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Correlation Between Perceived Social Presence and Perceived Animacy Induced by Haptic Stimuli

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***Abstract*—**
Social presence is known to enhance user engagement and task performance in computer-mediated communication. One approach to increasing social presence involves the use of haptic stimuli during interactions with mediated others. However, previous studies have primarily focused on binary comparisons between the presence and absence of haptic stimuli, without fully investigating which specific elements of haptic feedback contribute to social presence or identifying its key predictors to enable more detailed relationship modeling. Building on research in cognitive psychology on animacy perception, this study hypothesizes that animacy perceived through haptic stimuli serves as a predictor of perceived social presence. To test this hypothesis, we conducted an experiment using 12 different haptic stimulation patterns designed to evoke varying degrees of animacy and analyzed the correlation between perceived animacy and social presence. The results indicate a significant positive correlation between animacy perceived through haptic stimuli and perceived social presence, with haptic stimulus frequency playing a important role in shaping the degrees of perceived social presence. These findings provide a foundation for modeling the relationship between haptic stimuli and social presence and are expected to inform the design of user interfaces for remote communication and interactions with virtual agents.

***Index Terms*—social presence, animacy, haptic, perception.**

I. Introduction

Advances in media technology have significantly enhanced computer-mediated remote communication and interactions with virtual agents. In such virtual interactions with mediated others, social presence is defined as the extent to which users experience a "sense of being with another" and is considered a key factor in perceiving the agency and intentions of another [4]. A high perception of social presence has been shown to increase user motivation, enhance task performance, and predict continued engagement with media services [6], [7], [9], [21]. Understanding and controlling the mechanisms underlying social presence are therefore critical for designing effective user interfaces that enhance virtual interactions with mediated others.

Previous research has primarily focused on the influence of visual stimuli on social presence perception [20]. However, haptic stimuli have also been identified as a contributing factor in enhancing the perceived social presence of mediated others. Despite this, most studies examining the role of haptic stimuli in social presence have been limited to binary comparisons—simply evaluating the presence or absence of haptic feedback—without fully exploring the specific elements of haptic stimulation that contribute to social presence [2], [3], [6], [7], [11], [15], [23], [24]. As a result, the fundamental components needed for modeling the relationship between haptic stimuli and social presence remain insufficiently understood.

To address this gap, this study aims to identify predictors of perceived social presence, thereby contributing to a more comprehensive model of the relationship between haptic stimuli and social presence. Specifically, we propose the following hypothesis (H1): Animacy perceived through haptic stimuli is a predictor of perceived social presence. Animacy perception refers to the human ability to perceive lifelikeness in objects based on static information or motion patterns, particularly accidental or biologically inspired movements [8], [10], [25]. While most previous studies have investigated animacy perception in the context of visual stimuli, recent research suggests that animacy can also be perceived through haptic stimuli. For example, Takahashi et al. [26] have been reported that humans perceive higher animacy from low-frequency sinusoidal vibration haptic stimuli (e.g., 0.5 Hz or 5 Hz), which resemble heartbeats and breathing movements, than from high-frequency sinusoidal vibration haptic stimuli (e.g., 50 Hz). Animacy perception is considered a high-level cognitive function. When people perceive animacy in an object, they may attribute agency or intention to it [25]. Similarly, social presence involves perceiving agency and intentionality in mediated others [4]. Given this conceptual overlap, we hypothesize that animacy perceived through haptic stimuli correlates with perceived social presence (H1). Furthermore, since previous research suggests that the frequency of sinu-

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soidal vibration haptic stimuli affects perceived animacy [26], we propose a second hypothesis (H2): If H1 is correct, then perceived social presence will also depend on the frequency of sinusoidal vibrations presented as haptic stimuli.

In summary, this study aims to empirically test the following two hypotheses:

- H1: Animacy perceived through haptic stimuli is a predictor of perceived social presence.
- H2: When sinusoidal vibrations are used as haptic stimuli, perceived social presence depends on the frequency of vibrations.

This investigation is expected to deepen understanding of how social presence perception, as a high-level cognitive function, is influenced by haptic stimuli and provide insights into modeling their relationship. Additionally, the findings of this study are expected to inform the development of interface design guidelines for computer-mediated communication, ultimately enhancing the user experience in virtual and remote interactions.

Fig. 1. Experimental setup for Experiment I (Animacy Test). Participants received haptic stimulation patterns through the pad of their right index finger using the haptic display, and evaluated the perceived animacy of each stimulus using the questionnaire displayed on a PC screen in front of them.

II. Experiment I: Animacy

A. Method

1) Setup: This study aims to investigate H1 (Animacy perceived through haptic stimuli is a predictor of perceived social presence) and H2 (When sinusoidal vibrations are used as haptic stimuli, perceived social presence depends on the frequency of vibrations). To verify these hypotheses, the haptic stimuli used in the experiment must evoke sufficiently distinct perceptions of animacy to allow for a meaningful analysis of their correlation with perceived social presence. Therefore, as a preliminary step, we conducted an animacy evaluation experiment to determine whether the 12 haptic stimulus patterns designed for this study elicited distinguishable perceptions of animacy.

The experiment was conducted in a controlled environment, where a PC was positioned in front of the participant and a haptic display was placed on their right-hand side (Fig. 1). The haptic display presented the 12 different stimulus patterns, and participants were instructed to put the index finger pad of their right hand against it to receive the stimuli. The PC was used to cues the start and end of each trial. Additionally, the PC monitor displayed a questionnaire for participants to evaluate the animacy of each stimulus they received. To minimize external auditory interference, participants wore noise-canceling headphones, and white noise was continuously played throughout the experiment.

2) Stimuli and Conditions: In this experiment, we designed a total of 24 conditions by combining 12 types of haptic stimulation patterns with 2 different haptic displays.

The 12 haptic stimulation patterns comprised six monotonous vibration stimuli and six diverse vibration stimuli (Table I). The monotonous stimuli consisted of five single-frequency sinusoidal vibrations (Stimuli No. 1–5) and one white noise vibration (No. 6). The sinusoidal stimuli were selected based on previous findings that the frequency of haptic stimulation can influence perceived animacy [26]. The white noise vibration was included to explore whether mixing different frequencies affects animacy perception.

In contrast, the diverse vibration stimuli (No. 7–12) were either recorded from real-world physical events or artificially designed to evoke specific haptic impressions. Unlike the repetitive and predictable nature of the monotonous stimuli, these patterns exhibited complex and contextually rich temporal structures, which may contribute to the perception of animacy. Several stimuli were obtained from an online vibration data archive[1], including marbles colliding inside a cup (No. 7), tap dancing on a hard surface (No. 9), and other object-based interactions (e.g., No. 8 and No. 11). Additionally, one stimulus (No. 10) was artificially designed to replicate the haptic sensation of a hamster gnawing on a stick, developed by haptic content developers[2]. This stimulus was originally used in a system designed to simulate haptic interaction with a virtual hamster [16]. In that study, several participants reported that the experience evoked the feeling of a real hamster's presence, suggesting that the stimulus may be effective in eliciting a strong perception of animacy. Another stimulus (No. 12) was independently created to mimic the rhythm of a human heartbeat.

