Vision is a well explored modality; however haptics can greatly increase the richness of information provided to the user. The detailed differences in perception of motion between these two modalities are not well studied and can provide an additional avenue for communication between humans and haptic devices or robots. We analyze these differences in the context of users interactions with a non-anthropomorphic haptic device. In this study, participants experienced different levels and combinations of stiffness, jitter, and acceleration curves via a one degree of freedom linear motion display. These conditions were presented with and without the opportunity for users to touch the setup. Participants rated the experiences within the contexts of emotion, anthropomorphism, likeability, and safety using the SAM scale, HRI metrics, as well as with qualitative feedback. A positive correlation between stiffness and dominance, specifically due to the haptic condition, was found; additionally, with the introduction of jitter, decreases in perceived arousal and likeability were recorded. Trends relating acceleration curves to perceived dominance as well as stiffness and jitter to valence, arousal, dominance, likeability, and safety were also found. These results suggest the importance of considering which sensory modalities are more actively engaged during interactions and, concomitantly, which behaviors designers should employ in the creation of non-anthropomorphic interactive haptic devices to achieve a particular interpreted affective state.

CCS CONCEPTS

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

KEYWORDS

motion perception, haptics, affect, emotion, expressive robotics

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1 INTRODUCTION

Social communication between humans is critical for many interactions. Specifically, nonverbal cues, including gesture, posture, gaze, and expression, are an essential part of communication [Argyle 2013; Knapp et al. 2013; Siegman and Feldstein 2014]. Additionally, touch is a core method humans use to communicate with one another. Much work has gone into categorizing both the dimensions and functions of touch [Burgoon et al. 2016; Knapp et al. 2013]. Studies also have shown that touch can increase likeability between two strangers [Breed and Ricci 1973; Fisher et al. 1976] and compliance in a request [Willis and Hamm 1980]. Overall, touch is a powerful communicative tool utilized by humans.

With the increasing ubiquity of robots in our society, researchers have begun to address questions surrounding how humans and robots can most effectively communicate with one another. Social prompts are expected and interpreted with ease among people and, when exhibited by other agents, those agents are viewed as having a higher social intelligence [Byrne and Whiten 1989]. Thus, the addition of sensory modalities, such as touch, can often enhance interactions [MacLean 2008]. For example, Shiomi et al. found that touch between the robot and human increases human effort during a collaborative task [Nakagawa et al. 2011; Shiomi et al. 2017]. As humans generally use both sight and touch for nonverbal social communication, it makes sense that a robot-human pair should do the same. Utilizing and understanding touch can add rich information to human-robot communication as well as increase the range of haptic device outputs for social interactions.

Some commercial social robots have been created with the intention of being touched by their users to reduce levels of anxiety and provide emotional support [Block and Kuchenbecker 2019; Stiehl et al. 2005; Sumioka et al. 2013; Yu et al. 2015]. Many of these robots are either anthropomorphic or zoomorphic, and therefore depend upon our innate knowledge and understanding of humans and animals. While these systems begin to address how to interpret human interaction with a system, they do not examine mutual touch or touch with a more abstract, non-anthropomorphic robot interface. We aim to better understand the role of haptic feedback in social robotic interaction towards the goal of providing a broader range of perceived affect.

Nonverbal communication through motion can be perceived either through vision or direct touch, both kinesthetic and tactile. Differences between sight and touch exist and thus we can imagine differences in perception will exist due to multisensory integration, specifically within the context of robot motion. Studies investigating emotive robots have not delved deeply into distinctions in perception between sight and touch. Generally, vision cannot be used directly to perceive force, but rather indirectly through previous experiences and an internal understanding of physics [White 2012]. Beyond this, tactile stimuli can be a very potent method to convey other information that cannot be directly seen by the user [Jones and Piateski 2006], such as information regarding stiffness and high frequency noise. While this is low-level information, it can be used to encode high-level information. Some researchers have explored visual perception of robot motion [Knight and Simmons 2014; Lee et al. 2007; Saerbeck and Bartneck 2010] and haptic perception [Swindells et al. 2007; Tan et al. 2016] individually in the context of affective perception, not considering the discrepancies that may occur between the two modalities. Thus, it is important to investigate the possible impacts made by the addition of kinesthetic touch, as unintended information may be transmitted to the user during an interaction.

Through a formal laboratory study, we investigate the degree to which perception of non-anthropomorphic robotic motion changes with the addition of touch, as compared to solely visual perception. As such, we have selected motion parameters predominantly explored in visual motion perception and affective kinesthetic haptics, including stiffness, jitter, and acceleration curves. To more closely investigate these motion parameters, and as a first step in establishing categorizations correlated with different perceived affective states, we utilize a one degree of freedom haptic device which can be perceived through both vision and touch. As such, we also contribute to the broad parameterization of different motion characteristics in order to provide insight for designers creating affective devices.

