A Multimodal Illusion of Force Improves Control Perception in Above-Surface Gesture: Elastic Zed-Zoom

Dilan Ustek(✉), Kevin Chow, Haihua Zhang, and Karon MacLean

University of British Columbia, Vancouver, BC, Canada
dilanustek@gmail.com, maclean@cs.ubc.ca

Abstract. Emerging above-surface technology is an opportunity to exploit interaction spaces above a device's surface; however, the resulting loss of the proprioceptive feedback available from on-surface interactions degrades the user's sense of control and precision. We asked whether a pseudohaptic illusion (PHI) could help: a sense of force in the absence of actual contact, induced by manipulating the relation of body motion to graphical and auditory cues.

To examine the value of above-surface PHIs, we used a *zooming* micro-task, because finger occlusion impedes current implementations on small displays such as smartwatches. In a qualitative study ($N = 12$), we were able to trigger a physical illusion most often described as *elasticity* in 92% of participants through physical control/graphical display (C/D) manipulation, and that audio cues significantly strengthened the illusion. Participants experiencing this PHI reported improved sense of control when zooming, and found the interaction's physicality natural.

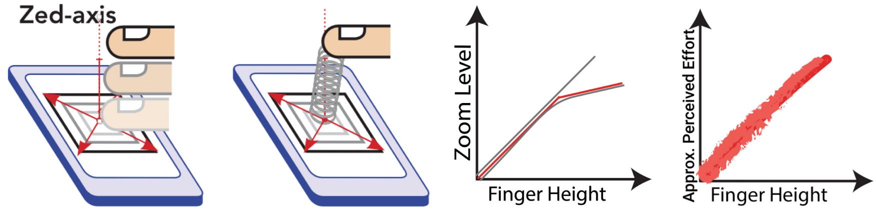
1 Introduction

With inexpensive vision systems, large gestures have become firmly entrenched as conventional interactive elements. However, only recently have promising practical mechanisms, such as electroactive polymers (EAP; [20]) and specialized optical systems [16], emerged to support gesture detection in the finger-scale space immediately above a sensed surface. The consequent increase in interaction volume is of particular value for small touch surfaces, such as those on wearable devices and in mobile contexts.

However, in-air spatial interaction lacks physical grounding (*e.g.*, from active force feedback, or the sliding passive constraint of a touchscreen), and with it a sense of control that is important for precise movements. Physical feedback can also support a metaphor that makes an interaction more intuitive [14]. The degradation of real and perceived control when users must rely solely on proprioceptive cues [18] may be more serious for small surface-linked movements ("above-surface") than for large ones, where users cannot compensate by making movements larger.

We ask whether the loss of feedback in above-surface interactions can be offset by inducing and exploiting *pseudohaptic illusions*, increasing naturalness through

D. Prattichizzo et al. (Eds.): EuroHaptics 2018, LNCS 10893, pp. 295–308, 2018.
https://doi.org/10.1007/978-3-319-93445-7_26



(a) *Zed-Zooming:* The user touches the graphical zoom target to select it, then moves finger up and down above the surface to zoom it.

(b) *EZ-Zoom:* An illusion of an elastic link between finger and screen adds an interaction metaphor to Zed-Zoom.

(c) A *scaling function* relates finger zed-height to zoom level. One function (red) triggers an illusion of increasing force.

(d) Users report linear perceived effort over (c)'s function (the PHI is movement-based, so static measures are unavailable).

Fig. 1. The *Elastic Zed-Zoom* concept (a-b); and what makes it work (c-d). (Color figure online)

physicality. In PHIs, users perceive or imagine haptic sensations despite their absence, by integrating proprioceptive cues with those from vision or audition [19]. One well-known PHI is "mouse acceleration", where control/display (C/D) manipulation induces a user's attribution of inertia to a mouse cursor. The result may differ from that of real haptic input – it is generally fainter and/or apparent only during motion; yet it can deeply alter the sense of an interaction. Here, we are interested in how these illusions might improve perceived control and thereby confidence and fluidity.

Approach: To understand the potential helpfulness and limitations of PHIs in remediating perceived-control drawbacks of above-surface interaction methods, we explored a specific PHI (*EZ-Zoom*) that we conjectured would improve the experience of an interaction task. We used this interaction as a vehicle to investigate questions regarding illusion triggering and usability of the augmentation, in a within-subject study that varied graphic and auditory display manipulations and use contexts.

We chose a micro-task of zooming (Fig. 1a) because extending the zooming interaction space to the above-surface region is a promising answer to the occlusion and selection issues caused by finger contact on limited screen area. The *illusion* is that of a physical connection between finger and screen (Fig. 1b). We reasoned that this PHI could restore a proprioceptive zoom-extent cue, indicate information such as an outer spatial limit to proximity sensing range, and provide a metaphor for direct manipulation.

To our knowledge, all PHIs reported to date act by modifying an ongoing physical contact. In EZ-Zoom, there is no physical contact during the illusion. This new class of PHI may be a way to confer physicality benefits on other non-contact interactions.