To ensure consistency across conditions, all haptic stimuli were standardized to a duration of five seconds. Additionally, fade-in and fade-out processing was applied to each stimulus to minimize abrupt onset and offset artifacts, particularly those associated with high-frequency components.

The 2 different haptic displays were used to examine whether the haptic display characteristics influence perceived animacy. The first was a Dielectric Elastomer Actuator (DEA)-based haptic display, which is composed entirely of soft materials and was expected to enhance perceived animacy due to its compliance. Specifically, we employed the DEA-based haptic

[1]TECTILE: http://www.techtile.org/techtiletoolkit/

[2]Kawaii Haptics: https://www.embodiedmedia.org/projects/kawaii-haptics

TABLE I
HAPTIC STIMULI FOR ANIMACY EXPERIMENT

No.	Name	Detail
1	5Hz	Sine wave at 5 Hz
2	10Hz	Sine wave at 10 Hz
3	30Hz	Sine wave at 30 Hz
4	50Hz	Sine wave at 50 Hz
5	100Hz	Sine wave at 100 Hz
6	WN	White noise
7	SM	Recorded soft material shaking
8	MB	Recorded marble balls collision
9	BDM	Recorded badminton shuttle lifting
10	HAM	Created hamster chewing
11	TPD	Recorded tap dance vibration
12	HRT	Created heart beat vibration

display developed by Kurogi et al. [13], capable of generating vibrations in the 5–250 Hz range and was expected to elicit a broad spectrum of animacy perceptions based on frequency variations. The second haptic display was the Haptuator Mark II[3], a commercially available vibrotactile actuator that, while harder than the DEA-based display, is capable of presenting vibrations across a similarly broad frequency range. Given its capacity to deliver diverse haptic feedback, it was included as a complementary display for comparison

During the experiment, participants experienced 48 trials in total, consisting of 24 conditions (12 haptic stimulation patterns $\times$ 2 haptic displays), each presented twice. The experiment was divided into two sections: in the first, participants received 24 trials using one haptic display, while in the second, they received the remaining 24 trials using the other display. To control for order effects, the sequence of haptic displays was counterbalanced across participants. Additionally, within each section, the presentation order of the 12 haptic stimulation patterns was randomized.

3) Procedure: We used a two-factor within-participant design. The experiment began with participants placing the pad of their right index finger on a haptic display positioned on the desk. In each trial, one of the 12 haptic stimulus patterns was presented through the display, and participants experienced the vibration for five seconds. Following the stimulus presentation, participants completed a six-item questionnaire [1] displayed on a PC screen to assess their perceived animacy. The questionnaire employed the Semantic Differential method, requiring participants to provide subjective evaluations for each item. After completing the questionnaire, the next trial commenced with the presentation of the next haptic stimulus pattern. This process was repeated until all trials were completed.

4) Collected Data: After each haptic stimulus presentation, participants completed a questionnaire based on the Semantic Differential method to assess their perceived animacy. The

[3]Haptuator Mark II: http://tactilelabs.com/products/haptics/haptuator-mark-iiv2/

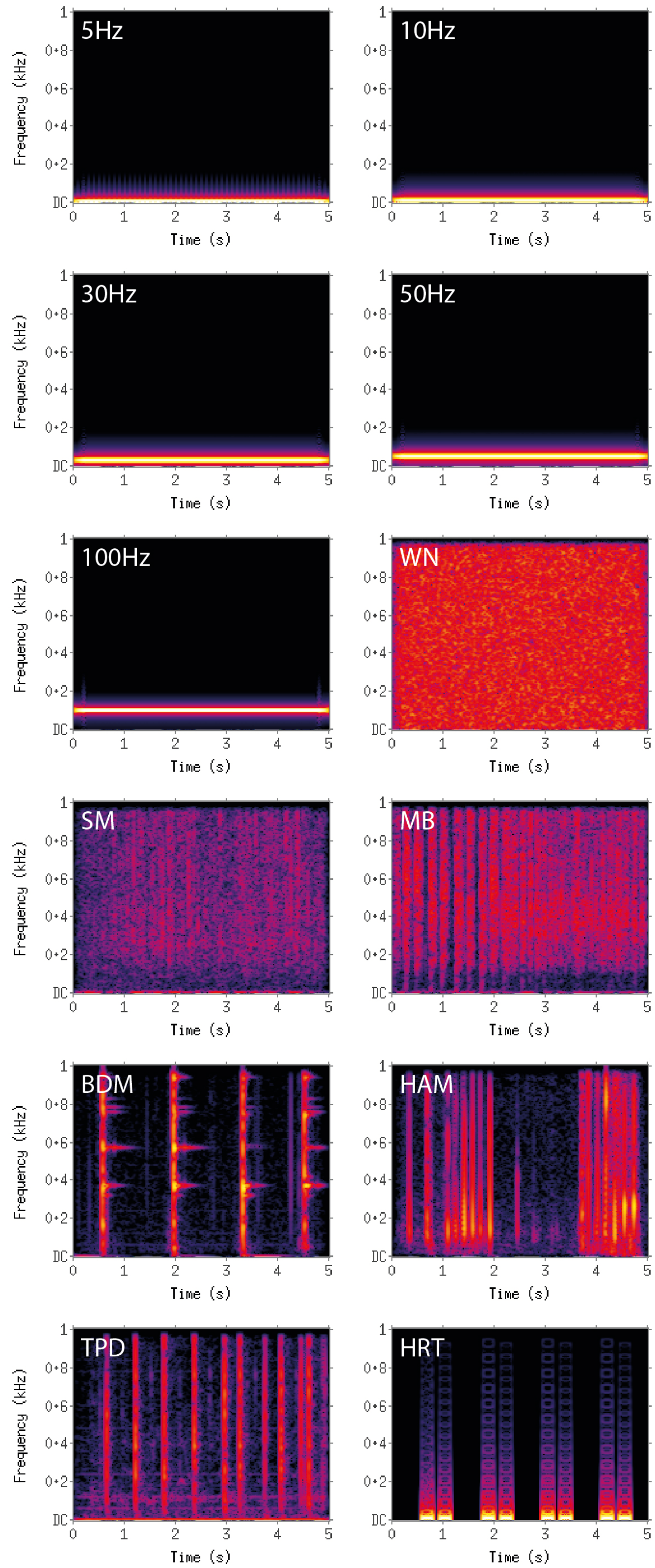

Fig. 2. Spectrograms of the haptic stimulation patterns. The vertical axis represents frequency and the horizontal axis represents time. Brighter colors indicate higher amplitude.