2 RELATED WORK

2.1 Touch and Sight

Sense of touch is important for day-to-day life as well as affective communication. When discrepancies exist, sight often dominates haptic perception [Srinivasan et al. 1995]; however in most situations perception is a multisensory integration process. Enhancement occurs when two or more senses receive homogeneous information that results in an intensification of the signal [MacLean 2008]. Overall, this produces a wide space for researchers to explore how these two senses can interact to change perception of robot motion. Several works in psychology have focused on emotion perception from both facial and auditory cues [Busso et al. 2004], however less have focused on more abstract identification of emotion through multisensory modalities. There are many other avenues of emotional communication that rely upon haptic cues [Argyle 2013; Burgoon et al. 2016; Knapp et al. 2013].

We study the interplay between sight and touch by investigating how perception of motion changes with the addition of haptic information, specifically through changes in perceptible motion introduced by parameters such as jitter and stiffness.

2.2 Human Motion

Humans often communicate nonverbally. Quite early during development, we learn how to express ourselves and understand other's feelings [Montagu and Montague 1971]. As such, much work has gone into exploring human motion including gesture and posture and the correlation to particular perceived emotions [Argyle 2013; Bianchi-Berthouze et al. 2006; Bianchi-Berthouze and Kleinsmith 2003]. Researchers have worked to comprehend how to transform neutral human movement into affective movement by modifying timing and range of motion [Amaya et al. 1996]. Others have looked at arm movements and found that perceived affect directly relates to kinematics of the movement [Pollick et al. 2001]. Several other works have explored more directly touch between humans. Hertenstein et. al found that participants who watched one person touch another were able to accurately determine the emotion conveyed; additionally, in a secondary study, participants who were touched were also able to discern the emotion displayed to them [Hertenstein et al. 2006]. Further work has been undertaken to gather this human-human touch based data. Silvera-Tawil et. al utilized touch sensitive material to gather information and classify how humans touch one another within affective contexts [Silvera-Tawil et al. 2014]. Work such as this can help us to codify touch and try to understand communication of emotion between humans.

Consideration of the range of human motions and perceptions of emotion are also important in developing haptic devices for social interactions. We utilize this as a base of information, but endeavor to expand the work to non-anthropomorphic agents to see what relationships and trends exist.

2.3 Emotive Movement in Robots

Motion parameters, and their effect on affect, have been explored as a method of creating simple social robots and emotive shape-changing platforms. Lee et al. created a bar that can extend and retract as well as rotate around its base in order to examine the effects of velocity, smoothness, and openness on affect [Lee et al. 2007]. It was determined that a combination of velocity and smoothness correlated to activation and pleasantness. Similarly, Tan et al. found correlation between velocity and arousal with an agent that moved up and down and changed orientation [Tan et al. 2016]. Saerbeck et al. used commercial robotic platforms, Roomba and iCat, in order to understand curvature, acceleration, and orientation [Saerbeck and Bartneck 2010]. They found that both embodiments garnered similar results as well as correlations between acceleration and arousal. Knight et al. explored using translation and rotation of 2D mobile robots to understand affective motion in the frame of Laban Effort Features [Knight and Simmons 2014]. Others have explored affective human communication with robots. Haptic devices, such as the Haptic Creature, have been created to understand how humans touch and interact with robots on an affective level [Yohanan and MacLean 2012].

While research has begun to explore affective motion, there is no study that looks at the specific differences in response that occur with varied levels of multi-modal interactions. We are interested in determining what differences exist between solely visual as opposed to visual with haptic interaction.

2.4 Communication with Haptic Devices

The ease with which humans emote through touch is difficult to replicate with mechanized platforms. Early work in the field focused on remote human-human touch through actuated rollers utilized in inTouch [Brave et al. 1998]. Another body of work has focused on wearable devices for social touch, with several focused

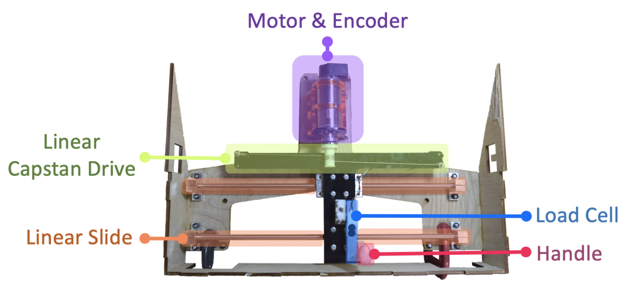

Figure 1: The haptic device with components labeled

on developing wearable sleeves for communicating affective touch from a distance [Culbertson et al. 2018; Huisman et al. 2013]. While these are all methods for communicating remotely, wearable devices tend to rely purely on the cutaneous feedback incurred and less upon the impacts of a combined visual and haptic channel. Several others have focused more on kinesthetic feedback. Work by Bailenson et. al explored the use of a haptic handle for transmitting and recognizing emotional information, again in a human-human scenario but now with a haptic device as a mediator [Bailenson et al. 2007]. The Haptic Knob [Swindells et al. 2007] was developed for understanding human emotional response to variable friction, inertia, and detents; this study found smaller magnitude renderings were preferred by users. With our work we hope to increase knowledge on the important factors to consider when building a haptic device for such a context.

