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The Effect of Implementation Strategies in Compliance Illusions

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I. Introduction

Grain-based compliance illusion is a haptic illusion technique that allows users to perceive compliance even on rigid surfaces [1]. It increases immersion by conveying the sensation of a deformable virtual object through vibrations and also supports eyes-free control [2]. Because the vibration pattern varies depending on the force's magnitude and rate, it can provide tactile feedback not only about whether force is applied but also about how it is applied. As a result, varied user interactions can be translated into different patterns of haptic feedback, allowing different force interactions, such as gentle or forceful pressing, to be reflected in distinct tactile responses.

Previous studies have investigated factors such as vibration type, interval, and reference force value in compliance perception [3], [4]. To the best of our knowledge, the effects of algorithmic differences on perceived compliance have not been directly examined. The two commonly used implementation strategies are fixed threshold, where vibration occurs whenever the force crosses a constant threshold [3], and adaptive threshold, where vibration occurs only when the change in force from the last vibration point is greater than the threshold [2]. This difference affects the vibration pattern, especially under noisy or sustained conditions. For instance, the fixed threshold strategy may produce continuous vibrations when the applied force fluctuates around the threshold, while the adaptive strategy suppresses repeated triggers unless a new threshold is exceeded.

In this study we compared the effect of two implementation strategies on the perceived compliance. To make fair comparison, we considered different types of force-based interactions requiring short and long tap, slow and fast click, and light and hard press. Finally, Fig. 1 summarizes the force profile parameters used in our study.

II. Apparatus

The two implementation strategies generate different vibration patterns even when the threshold value remains constant. In the fixed threshold strategy, vibration occurs whenever the applied force crosses a preset value. In the adaptive threshold strategy, vibration is triggered only when the force deviates from the last triggered point by more than the threshold.

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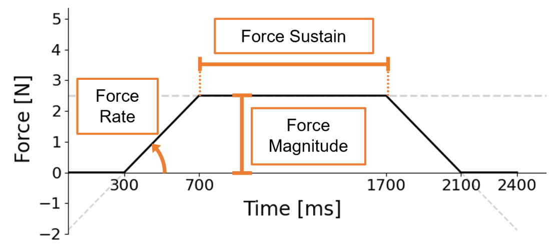

Force Magnitude	Low (2.5N)	High (5N)
Force Rate	Slow (6.25N/s)	Fast (12.5N/s)
Force Sustain	None	Sustained (1s)

Fig. 1. Force-based interaction with annotated force profile parameters: force magnitude, rate, and sustain.

We used the same hardware and software setup as in Mun et al. [4]. The device included a load cell (TAL220) and a surface transducer (COM-10917), which delivered vibration feedback according to the pressing force of the index finger. The threshold value was fixed at 0.25 N. We constructed eight force-based interactions by varying force magnitude (2.5 N or 5.0 N), force rate (6.25 N/s or 12.5 N/s), and force sustain for 1 second (present vs. absent).

III. Experiment

Eight participants (ages 22–26, 2 females and 6 males, all right-handed) were recruited. On average, the participants took 47 minutes. The order of the force-based interactions was counterbalanced using a Latin square design. In each session, both implementation strategies were presented in random order five times. In total, 640 data points were collected (8 participants $\times$ 8 force-based interactions $\times$ 2 strategies $\times$ 5 repetitions).

Participants wore earplugs and headphones playing pink noise to mask auditory cues, ensuring that all judgments were based solely on tactile feedback. We instructed participants to press the device with their dominant hand and submit their answers using the GUI buttons displayed on the tablet with their non-dominant hand. On the tablet screen, as in Mun et al. [4], an animated bar graph presenting reference force profile was displayed to indicate the target force magnitude, rate, and sustain duration. Participants were instructed to press the device following the graph. A press was considered valid press only when the difference between the target and actual force was within 2N for low magnitude and 4N for high magnitude.

Each session started with a tutorial to practice the ref-

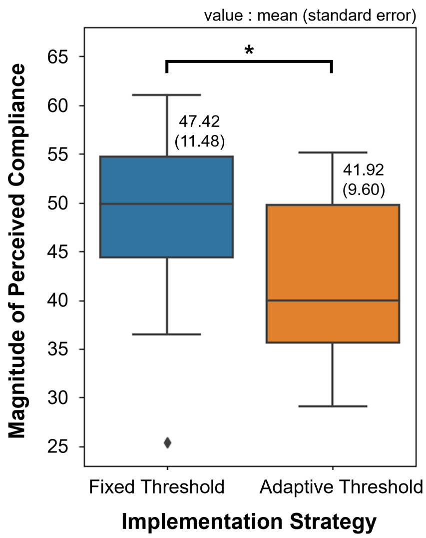

Fig. 2. Magnitude of perceived compliance by implementation strategy. Each group shows average values across force-based interactions.

erence force profile for the session. The tutorial continued until the participant achieved five consecutive valid presses. It took approximately 3 minutes on average. After two valid pressing, the participants were asked to rate the perceived magnitude of compliance using a slider on a tablet selecting a value from 0 (no compliance) to 100 (maximum compliance). To prevent any saturation, we included 10-second breaks between trials and 30-second breaks between sessions.

IV. Results, Discussion and Future Work

We averaged the five repetitions per condition for each participant, resulting in 128 data points (8 force-based interactions $\times$ 2 strategies $\times$ 8 participants). After verifying normality, we conducted a four-way ANOVA with force magnitude, rate, sustain, and implementation strategy as independent variables.

The results showed a statistically significant main effect of the implementation strategy ($p < 0.05$), with the fixed threshold strategy leading to higher perceived compliance values. No significant effects were found for the other factors or their interactions. Fig. 2 presents results grouped by implementation strategy, the only variable that showed a statistically significant effect.

Despite the small number of participants, the results showed the main effect of the implementation strategy on the perceived magnitude of compliance. Though it was not our main focus of analyzing the effect of different force profile and there was no significant effect of them, the more number of participants may reveal the main effect or interactions between the pressing profile.

Our results show that the implementation choices can affect the sensation of grain-based compliance illusion. Our future work includes the effect of implementation strategy on other perspectives of compliance feeling, such as its quality.

References

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