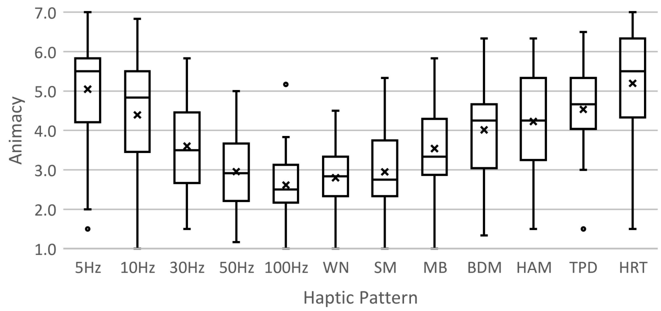

Fig. 3. Perceived animacy scores for each haptic stimulation pattern. Each boxplot shows the median (black line), mean (x), first and third quartiles (box), and outliers (o) defined as values exceeding 1.5 times the interquartile range below the first quartile or above the third quartile. Whiskers extend to the minimum and maximum values excluding outliers. (WN: White Noise, SM: Soft Material Vibration, MB: Marble Balls Collision, BDM: Badminton Lifting, HAM: Hamster Chewing, TPD: Tap Dance, HRT: Heartbeat)

questionnaire consisted of six items designed to measure the perception of animacy [1], with participants rating each item on a seven-point Likert scale ranging from 1 to 7.

- Q1: Dead — Alive
- Q2: Stagnant — Lively
- Q3: Mechanical — Organic
- Q4: Artificial — Lifelike
- Q5: Inert — Interactive
- Q6: Apathetic — Responsive

The overall perceived animacy score was calculated as the average of the six ratings, with higher values indicating a stronger perception of animacy in the haptic stimuli.

5) Participants: Nine non-disabled participants (4 females) aged between 24 and 33 (Mean: 28.6, SD: 3.9) participated in this experiment. They were given a 1,000 JPY gift card as compensation for their time spent.

B. Results

To examine the distribution of perceived animacy scores obtained in the experiment, a Shapiro-Wilk normality test was conducted, revealing that the data were not normally distributed. Consequently, the Aligned Rank Transform [27] was applied to the data before performing a two-way repeated-measures Analysis of Variance (ANOVA). The results indicated significant main effects of both the haptic stimulation pattern ($F = 14.37$, $p < 0.01$, Fig. 3) and the haptic display ($F = 6.21$, $p = 0.014$, Fig. 4) on perceived animacy scores, but no significant interaction between the two factors was observed. Given the significant main effect of the haptic stimulation pattern, post hoc multiple comparisons were conducted to identify which specific haptic patterns differed significantly. A Wilcoxon signed-rank test with Bonferroni correction was performed for pairwise comparisons among all haptic stimulation patterns. The analysis revealed significant differences between several conditions, as shown in Table II, such as between the 5 Hz vibration (mean score: 5.0) and the 30 Hz vibration (mean score: 3.6).

TABLE II
PAIRS OF HAPTIC STIMULATION PATTERNS SHOWING SIGNIFICANT DIFFERENCES IN PERCEIVED ANIMACY BASED ON MULTIPLE COMPARISONS ($p < 0.05$).

haptic stimuli pattern with HIGHER animacy	haptic stimuli pattern with LOWER animacy	p-values
5Hz	10Hz	= .026
	30Hz	< .01
	50Hz	< .01
	100Hz	< .01
	WN	< .01
	SM	< .01
	MB	< .01
10Hz	50Hz	< .01
	100Hz	< .01
	WN	< .01
	SM	< .01
30Hz	50Hz	< .01
MB	100Hz	< .01
BDM	50Hz	= .037
	100Hz	< .01
	WN	< .01
	SM	= .016
HAM	50hz	< .01
	100hz	< .01
	WN	< .01
	SM	< .01
	MB	< .01
TPD	50hz	< .01
	100hz	< .01
	WN	< .01
	SM	< .01
	MB	< .01
HRT	30hz	< .01
	50hz	< .01
	100hz	< .01
	WN	< .01
	SM	< .01
	MB	< .01
	BDM	= .034

C. Discussion

1) Haptic Stimuli Pattern: The results of this experiment confirmed significant differences in perceived animacy scores across several haptic stimulation patterns (Table II), suggesting that the haptic stimuli employed in this study had a substantial impact on animacy perception. In particular, for single-frequency sinusoidal vibrations (No.1–5), lower-frequency vibrations such as 5 Hz (mean score: 5.0) and 10 Hz (mean score: 4.4) elicited significantly higher animacy ratings than higher-frequency vibrations such as 50 Hz (mean score:

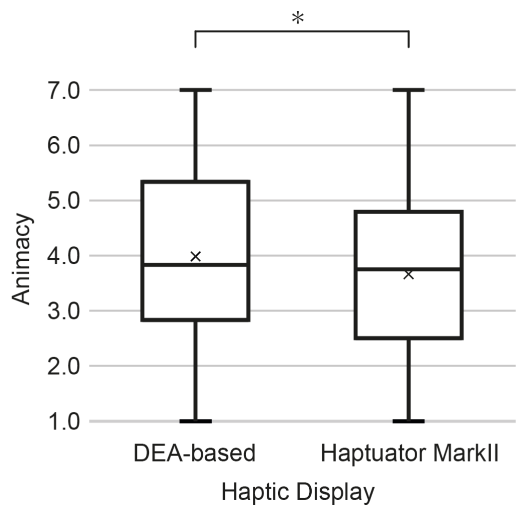

Fig. 4. Perceived animacy scores for each haptic display. Each boxplot indicates the median (black line), mean (x), first and third quartiles (box), and whiskers extending to the minimum and maximum values excluding outliers. An asterisk (*) denotes significant differences with $p < 0.05$.

3.0) and 100 Hz (mean score: 2.6). This finding aligns with previous research [26], which suggests that low-frequency vibrations may evoke associations with biological rhythms, such as heartbeats, pulses, or breathing, thereby enhancing animacy perception.

Similarly, among the complex multi-frequency vibration haptic patterns (No.7–12), the heartbeat-mimicking vibration (HRT, mean score: 5.2) and the tap dance floor vibration (TPD, mean score: 4.5) induced significantly higher animacy ratings than SM (mean score: 2.9), which recorded the vibration of a soft material shaking, and MB (mean score: 3.5), which recorded marbles colliding inside a cup. The higher animacy rating for HRT compared to MB may be attributed to its lower-frequency components, as shown in Figure A, which may be evoked associations with biological rhythms such as heartbeats and respiration, similar to the low-frequency sinusoidal vibrations (No.1, 2).