3 METHOD

This user study was designed to analyze the differences between visual and visual with kinesthetic transfer of information created by a haptic device and displayed to a human. The device uses only motion to transmit this information, as this is something that most robotic platforms are already equipped to do.

3.1 Device

Many previous studies have explored multi-degree of freedom robots [Knight and Simmons 2014; Lee et al. 2007; Saerbeck and Bartneck 2010; Swindells et al. 2007; Tan et al. 2016]. However, these do not permit discrete understanding of how basic movements are perceived as many of the motion parameters and movements are coupled together. Constraining the system to 1 DoF allows us to better understand and isolate how different parameters impact perceived affect.

In order to achieve this motion, we built a device that enables a handle (both a visible and graspable part) to move with one degree of freedom in a linear path, as shown in Figure 1. The translational motion was achieved via a linear capstan drive, to which the handle was attached through a load cell (5kg cell with a HX711 amplifier), mounted to measure tangential forces applied by the user. This setup allowed users to physically backdrive the motor in certain conditions, which was important for full interaction between users and the device. The load cell was not used for the control, but rather as a way to measure users' applied force during the interaction.

A direct drive Maxon motor (DCX35L GB KL 12V) with a quadrature encoder (AVAGO AEDL-5810-J11, with 1024 CPR) was used in order to produce high levels of force and torque (the motor is capable of providing 77.7 mNm of constant torque) and to provide very accurate position measurements. A motor capable of large torque outputs was chosen in order to create motions that people could not substantially alter, as the device is meant to be both viewed and touched. It was driven with a Pololu breakout board for a VNH5019 motor driver IC. Impedance control was used to produce the desired motions.

3.2 Measures

3.2.1 *Affect.*

A variety of scales have been created by psychologists with the aim of measuring affect. Positive Affect Negative Affect Scales (PANAS) [Watson et al. 1988] and Pleasure-Arousal-Dominance (PAD) [Mehrabian 1996] are the most commonly used. Within PAD, the Self-Assessment Manikin (SAM) is universally accepted as a fast, visual way to determine affect on those three dimensions [Bradley and Lang 1994]. We chose to use SAM to gather feedback because of its wide use, acceptance, and reduced number of questions, thus decreasing the time spent per response, while still gathering the full spectrum of data. While this assessment was developed for understanding one's own emotional state, we are extending it to quantify perception of the device's state.

All three dimensions (valence, arousal, and dominance) of SAM were presented as seven point likert scales. Valence spans from unpleasant (1) to pleasant (7). For arousal, responses range from mild to intense. Finally, for dominance, a low score suggests submissiveness while a high score indicates dominance.

3.2.2 *Perception of Robots.*

In order to better understand how users experience the haptic device, we chose to use the Godspeed questionnaire [Bartneck et al. 2009] which is commonly used by other researchers in the field [e.g., Deshmukh et al. 2018; Kim and Follmer 2017]. Anthropomorphism, Likeability, and Safety are most applicable to our system and the hypotheses posed in the following section, so we choose to only include these three measures. The Godspeed questionnaire was also presented on a likert scale from 1 to 7. A score of 1 in Anthropomorphism corresponds to fake, machinelike, unconscious, artificial, and moving rigidly, while a 7 is natural, humanlike, conscious, lifelike, and moving elegantly. Likeability ranges from dislike, unfriendly, unkind, unpleasant, and awful, to like, friendly, kind, pleasant, and nice. Finally, a low rating for Safety suggests feelings such as anxious, agitated, or surprised, while a high score indicates that the user feels relaxed, calm, and quiescent.

3.2.3 *Qualitative Data.*

For every trial, users were asked to "describe the interaction in a few words." Every user was also presented with a post-survey that asked for additional information about the motions that they liked best and least as well as any additional general feedback.

3.3 Choice of Parameters

While there are many motion parameters that could be chosen, we focused our efforts on those that had previously shown potential or had not been explored in related literature—namely sensory modality, stiffness, jitter, and acceleration curves (Figure 2). Additionally, these parameters were selected due to documented variations in

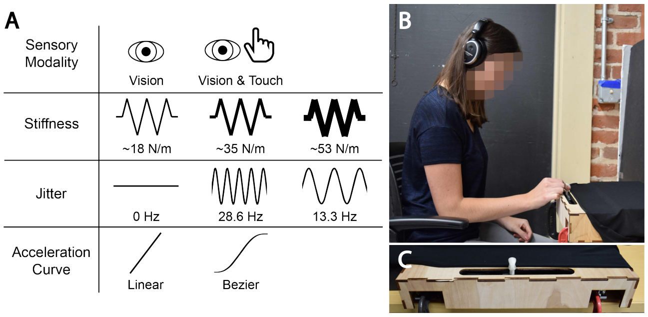

Figure 2: (A) Parameters: Sensory Modality, Stiffness, Jitter, & Acceleration Curve. (B) User seated with their dominant hand grasping the handle while wearing noise-canceling headphones. (C) Picture of the device from the user's perspective.

what can be perceived with vision as compared to touch, as described below.