In contrast, the vibration frequency characteristics of TPD differ from those of HRT, and it does not significantly contain more low-frequency components than MB or SM. Nevertheless, two factors may explain why TPD elicited significantly higher animacy ratings. First, during the initial phase of TPD (0.6–2.4 s), the vibration pattern exhibited periodic oscillations at approximately 0.6 second intervals. Although TPD contained high-frequency components up to 1 kHz, Fig. 2 shows that its envelope exhibited a low-frequency periodic structure. Such periodicity may have enhanced the perception of animacy by evoking biological rhythms, similar to the effect observed with low-frequency sinusoidal vibrations (No.1, 2). Second, the latter phase of the TPD vibration pattern (2.8–4.8 s) included irregular, non-periodic vibrations. These vibrations may have violated Newtonian laws, particularly the law of conservation of energy. Prior research suggests that when an object's motion appears to defy Newtonian laws, observers may infer intentionality or attribute an autonomous energy source to the object. Thus, the irregularity in the latter half of TPD may have contributed to the perception of animacy by suggesting self-generated motion or agency.

These results suggest that the 12 haptic stimulus patterns used in this experiment contained distinct elements that led participants to perceive significantly different degree of animacy. By incorporating these haptic stimulation patterns in the next experiment exploring the relationship between perceived animacy and perceived social presence, these patterns are expected to elicit sufficiently distinct perceptions of animacy, enabling a meaningful analysis of their correlation with perceived social presence.

2) Haptic Display: As described in the experimental results, the two-way repeated-measures ANOVA revealed a significant main effect of the haptic display on perceived animacy scores (Fig. 4). Specifically, the DEA-based haptic display (mean score: 4.0) elicited significantly higher animacy ratings compared to the Haptuator Mark II (mean score: 3.7). However, no significant interaction was found between the haptic stimulus pattern and the haptic display.

One possible explanation for the significant difference between the haptic displays is that the soft and compliant nature of the DEA-based haptic display may have enhanced the perceived animacy of the presented haptic stimuli. However, this experiment does not ensure that the vibrations generated by the two haptic displays were fully consistent across all frequency bands. Further investigation is necessary to precisely determine the underlying cause of this difference. Nevertheless, the primary objective of this study is not to examine the influence of haptic display material properties on perceived animacy but rather to explore the correlation between animacy perceived through haptic display and perceived social presence. Therefore, additional experiments on this aspect will not be conducted within the scope of this study. More importantly, the absence of a significant interaction between the haptic display and the haptic stimulus pattern suggests that specific combination of a haptic display and a particular stimulus pattern produced a unique effect on perceived animacy was not found. For instance, with the DEA-based haptic display, all haptic stimulation patterns elicited consistently high perceived animacy scores, and no instance was observed where the significant differences in perceived animacy scores between haptic stimulation patterns diminished.

These findings indicate that the 12 haptic stimulus patterns used in this study elicited distinct perceptions of animacy regardless of which of the two haptic displays was used. Therefore, in the subsequent section investigating the relationship between perceived animacy and perceived social presence through haptic stimuli, the DEA-based haptic display was selected as the primary haptic display.

III. Experiment II : Social Presence

A. Method

1) Setup: The purpose of this experiment was to investigate whether perceived animacy based on haptic stimuli could serve as a predictor of perceived social presence. To accomplish this, both haptic and visual stimuli were presented to participants. This approach was chosen because, if only haptic stimuli were provided as in Section II, participants might interpret the sensations as merely originating from the haptic display rather than attributing them to another entity. Such an interpretation could hinder the perception of social presence, making it essential to incorporate visual stimuli to create a more immersive and socially relevant context.

As illustrated in Fig. 5, the experimental setup consisted of the following components:

- The DEA-based haptic display for presenting haptic stimuli
- An mid-air projection autostereoscopic display for presenting visual stimuli
- An optical motion capture system to detect participants' contact with the visual stimuli (OptiTrack V120: Trio)
- A computer to control and synchronize these systems (Little Gear, OS: Windows 10, RAM: 32 GB, CPU: Intel Core i7-4790@3.5 GHz)

For haptic stimulus presentation, the same DEA-based haptic display used in Section II was employed. Since the results from Section A indicated that both haptic displays could generate varying degrees of animacy depending on the stimulus pattern, the DEA-based haptic display was chosen due to its ability to elicit higher perceived animacy.

To present visual stimuli, a mid-air projection autostereoscopic display, as proposed by Kurogi et al. [14], was utilized. This 3D display was selected based on three key considerations. First, prior research has shown that 3D images enhance the perception of social presence more effectively than 2D images [22]. To increase the likelihood of participants perceiving social presence, a 3D display was chosen. Second, the use of an autostereoscopic display avoids the cognitive and social effects associated with wearing and removing a head-mounted display (HMD). Previous study [12] suggests that wearing and removing an HMD can introduce cognitive, psychological, and social biases ; therefore, higher-order cognitive functions such as the perception of social presence and animacy may be affected. To avoid such influences, an autostereoscopic display that did not require participants to wear any additional equipment was preferred. Third, a mid-air projection display reduces the likelihood of convergence-accommodation conflict when participants reach out to interact with the visual stimuli. Conventional 3D displays often induce such conflicts when participants reach out to interact with the 3D images, which could influence participants' perception of social presence and animacy. By adopting a 3D display that projects images into the air, this issue was mitigated.

The optical motion capture system was positioned behind the 3D display, continuously tracking the participants' right index fingertips using optical markers. This setup enabled precise detection of the moment when participants made contact with the visual stimulus. All devices were connected to a single computer and controlled at an update rate of 120 Hz.

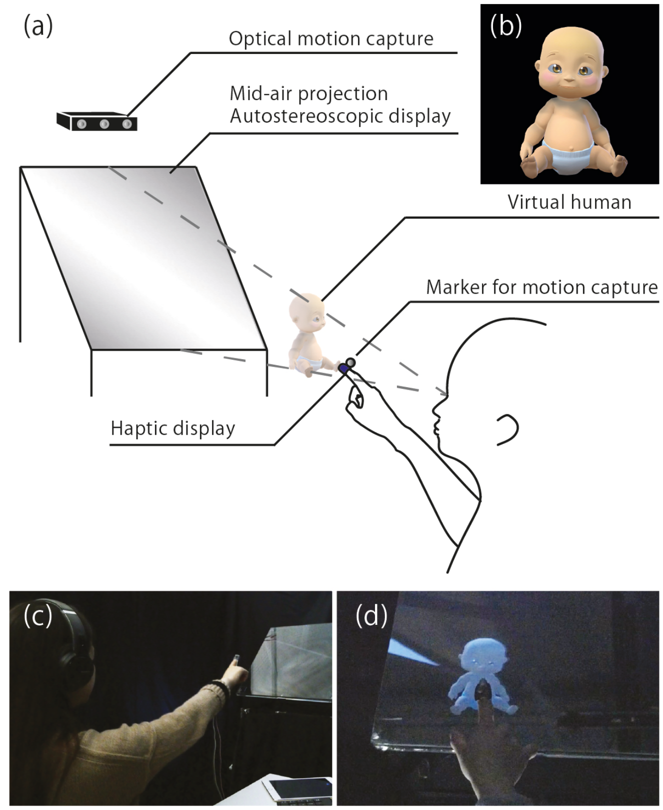

Fig. 5. Experimental setup for Experiment II (Social Presence test). (a) Participants touched a floating virtual human projected by the autostereoscopic display using their right index fingertip. Finger position was tracked via optical motion capture, and haptic stimulation was delivered when the finger entered a predefined interaction zone. (b) An infantile virtual human was projected in mid-air using the autostereoscopic display. (c) Participants reached out to touch the floating virtual human in the touch with finger condition. (d) From the participants' point of view in the touch with finger condition, their finger and the virtual human appeared to overlap visually.

Following each trial, a questionnaire was displayed on an iPad to assess the perceived animacy and social presence of the stimuli. To eliminate the influence of external environmental sounds, participants wore noise-canceling headphones, and white noise was played continuously throughout the experiment.

2) Stimuli and Conditions: In this experiment, a total of 36 conditions were established, combining 12 types of haptic stimulation patterns with 3 types of visual patterns. The 12 haptic stimulation patterns were identical to those used in Section II, as the results of Experiment I indicated that different patterns could elicit varying degrees of perceived animacy. Given the study's objective of investigating the correlation between perceived animacy and social presence, these stimuli were considered appropriate.

For visual stimulation, a non-highly anthropomorphized, anime-style, infantile virtual human was used (Fig. 5). This choice was made to mitigate the potential decrease in perceived social presence that could arise if a highly anthropomorphized character failed to meet participants' expectations in terms of animation or interaction [19]. Highly anthropomorphized characters often require sophisticated animation, interaction design, and careful consideration of the uncanny valley effect. To avoid these complexities and ensure stable experimental conditions, a moderately stylized, anime-like representation was adopted, allowing the study to focus on the influence of haptic stimuli. To maintain a consistent sense of animacy, the virtual human was animated with a simple, periodic breathing motion. A completely static image could reduce perceived animacy, while excessive movement or exaggerated reactions to participant interactions might introduce confounding factors and make analysis difficult. The inclusion of minimal breathing animation ensured that the virtual human retained a baseline degrees of animacy without introducing additional variables.

Three types of visual patterns were implemented, each representing different ways of interacting with virtual characters in mediated environments:

(A) 2D image + touch with pointer: A 2D virtual human was displayed on the screen, and a pointer, controlled by the movement of the participant's fingertip, was used to make contact. This condition simulated interactions with virtual characters on traditional 2D displays, such as touching an avatar using a mouse cursor on a monitor.
(B) 3D image + touch with pointer: Similar to Condition (A), participants used a pointer to touch the virtual human. However, in this case, both the virtual human and the pointer were displayed in 3D. This condition reflected scenarios where a virtual character is interacted with using a 3D display or a distant avatar is touched via a pointer in a VR environment with an HMD.
(C) 3D image + touch with finger: Participants directly touched the virtual human with their fingertip, without the use of a pointer. The virtual human was displayed in 3D, simulating direct interaction with a virtual character within physical reach, as in a VR environment where users can extend their hands to touch objects.

These three visual patterns were designed to examine how different methods of mediated touch influence perceived animacy and social presence, in alignment with hypotheses H1 and H2.

During the experiment, participants wore the haptic display on the index finger of their right hand and interacted with the virtual human. Haptic feedback was provided continuously while contact with the virtual human was detected. However, the virtual human did not exhibit any visual reaction beyond the baseline breathing motion, ensuring that haptic stimuli remained the primary factor influencing participants' perceptions. To prevent occlusion issues when participants pressed their finger or pointer too far into the virtual human, the virtual human was controlled to shift its position in response to the detected depth of contact. When contact ceased, the virtual human returned to its initial position.

A total of 36 trials were conducted, with each participant experiencing all 36 conditions (12 haptic stimulation patterns $\times$ 3 visual patterns). The order of haptic stimulation presentation was randomized to minimize order effects, while the visual patterns were counterbalanced across participants.

3) Procedure: We used a within-participant design with 12 haptic stimulation patterns and 3 visual patterns as independent variables. Before the experiment began, participants wore the DEA-based haptic display on the index finger of their right hand and were seated in front of the mid-air projection autostereoscopic display (Fig. 5). The chair height was adjusted to ensure that the test image appeared at the center of the 3D display.

At the start of the experiment, participants were instructed to touch the infant virtual human displayed on the 3D screen. Depending on the visual pattern, they either directly touched the virtual human with their finger or indirectly touched with it using a pointer. Upon contact with the virtual human, one of twelve predefined haptic stimulus patterns was delivered through the haptic display. The haptic stimulation was presented only while the participant maintained contact with the virtual human. If they removed their finger, the haptic stimulation paused, and upon re-contact, it resumed from where it had stopped. Once the cumulative duration of haptic stimulation reached five seconds, the trial concluded, and participants were asked to complete a seven-item questionnaire. After submitting their responses, the next trial began, requiring them to touch the virtual human again. This procedure was repeated until all trials were completed.

4) Collected Data: After the presentation of the haptic stimuli in each trial, participants completed a questionnaire assessing their perceived animacy and social presence. The questionnaire consisted of six items measuring perceived animacy, as used in Section II, and one item assessing perceived social presence. The social presence question was adapted from Nakanishi et al. [18] with modifications to align with the objectives of this experiment.

- Q1: Dead — Alive
- Q2: Stagnant — Lively
- Q3: Mechanical — Organic
- Q4: Artificial — Lifelike
- Q5: Inert — Interactive
- Q6: Apathetic — Responsive
- Q7: I felt as if I were close to the character in the same room

Participants rated all items using a 7-point Likert scale, ranging from 1 to 7. The final perceived animacy score was calculated as the average of the six animacy-related items (Q1–Q6), with higher scores indicating a stronger perception of animacy. The perceived social presence score (Q7) was rated on the same scale, where a higher value represented a stronger perception of social presence.

5) Participants: Seven non-disabled participants (2 females) aged between 24 and 33 (Mean: 27.9, SD: 3.5) participated in this experiment. They were given a 1,000 JPY gift card as compensation for their time spent.

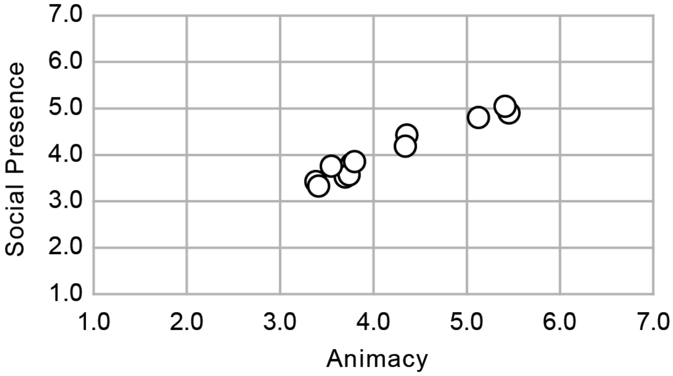

Fig. 6. Relationship between perceived animacy and perceived social presence. Each data point represents the average scores of perceived animacy and perceived social presence for each haptic stimulation pattern. A significant strong positive correlation was found between the two variables ($\rho = 0.956$, $p < 0.01$).