3.3.1 Sensory Modality. Most prior work focuses on either sight or kinesthetic haptic feedback, allowing users to watch an agent move [Knight and Simmons 2014; Lee et al. 2007; Saerbeck and Bartneck 2010] or touch an agent as it moves [Swindells et al. 2007; Tan et al. 2016]. To the best of the authors' knowledge, there is no work that characterizes the differences in perception that occur between these two cases and we begin to fill in that gap. Touch alone was not tested because this study is focused on the amplification in perception due to the addition of touch.

3.3.2 Stiffness. Stiffness is not often tested in the context of non-anthropomorphic affective devices. However, a study of hand-shaking with a robot found that stiffness was correlated with arousal and dominance [Ammi et al. 2015]. This result is coupled with touch and the anthropomorphic qualities of the interaction. We feel that there is still substantial information that we can gain from using stiffness as a parameter. While some work has shown that humans can estimate joint stiffnesses from watching a computer-based model [Huber et al. 2017], this was considered to be due to integrating information from two joints. Therefore, it is unlikely that this visual perception of stiffness will hold for a single degree of freedom device. Additionally, a line of work has been focused on *safe* robot-human interactions and one avenue has explored using stiffness controllers to allow for compliance in robot movement [Bicchi et al. 2008]. Based upon these findings, we present two hypotheses:

(H1) *In the trials with combined vision and touch, increasing stiffness will raise perception of the device's arousal and dominance, while this will not be apparent in the vision only condition.*

(H2) *In the trials with combined vision and touch, increasing stiffness will lower perception of safety and likeability.*

In order to determine if this relationship will carry-over to other non-humanoid platforms, we chose to have three levels of stiffness: soft (18 N/m), medium (35 N/m), and hard (53 N/m) - the values of which were experimentally determined based upon our impedance controller. Low stiffness was the minimum value at which the controller moved without a reduction in total distance traveled, the upper end was limited to reduce system overshoot, and the middle value selected was the midpoint between the two bounds. We chose to use only three levels in order to keep the total study time under 60 minutes to ensure that participants would not fatigue.

3.3.3 Jitter. Many machines and devices normally have some amount of vibration or jitter that humans see and or feel during an interaction. Thus, we felt it was important to include it as a factor. Here, jitter is manifested in timing variations from the original signal. Within this affective literature, there is no clear consensus on its associations to affect. Some report smoothness correlates to pleasantness in a visual experiment [Lee et al. 2007], while others indicate there is no clear association in a touch based interaction [Tan et al. 2016]. In an exploration of haptic interactions with a swarm of robots, smooth motion was found to be more likeable and safe than jittery motion [Kim and Follmer 2017]. From these observations we hypothesize the following:

(H3) *In the trials with combined vision and touch, the addition of low frequency jitter will raise the perception of the device's arousal and lower the perceived valence, while this will not be apparent in the vision only condition.*

(H4) *As jitter increases, safety and likeability will decrease.*

In order to better understand the role jitter plays, we introduced three levels: none, high frequency (28.6 Hz), and low frequency (13.3 Hz). The values were determined empirically; the low frequency was chosen because it would not be visibly perceptible, but could be felt in combination with all other conditions, while the higher frequency created visible deviations. These varying amounts of jitter were achieved by superimposing a sine wave on top of the nominal signal. The amplitude of the wave was kept constant across conditions, while only frequency changed.

3.3.4 Acceleration Curve. For visual perception of robot motion, interactions between acceleration and curvature were found to effect valence [Saerbeck and Bartneck 2010], but the independent significance of acceleration could not be isolated. In human arm movements, it was determined that peak acceleration and deceleration was correlated with perceived levels of arousal [Pollick et al. 2001].

In order to further study this factor, we chose two different acceleration curves: Linear and Ease-in/Ease-out. Linear curves are very standard for many motions and provide no acceleration except at points where the direction of motion alternates. Ease-in and Ease-out curves are often used in animation [Neff and Fiume 2002] and robot controllers [Jolly et al. 2009] as they give the user or designer more freedom to control the movement and also provide a gradual change of acceleration. The Ease-in/Ease-out curve was created through the use of a quintic Bezier function. Determining an ideal trajectory is a component of safe robot-human interactions, and we believe that because the Bezier curve is more similar to how humans move it would seem more anthropomorphic and less aggressive than linear motion. Utilizing this as a base, we hypothesize:

(H5) *The Bezier acceleration curve will be perceived as less dominant than the linear curve.*

(H6) *The Bezier acceleration curve will be perceived as more anthropomorphic and safer compared to the linear curve.*

3.3.5 Velocity. The speed at which an agent moves has been shown to directly correspond to the level of the arousal and pleasantness perceived by the user [Lee et al. 2007; Tan et al. 2016]. Tan et al. also found correlations with dominance, while Lee et al. did not utilize a scale that included it as a measurement point. Therefore, we ran all experiments with only one velocity, as there were many other factors that have not been explored with as much depth. We chose an average velocity of 0.15 m/s, which both ran smoothly with our device and did not interfere with the perceivability of the other parameters.