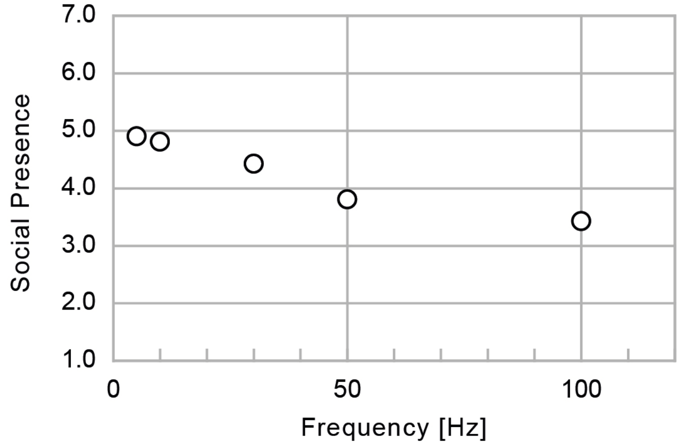

Fig. 7. Relationship between stimulation frequency and perceived social presence. Each data point represents the average perceived social presence score for each haptic stimulation pattern using a sinusoidal waveform. A significant strong negative correlation was found between stimulation frequency and perceived social presence ($\rho = -1$, p = 0.0167).

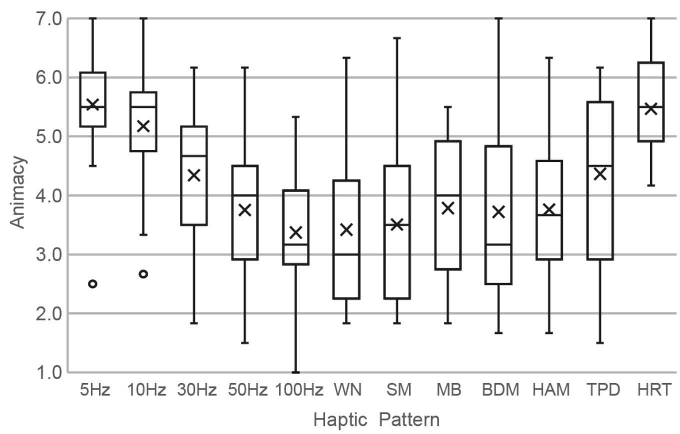

Fig. 8. Perceived animacy scores for each haptic stimulation pattern in social presence experiment. Each boxplot displays the median (black line), mean (x), first and third quartiles (box), and outliers (o) defined as values exceeding 1.5 times the interquartile range below the first quartile or above the third quartile. Whiskers extend to the minimum and maximum values excluding outliers.

B. Results

Statistical analyses were conducted to examine differences among the 12 haptic stimulation patterns and the three visual display conditions. The Shapiro-Wilk normality test indicated that the data for perceived animacy and perceived social presence scores were not normally distributed. Consequently, the Aligned Rank Transform [27] was applied, followed by a two-way repeated-measures ANOVA. The results revealed a significant main effect of the haptic stimulation pattern on both the perceived animacy and perceived social presence scores ($F = 10.74$, $p < 0.01$, $F = 4.71$, $p < 0.01$). However, no significant main effect of the visual pattern or interaction between the haptic stimulation pattern and the visual pattern was observed for either score.

To further investigate the relationship between perceived animacy and perceived social presence, the average scores for each haptic stimulation pattern were computed, and a Spearman correlation analysis was performed. The analysis revealed a significant strong positive correlation between perceived animacy and perceived social presence ($\rho = 0.956$, $p < 0.01$, Fig. 6). Additionally, to examine the relationship between perceived social presence and the frequency of the haptic stimulation, a Spearman correlation analysis was conducted for the perceived social presence scores and five single-frequency sinusoidal vibration stimuli (5, 10, 30, 50 and 100 Hz). The results showed a significant strong negative correlation between haptic stimulation frequency and perceived social presence, indicating that lower-frequency vibrations were associated with higher perceived social presence ($\rho = -1$, $p = 0.0167$, Fig. 7).

Given the main effect of the haptic stimulation pattern on both perceived animacy and perceived social presence, multiple comparisons were performed to determine which specific haptic stimulation patterns exhibited significant differences. A Wilcoxon signed-rank test with Bonferroni correction was conducted for pairwise comparisons across all haptic stimulation patterns for each score. For the perceived animacy score, as shown in Table III, significant differences were observed between several haptic stimulation patterns. For instance, the heartbeat-mimicking vibration (HRT, mean: 5.5) exhibited significantly higher perceived animacy than the lifting badminton shuttlecock vibration (BDM, mean: 3.7). Similarly, for the perceived social presence score, as shown in Fig. 9, significant differences were found between multiple stimulation patterns; the HRT (mean: 5.0) produced significantly higher perceived social presence than both the BDM (mean: 3.5, $p = 0.025$) and the 100 Hz sinusoidal vibration (mean: 3.4, $p = 0.044$).

C. Discussion

1) Social Presence and Animacy: The experiment revealed a strong and significant positive correlation between perceived animacy induced by haptic stimuli and perceived social presence. This relationship was consistent across all 12 haptic

TABLE III

PAIRS OF HAPTIC STIMULATION PATTERNS SHOWING SIGNIFICANT DIFFERENCES IN PERCEIVED ANIMACY IN THE SOCIAL PRESENCE EXPERIMENT ($p < 0.05$).

haptic stimuli pattern with HIGHER animacy	haptic stimuli pattern with LOWER animacy	p-values
5Hz	30Hz	= .036
	50Hz	= .020
	100Hz	< .01
	WN	= .029
	SM	= .013
	MB	= .024
	BDM	= .021
	HAM	= .036
10Hz	50Hz	= .013
	100Hz	< .01
HRT	50hz	= .016
	100hz	= .010
	WN	= .029
	SM	= .020
	MB	< .01
	BDM	< .01
	HAM	= .034

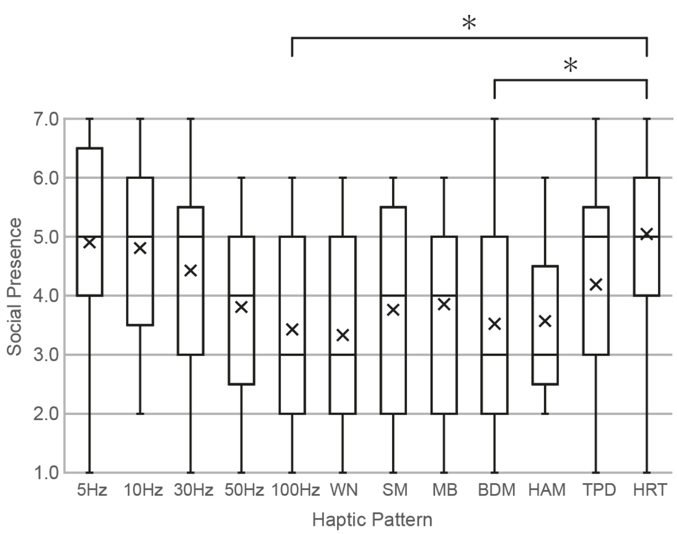

Fig. 9. Perceived social presence scores for each haptic stimulation pattern. Each boxplot shows the median (black line), mean (x), first and third quartiles (box), and whiskers extending to the minimum and maximum values excluding outliers. Asterisks (*) indicate significant differences where $p < 0.05$.

stimuli, including both single-frequency sinusoidal vibrations (No. 1–5) and more complex multi-frequency vibration patterns (No. 7–12). These results suggest that perceived social presence is not solely determined by the frequency content of the vibrations, but is instead closely tied to the degree of animacy perceived from haptic stimuli.

At first glance, the results may seem to suggest that perceived social presence is simply enhanced when haptic feedback temporally aligns with visual cues, such as the breathing motion of the virtual human. For example, the heartbeat-mimicking vibration (HRT, mean animacy: 5.5, mean social presence: 5.0) may have induced higher social presence because its rhythmic properties naturally matched the visual breathing animation. However, this explanation alone is insufficient to account for the lower perceived social presence of the lifting badminton shuttlecock vibration (BDM, mean animacy: 3.7, mean social presence: 3.5). As shown in Fig. 2, although BDM contained high-frequency components up to 1 kHz, its envelope followed a periodic pattern of approximately 1.4 seconds (0.71 Hz), which is comparable to human rhythms such as breathing or heartbeat. If perceived social presence were solely determined by temporal alignment between haptic and visual cues, BDM would be should have elicited similarly high social presence. However, the experimental results contradict this assumption. This discrepancy can be explained by positing that perceived animacy derived from haptic stimuli is closely linked to social presence. Specifically, the high-frequency components in BDM stimulus may have suppressed perceived animacy, leading to a corresponding reduction in perceived social presence. This interpretation supports Hypothesis H1, which posits that perceived animacy elicited by haptic stimuli predicts perceived social presence.

The relatively low perceived social presence observed in the BDM condition, despite its temporal alignment with the visual breathing animation, underscores the role of perceived animacy. However, it is important to note that congruent visual and haptic cues may still contribute to enhancing the perception of social presence. For instance, if the visual stimulus had depicted a hamster rather than a virtual human, the HAM condition haptic stimulus might have elicited a higher level of perceived social presence. To gain a more comprehensive understanding of the relationship between haptic stimuli and perceived social presence, future research should systematically investigate how the similarity between visual and haptic cues influences social perception.

Furthermore, if the interpretation is correct that the high-frequency components contained in the BDM vibration suppressed perceived animacy and consequently reduced perceived social presence, this suggests an important implication. Specifically, when simulating contact with virtual human, using vibrations with high-frequency components—such as those representing collisions or the texture of clothing—could potentially diminish the perceived social presence. This indicates that reproducing realistic haptic sensations does not necessarily lead to higher social presence, which may appear counterintuitive.

To properly interpret this phenomenon, two considerations must be taken into account. First, the observed decrease in perceived social presence with high-frequency components should be understood as a relative decrease compared to low-frequency-only conditions. In other words, even if high-frequency components are included, perceived social presence may still increase when haptic feedback is provided, compared to when no haptic stimuli are presented at all. This interpretation is supported by prior studies, which have reported increased perceived social presence when haptic stimuli are presented, as compared to no-stimulus conditions [2], [3], [6], [7], [11], [15], [23], [24].

Second, real-world interactions with animate beings, the haptic experience is not limited to vibrations alone. Instead, it encompasses a complex multimodal integration of sensory information, including distributed pressure, force feedback, and thermal cues. When touching a living being, for instance, humans perceive not only vibrations (e.g., from collisions or texture) but also the softness of skin or fabric via distributed pressure and force feedback, and body warmth through thermal sensations. These diverse sensory signals are integrated to form a coherent and convincing sense of social presence.

Therefore, the phenomenon observed in this study—that high-frequency vibrations resulted in lower perceived social presence can be reasonably explained by two key factors: (1) the relative comparison to stimuli composed solely of low-frequency components, and (2) the fact that the haptic feedback used in this study was limited to vibrotactile stimuli. In the absence of other sensory cues such as force or temperature, the introduction of high-frequency vibration alone may have disrupted the perception of animacy, thereby leading to a decrease in perceived social presence compared to low-frequency-only conditions.

Finally, these findings (perceived animacy from haptic stimuli predicts perceived social presence) contrast with those of Jin et al. [9] who reported no significant correlation between perceived animacy and perceived social presence. A plausible explanation for this discrepancy lies in the nature of the stimuli employed in their study. Specifically, the set of haptic stimuli may not have been sufficiently diverse to evoke a broad range of perceived animacy. In contrast, the haptic stimuli employed in this study were carefully designed and validated to induce significantly different degrees of animacy as demonstrated in Section II. This methodological difference likely enabled the detection of a significant correlation in our study by providing a broader range of haptic experiences capable of modulating participants' perception of animacy.

Despite these contributions, this study has several limitations. First, the sample size was relatively small (seven participants), and the number of trials per condition was limited. As a result, caution is required when generalizing these findings. Additionally, there were demographic imbalances in gender and age among participants, which may have influenced the results. To establish the robustness of these findings, future studies should employ larger and more diverse participant samples.

Another limitation is that the study does not provide definitive evidence of a causal relationship between perceived animacy and social presence. While the results suggest that perceived animacy may serve as a predictor of social presence, it remains unclear whether this relationship is causal or arises from a confounding factor. Since both perceived animacy and social presence are higher-order cognitive constructs, disentangling their relationship is inherently challenging. One promising approach for clarifying this relationship is to incorporate neuroscientific methods. By leveraging neuroimaging and other neuroscience techniques, future research may investigate the underlying brain mechanisms associated with perceived animacy and social presence. This approach could offer deeper insights into how haptic stimuli influence social cognition and contribute to a more comprehensive understanding of mediated social interactions. Incorporating such methods in future studies would enhance the theoretical and empirical foundations of research on social presence and perceived animacy in haptic interactions.