4 STUDY

4.1 Participants

A total of 16 participants completed the study (6 Males, 10 Females) with an average age of 25.4 (σ = 3.7). Before beginning the study, we explained the experimental protocol to each participant and received their consent to be a part of the study.

4.2 Experimental Setup

The 1DoF emotive device was rigidly mounted to the table. It was covered with a black cloth and a black foam board was placed behind it to remove distraction and encourage participants to focus on their perception of movement (Figure 2). Participants were given both earplugs and noise-canceling headphones (that played white noise) in order to remove any distraction from external noise or the sound made by the display itself.

For each trial, the handle moved for 10 seconds, during which it traversed the length of the device 5 times. If the trial was vision only, participants were instructed to simply watch the device move. If the trial was vision with touch, participants were instructed to grasp the handle with their dominant hand and were told that they could move as they wished (e.g. follow along with the motion, oppose the motion, or any combination of movements).

Participants experienced each of the 36 conditions once (see Figure 2) in two blocks of eighteen. The vision trials were conducted together as a single block and, similarly, the vision with touch trials were completed together. The ordering of blocks was randomized for each subject. The order of the conditions within those blocks was also randomized. Participants were given a short break between the two segments of the experiment.

After each trial, participants responded to a survey that asked for a brief description of the interaction, a response for the emotion displayed by the device using the SAM scale, and their own impressions using the Godspeed questionnaire. At the end of both blocks of trials, participants completed a post-survey. The entire experiment took 45 to 60 minutes to complete for each individual. Participants were compensated with a $15 gift card for their time.

5 RESULTS

In order to determine the effects of the chosen parameters on the measured responses in the survey, two Linear Mixed Effects Models (LMERs) were created for each of the dependent variables — one simple and one complex. Within these models, random slopes were added for each independent variable (modality, acceleration, stiffness, and jitter) and a random intercept was included for participants. In addition, sex and user interaction type (manually coded afterwards to represent how people choose to interact with the device) were included in order to account for possible effects. The complex model had additional terms to account for interaction effects between modality and each of the motion parameters. An ANOVA was used to compare the two models, as well as to determine the significant factors within the chosen model. For significant parameters ($p<0.05$), an additional Bonferroni-corrected post-hoc test was carried out in order to determine which pairs within the factor were significant.

Figures 3-6 show the individual data points (represented by the faded circles), means, and confidence intervals for each of the parameters against the results from the questionnaire.

5.1 Valence, Arousal, and Dominance

First, the two different models (simple and complex) were evaluated against each other for each of the independent variables. For valence and dominance, the complex model accounts for significantly more of the variance and was chosen above the simple model. However, for arousal the simple model was more effective at explaining the variance than the model with interaction effects. The statistically significant factors for these results are shown Tables 1 and 2. The effect size of most of the factors are relatively small, ranging from a maximum η_p^2 of 0.221 to a minimum of 0.013. However, the majority of these results appear to be similar in magnitude to results from others in the field of affective robots and devices. [e.g., Podevijn et al. 2016; Seebode 2015; Tan et al. 2016]. Thus, even though the effect size is small for some factors, it is similar to others' findings.

Variance in the model for dominance was much higher than for both valence and arousal, implying participants were quite dissimilar in determining and reporting values within this field.

5.2 Anthropomorphism, Likeability, and Safety

Similar to above, for each of the independent variables two different models (simple and complex) which were evaluated. In this case, the simple model was more effective for both anthropomorphism and safety. For likeability, however, the complex model accounts for significantly more of the variance. The statistically significant factors for these results are summarized in Tables 3 and 4. The effect sizes for many of these results are seemingly smaller than any reported for Valence, Arousal, and Dominance. However, many are still comparable to results from related work mentioned in the above section.

5.3 Sex

There were no significant effects due to sex.

5.4 Qualitative Data

As a free response section was provided for every trial, there are a total of 576 descriptive statements, which ranged in their level of affective response on a variety of factors including negative versus positive and humanized versus mechanized.

5.5 Force Data

There were two distinct methods of interaction with the device during the haptic condition: (1) fighting against the device and (2)

Table 1: SAM Main Effects for all conditions: * p<0.05, ** p<0.01, *** p<0.001

	Modality			Acceleration			Stiffness			Jitter		
	F	p	η_p^2	F	p	η_p^2	F	p	η_p^2	F	p	η_p^2
Valence	F(1,549) = 0.209	0.647	0.000	F(1,549) = 0.000	1.000	0.000	F(2,549) = 10.511	***	0.037	F(2,549) = 63.371	***	0.187
Arousal	F(1,554) = 3.389	0.066	0.006	F(1,554) = 2.231	0.136	0.004	F(2,554) = 46.225	***	0.143	F(2,554) = 78.902	***	0.221
Dominance	F(1,549) = 11.401	***	0.020	F(1,549) = 7.297	**	0.013	F(2,549) = 17.736	***	0.061	F(2,549) = 0.408	0.665	0.002

Table 2: SAM Interactions: * p<0.05, ** p<0.01, *** p<0.001; Arousal is not listed as the simple model was more significant