2) Social Presence and Frequency: The experiment confirmed a significant strong negative correlation between the frequency of single-frequency sinusoidal vibration stimuli and perceived social presence. This result supports Hypothesis H2, which posits that perceived social presence is influenced by the frequency of sinusoidal haptic stimuli. At first glance, this finding may appear self-evident, as prior research has shown that low-frequency sinusoidal vibrations enhance perceived animacy [26], combined with our Hypothesis H1, which suggests a correlation between perceived animacy and social presence in haptic stimuli. However, the one of key contribution of this study lies in extending previous research [2], [3], [6], [7], [11], [15], [23], [24] demonstrating that haptic feedback enhances social presence by identifying a specific physical factor of haptic stimuli that influence perceived social presence. These findings offer valuable insights for quantitatively modeling the relationship between haptic stimuli and perceived social presence and represent a significant contribution to the field.

Despite these contributions, this study has limitations. The sinusoidal vibration haptic stimuli tested were restricted to only five frequencies ranging from 5 Hz to 100 Hz, which may constrain the generalizability of the observed negative correlation. Previous study [26] suggests that perceived animacy decreases when sinusoidal vibration frequency falls below 1 Hz. Given our Hypothesis H1, it is possible that extremely low-frequency vibrations below 1 Hz may not exhibit the same negative correlation with social presence. Future research should explore a broader frequency range to clarify this point.

3) Social Presence and 2D/3D: In this experiment, no significant main effect of visual patterns on perceived social presence and animacy were observed, nor were there an interaction between haptic stimulation patterns and visual patterns. This indicates that perceived social presence did not differ significantly between 2D and 3D images in this experiment.

Previous research by Prussog et al. [22] suggested that 3D image enhance the sense of shared space compared to 2D image. Based on this, it was hypothesized that 3D image would lead to higher perceived social presence, but this study did not support that prediction. One possible explanation is that participants did not perceive a meaningful difference between the 2D and 3D images. Post-experiment interviews revealed that none of the participants explicitly recognized the distinction between the two. This lack of perception may be attributed to the absence of strong depth cues in the visual stimuli of this experiment. In previous study [22], a life-size human figure was displayed on a large screen (1130×850 mm), likely preserving depth information effectively. In contrast, the autostereoscopic display used in this experiment projected images into the air to minimize convergence-accommodation conflict, but the scale of the virtual human was reduced rather than life-size (Fig. 5). Consequently, the available depth cues was also diminished, with the maximum surface depth variation of the virtual human being only 18.2 mm. This reduction may have resulted in insufficient depth cues, making it difficult for participants to perceive depth even in the 3D image condition. Additionally, while previous study included the surrounding environment in the display [22], this experiment presented only the virtual human without background elements. The absence of environmental depth references may have further contributed to the participants' inability to perceive depth differences. As a result, the expected distinction between the 2D and 3D images conditions may not have been perceived, and no corresponding difference in social presence was detected.

Future studies investigating the effects of 2D and 3D images on the relationship between haptic stimuli and perceived social presence should consider designing visual conditions that provide clearer depth perception. Increasing the scale of the virtual human to approximate life-size and incorporating environmental elements that enhance depth perception may be effective strategies.

4) Social Presence and Touch with Pointer/Finger: The results of this experiment revealed no main effect of the visual pattern on perceived social presence, nor any interaction between haptic stimulation patterns and visual patterns. This indicates that there was no significant difference in perceived social presence between direct contact with a virtual human using a finger and indirect contact using a pointer in this experiment. These results provide valuable insights into how mediated touch should be visually represented in human-computer interaction. However, the small sample size (seven participants) and the limited number of trials per condition may have reduced the statistical power of the experiment. As such, these results should be interpreted with caution when considering their generalizability. In real-world interactions, the sense of risk and object presence may differ depending on whether an object is touched directly with a finger or indirectly through an intermediary tool, such as a stick. Additionally, prior research has demonstrated psychological and cognitive differences—such as variations in perceived ownership and the valuation of items—between direct and indirect touch [5], [17]. Given these considerations, it remains possible that differences in the visual representation of contact could influence social presence, which involves high-order cognitive processing. Further research is therefore necessary to explore how visual representations of touch with mediated others impact the perception of social presence. A deeper understanding of this topic could inform the development of user interface guidelines for remote communication and virtual interaction systems that incorporate virtual touch in digital environments.

5) Limitation: This study has several limitations that should be acknowledged. First, the sample size was relatively small, and the number of trials per condition was limited. These factors may constrain the generalizability of the results. Additionally, the sample exhibited imbalances in participant demographics, such as gender, age, and handedness, which could have influenced the outcomes. To improve the external validity of these findings, further studies with larger and more demographically representative samples are needed.

Another limitation lies in the measurement of perceived social presence. In this experiment, social presence was assessed using a single item focused on the "sense of being with another" based on the conceptualization proposed by Biocca et al. [4]. However, prior literature on social presence in some cases includes additional dimensions, such as mutual awareness, psychological involvement, and behavioral engagement. Since our study did not assess these aspects, it remains unclear whether the perceived animacy induced by haptic stimuli also influences these broader cognitive and behavioral dimensions of social presence. Given the complexity of social presence, future research should adopt more comprehensive measurement. This would enable a deeper understanding of how haptic stimuli affect users' cognitive, emotional, and behavioral responses in social interaction contexts.

IV. Conclusion

In this study, we tested two hypotheses: (H1) that the animacy perceived from haptic stimuli serves as a predictor of social presence, and (H2) that perceived social presence is influenced by the frequency of sinusoidal vibrations presented as haptic stimuli.

In Experiment I, we employed 12 types of haptic stimulus patterns and two types of haptic displays to examine whether different haptic stimuli elicited varying degrees of perceived animacy. The results confirmed that each haptic stimulus induced distinct perceptions of animacy.

In Experiment II, we combined the same 12 haptic stimulus patterns with three types of visual patterns to investigate the relationship between perceived animacy and social presence in a task where participants touched a virtual human. A two-way repeated-measures ANOVA revealed a significant main effect of the haptic stimulus pattern on both perceived animacy and social presence. Furthermore, Spearman's correlation analysis demonstrated a strong positive correlation between perceived animacy and social presence. Additionally, an analysis of five types of single-frequency sinusoidal vibration haptic stimuli revealed a strong negative correlation between stimulus frequency and perceived social presence.

These findings support hypothesis H1, indicating that perceived animacy from haptic stimuli serves as a predictor of social presence, and hypothesis H2, demonstrating that perceived social presence is influenced by the frequency of haptic stimuli. Moreover, this study provides novel evidence that the physical factor of haptic stimuli, particularly frequency, play a role in shaping the degree of social presence.

The insights gained from this study contribute to a deeper understanding of the relationship between haptic stimuli and social presence. These findings provide a foundation for developing models that describe this relationship and inform the design of effective user interfaces for virtual interactions with mediated others, including remote communication and interactions with virtual agents.

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