	Modality*Acceleration			Modality*Stiffness			Modality*Jitter		
	F	p	η_p^2	F	p	η_p^2	F	p	η_p^2
Valence	F(2,549) = 0.093	0.760	0.000	F(2,549) = 0.681	0.507	0.003	F(2,549) = 11.233	***	0.039
Arousal	-	-	-	-	-	-	-	-	-
Dominance	F(2,549) = 0.094	0.759	0.000	F(2,549) = 10.579	***	0.037	F(2,549) = 6.536	**	0.023

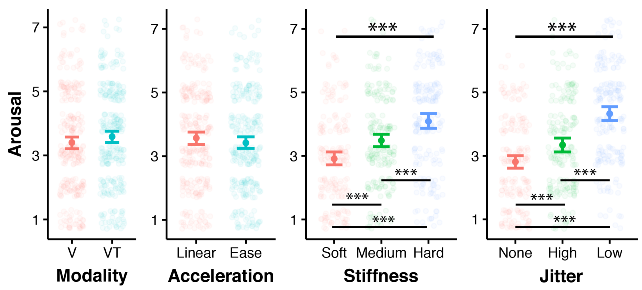

Figure 3: SAM Main Effects: * p<0.05, ** p<0.01, *** p<0.001; V = Vision, VT = Vision & Touch

allowing the device to move - following its motion. These trajectories were captured with the force data from the load cell as well as information stored about the current position of the device. The user interaction types were identified visually by the experimenter, and then confirmed by examining the recorded force data from each trial. Additionally, the two response types were incorporated into the model in order to determine if this user-made choice had a significant effect. The results indicate that there was significant difference in results for valence, however it had the smallest effect size of all the significant factors within the model (F(1,13) = 5.461, * $p < 0.05$, $\eta_p^2 = 0.010$).

6 DISCUSSION

6.1 Sensory Modality

We observed differences between Vision and Vision & Touch across all tests. Specifically, we found that there was a significant difference in perceived dominance, with the haptic condition resulting in increased ratings of dominance compared to the visual condition (Figure 3). In the haptic condition, the motion of the device either leads or fights against the user; thus, the addition of this sense amplifies the perception of dominance to the user.

Qualitatively, the addition of haptic feedback seemed to provide more information to participants. As velocity was kept constant and some of the parameters are difficult to visually perceive (i.e. stiffness, high frequency noise), many of the trials looked quite similar; this was confirmed responses to the post-questionnaire. For example, one user stated "I found the visual part harder to evaluate" when giving feedback on the study.

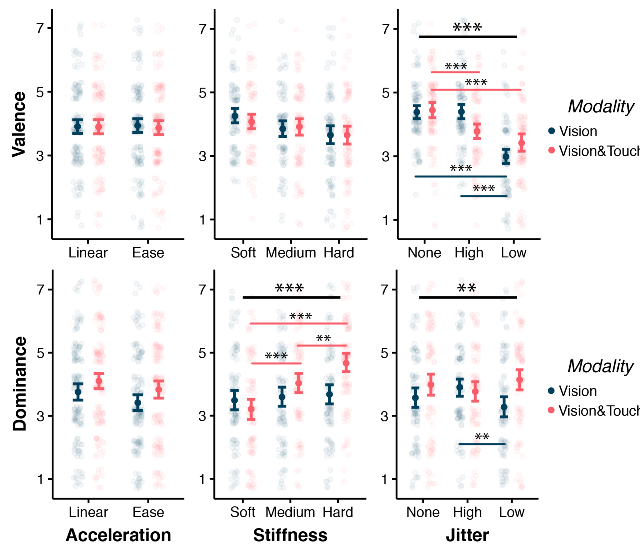

Figure 4: SAM Interactions: * p<0.05, ** p<0.01, *** p<0.001

Several interaction effects were found between sensory modality and the other parameters (Figure 4 and 6). These, along with the main effects, are discussed in the following sections.

6.2 Stiffness

Between the Vision and Vision & Touch conditions, stiffness had a significant effect on user ratings of dominance. The vision only trials appear to have very similar means, whereas the combined visual and touch condition shows that the rated dominance increases with stiffness, which aligns with previous research [Ammi et al. 2015]. This is reasonable as stiffness cannot inherently be seen. However, this finding differs from work that has shown that humans can visually estimate joint stiffnesses [Huber et al. 2017], probably because this research used a multiple degree of freedom system which likely provided more visual information to the user.

Overall, a statistically significant positive correlation was seen between stiffness and arousal as well as dominance (Figure 3 and Table 1), which confirms H1. This supports previous research that examined stiffness for a hand-shaking robot [Ammi et al. 2015]. As the device fights harder against the user (with increased stiffness), it appears to be more dominant and more aroused. It is essential to

Table 3: Godspeed Main Effects for all conditions: * p<0.05, ** p<0.01, *** p<0.001

	Modality			Acceleration			Stiffness			Jitter		
	F	p	η_p^2	F	p	η_p^2	F	p	η_p^2	F	p	η_p^2
Anthropomorphism	F(1,554) = 1.774	0.183	0.003	F(1,554) = 0.042	0.838	0.000	F(2,554) = 7.266	***	0.026	F(2,554) = 3.813	*	0.014
Likeability	F(1,549) = 0.005	0.941	0.000	F(1,549) = 0.067	0.796	0.000	F(2,549) = 23.312	***	0.078	F(2,549) = 27.898	***	0.092
Safety	F(1,554) = 4.964	*	0.009	F(1,554) = 1.934	0.165	0.004	F(2,554) = 20.250	***	0.068	F(2,554) = 43.100	***	0.135

Table 4: Godspeed Interactions: * p<0.05, ** p<0.01, *** p<0.001; Anthropomorphism and Safety are not listed as the simple model was more significant

	Modality*Acceleration			Modality*Stiffness			Modality*Jitter		
	F	p	η_p^2	F	p	η_p^2	F	p	η_p^2
Anthropomorphism	-	-	-	-	-	-	-	-	-
Likeability	F(2,549) = 0.544	0.461	0.001	F(2,549) = 2.422	0.090	0.009	F(2,549) = 3.254	*	0.012
Safety	-	-	-	-	-	-	-	-	-

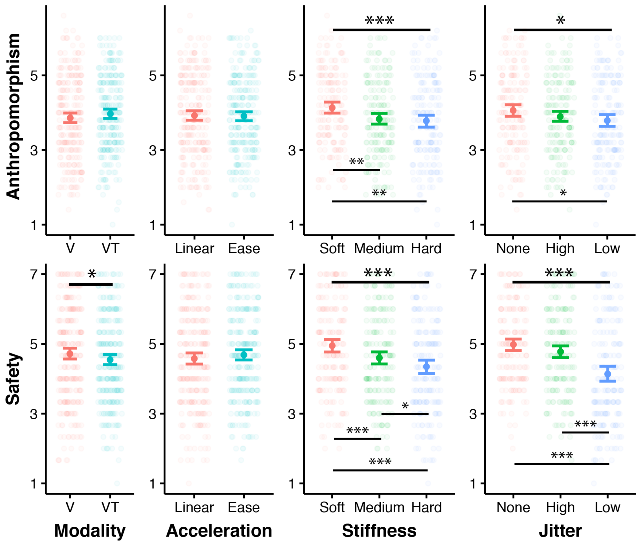

Figure 5: Godspeed Main Effects: * p<0.05, ** p<0.01, *** p<0.001; V = Vision, VT = Vision & Touch

note that this relationship is due to the combined visual and haptic trials as shown in Figure 4 and discussed previously.

There is a significant negative correlation between stiffness and valence—suggesting in general that the stiffer something feels the more negative it appears and vice versa. Additionally, there is a statistically significant negative correlation between stiffness and anthropomorphism, likeability, and safety, which supports H2. The decrease in likeability and safety is most likely due to the machine pushing back against the user. Alternatively it is possible that an increase in stiffness allows the device's other motion parameters to be more clearly perceived.

The interaction styles that users chose provided different kinds of haptic information. Some took this experiment as an opportunity to compare their strength with that of the "machine." Specifically, those that fought against the motion wrote descriptions that indicated conscious understanding of the levels of stiffness that were introduced into the system. For example, one participant stated that "Device was moving smoothly. I could feel some resistance when I opposed it." They later added that "The device was stronger than expected." These notations greatly differed from comments during

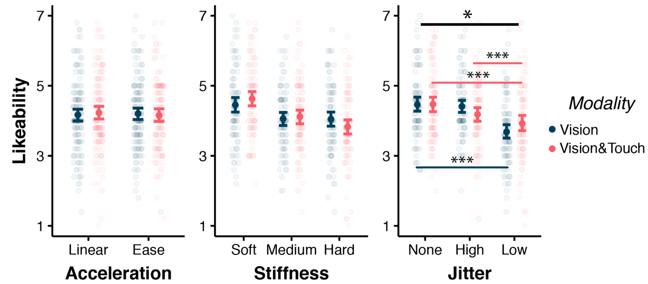

Figure 6: Godspeed Interactions: * p<0.05, ** p<0.01, *** p<0.001

the vision only trials which centered around the handle moving "slowly" and the smoothness of motion.

6.3 Jitter

Jitter also had several interaction effects with sensory modality (Figure 4 and 6). Arousal level ratings remained relatively constant between the zero and high frequency condition for visual trials, while the visual and haptic conditions showed a severely reduced rating of arousal for the high frequency condition which fails to support H3. There is also a higher mean for low frequency jitter in the combined visual and touch condition, which could be due to the natural damping that occurs when a user's hand is in contact with the system. Finally, there was also a significant relationship between jitter and modality for likeability, which indicates that the addition of perceivable jitter produces results that people enjoy less, possibly due to how much it moves their hand in the haptic case.

The study data shows a significant positive correlation between jitter and arousal (Figure 3). This could be due to the increase in motion that is induced by the addition of jitter. However, negative correlations were found between jitter and valence, likeability, and safety, which supports H4. One potential explanation for this is that when individuals see something vibrating extensively, those items are often broken, thought to have mechanical issues, and are perceived in a more negative fashion.

From the qualitative feedback, some perceived the two frequencies of vibrations as quite different. While the lower frequency was seen as "nervousness," "trembling," or "agitated fear", the higher frequency was described as "machinery-like" and "somewhat aggressive". This information could be leveraged to create systems that provide an array of emotions with limited additional actuation.

6.4 Acceleration Curve

Significance was found for perceived dominance, with the linear curve receiving a higher dominance score than the easing curve (Figure 3), which supports H5. This is what we would expect to see, as easing curves are generally used for applications in which humans are controlling robots with smooth paths [Jolly et al. 2009] as they produce less jarring motion. Visually, it has been found that instantaneous velocity change is much easier to perceive than gradual change [Schmerler 1976], and this would align with the limited differences found for the two acceleration curves compared. H6 was unsupported by this study, possibly because of the slight differences between the two curves and the natural damping that occurs in the system when a user's hand is making contact with the device. Thus, it is likely that people did not feel the subtle differences between the two acceleration curves.

6.5 Implications

Within the realm of emotive, non-anthropomorphic robots, shape-changing displays, and haptic devices that are created to provoke social interactions, one should contemplate the impact and appropriateness of motion parameters. Utilizing a kinesthetic haptic channel in addition to vision can provide a larger array of affective information to the user. Specifically even low-level motion parameters information can lead to a variety of different perceived emotions. This is something that is widely available in mobile robots, and thus could be applied without significant new hardware or actuators. Robots that are deployed in areas with humans, where physical contact might be made, could benefit from applying different motion parameters to modify how individuals perceive them as expressive entities. For example, to make a robot seem less dominant and more likeable, stiffness could be decreased. Similarly, a shape changing device could use vibrational or stiffness based-cues to enable richer user interactions. This also highlights that the sensitivity of each sense to a particular motion parameter or physical property can be used to expand the bandwidth possible during communication. Designers should consider which parameters are most appropriate to use, as well as what modifications should be made, when users will be interacting, through touch, with a robotic system.

7 LIMITATIONS AND FUTURE WORK

We tested how people perceived the various combinations of visual and haptic parameters. This work adds to research on social robots and devices that aim to create an emotional connection with users.

There are several limitations inherent to the system used. First, while a single degree of freedom allows for isolation of factors, there are possible differences in perceived affect with a multi-degree of freedom device as more movement options should provide a greater range of expression. Second, based upon the frequency of the jitter and optical thresholds for humans, the high frequency values used for jitter should have been perceptible visually; however, they were not visible due to the inherent impedance within the system. As mentioned briefly in the discussion section, it is also possible that the hand of the users acts as a damper on the system, which could change how it is perceived.

The physical appearance of this robot, a handle moving linearly in a slot, limits the ecological validity. The handle was designed to encourage lateral forces from users, as opposed to normal force. It is possible that variations in handle sizes, colors, or shapes would produce varied results. Furthermore, this is a simplification of the larger scheme of social contact in human-robot interaction. The motion is highlighted by this device, but further work would need to be completed to extend these results to a robot with a different form and more varied motions.

Only one velocity was used for the duration of the study, as others have extensively explored this and found a correlation with arousal [Lee et al. 2007; Tan et al. 2016]. However, as agents move faster, other motion additives (such as jitter) may be overpowered by speed. Furthermore, only two acceleration curves were compared. As significance was found in the perceived dominance, it would be worthwhile to explore additional curves, such as other levels of easing. Similarly, the granularity of most factors could be expanded in order to determine threshold levels. For example, some participants expressed divergent thoughts on the levels of jitter. It is possible that additional exploration of this factor could be executed to determine the threshold of jitter at which the perception of the system shifts from "nervous" to "mechanical".

This work could also be expanded to gain a better understanding of multi-sensory integration within an emotion context. By combining our device with a co-located visual display, we could isolate vision. This would enable a full exploration with the ability to independently control each sense - allowing for a more controlled investigation of how these two modalities work together. Additionally, we focused on kinesthetic haptic feedback. Future work could explore the responses to tactile or cutaneous stimuli. While more similar to work on wearable devices for social touch, the combination of kinesthetic and cutaneous information could provide new and interesting pathways for affective communication.

Finally, future analysis could investigate how these parameters can be applied to specific application areas such as remote social touch and therapy for those who are non-verbal. In these contexts, certain robots and devices, as well as specific motions and parameters, may be more appropriate and effective than others. Thus, investigating how these parameters map to different types of devices—shape changing displays and other haptic platforms—could produce additional insights into how people perceive abstracted, highly actuated motion.

8 CONCLUSION

This study demonstrates differences in affective perception between solely visual and combined visual and haptic interactions. Specifically, our study shows that increased levels of dominance were associated only with increased stiffness in the haptic condition. There was also a decrease in likeability and arousal with the introduction of jitter within the haptic condition. Overall, we found trends relating acceleration curves to perceived dominance, and stiffness and jitter to valence, arousal, dominance, likeability, and safety. This information can be used to enhance future social interactions with robots and haptic devices.

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