Overview of the EZ-Zoom PHI: We examined the relation between finger height and graphical image scaling (Fig. 1c) for ability to trigger an illusion of a physical connection, via coordinated physical-graphic movement. In pilot, participants experienced an illusion more often under specific control-display (C-D) functions. The most successful of these is a piecewise-linearized logarithmic scaling (Fig. 1c's red line).

In our implementation, the image grows larger as the finger "pulls" it upwards. Beyond a sensed threshold, the connection might "pop" loose, the image resetting to its initial size. The illusion occurs as an artifact of coordinated finger-image movement: the perception appears to be of a *change* in (rather than absolute) force, and thus this illusion does not manifest at standstill. We also designed an auditory cue (a stretching sound), to allow investigation of illusion strengthening due to multimodal reinforcement.

RQ1 – Multimodal Influence on Illusion: *Is there a pseudohaptic illusion that a majority of the users feel? If so, how is user perception of the strength of the pseudohaptic illusion of elasticity impacted by auditory feedback and image content?* Auditory event feedback (*e.g.*, "popping" through a boundary) can modify haptic perception of *actual* compliance [22]. Can it have a similar effect on an illusory percept, thus facilitating the elastic illusion? We also noticed that different graphic content sometimes "felt" different during zooming, suggesting that image type might vary in facilitation.

RQ2 – Scaling Function Limit Warning: *Proximity sensors have a limited detection range above the screen surface. Can a PHI inform users of this limit?* Awareness of sensing range limit above the display could be a valuable control cue. With the flattening scaling function which seemed to best trigger the PHI (Fig. 1c), image scaling slows for vertical movement at the top of the interaction space. We examined whether this PHI could (a) effectively signal the limit's approach, and (b) increase perceived control.

Contributions: From our interaction technique design and evaluation, we offer:

1. A non-contact pseudohaptic illusion induced in the context of graphic zooming.
2. Evidence that an above-surface PHI can augment users' sense of control.
3. Insight into how auditory feedback and image content factor into this PHI's strength, and recommendations on how to incorporate minimally-intrusive auditory feedback.

2 Related Work

This study builds on prior findings in haptics, illusion, and above-surface interaction.

Haptic Feedback and Precise Interaction: Humans rely on haptic feedback and physical constraints for precise interactions [17]. Recent empirical studies of modern in-air interactions confirm this; *e.g.*, freehand techniques on wall-sized displays produced lower accuracy and efficiency relative to grounded input gestures [18].

Documented Pseudohaptic Illusions: Reported PHIs have generally involved altered perception of an extant haptic stimuli, *e.g.*, sliding on a real or virtual (haptically rendered) constraint, where reduced haptic reliance might be due to inadequate proprioceptive acuity [4,5]. Examples [7] include graphic and auditory manipulations to modify perceived spring stiffness [11,23] and material properties [9]. A PHI can persuade us that our hand is sliding over a bump when actually on a flat surface [12].

Exploiting PHI in Interaction: Adding physicality to graphics can improve usability and precision; reinforcing a metaphor can make an interaction more intuitive [1]. A designer can also use PHIs to mitigate hardware limitations in haptic cue amplitude, resolution or controllability. Many examples utilize physical simulation for realism.

One practical PHI use is in making boundaries apparent. Mandryk et al. reduced inadvertent cursor screen-crossing in multi-monitor displays when a user accesses a widget near the boundary [15]. If the mouse is moving quickly towards the target, the cursor slows down over it, creating a 'sticky' feeling and avoiding an unwanted leap. Lee et al. showed how a circular cursor can "squeeze" as though it is made of rubber when it is "pushed" against the display borders [13].

Here, we trigger a PHI without haptic contact, by manipulating the amount of graphic zoom per distance the finger travels in the zed-axis, to support in-air interaction.

In-air Zooming, Panning and Selection: Studies of non-surface gesture solutions on small displays show promise in mitigating known problems with on-surface interaction. Kratz et al. prototyped *Around-Device interaction* by equipping mobile devices with infrared distance sensing of coarse hand movements to sense sweeping hand strokes and rotations to scroll and select, and found advantages in terms of small-screen occlusion [8].

In an example of off-surface zooming, Sridhar et al. sensed mid-air and multitouch finger input on the back of the hand via a high-resolution optical sensor on the side of a watch [21]. This exercise demonstrated promise in applications such as music control, virtual reality/augmented reality input, navigation, image exploration and game control. While lacking a path to practical near-term implementation, this work underscores the need for advances in close-range proximity sensing for small-screen interaction.

Air+Touch [2] comprises two in-air zooming techniques: (a) lifting the thumb high above the control surface toggles zoom/pan modes before a tap, followed by scrolling to pan or zoom in/out – like a virtual slider; (b) pan by touch, and zoom with in-air cycling.

Transture was motivated by insufficient small-screen space for *pinch-to-zoom* gestures [6]. To trigger zooming, the user circles in-air and continues circling to zoom; movement outside the initial circle registers as panning. The authors found that "participants wanted to disable panning function in the zooming zone", implying that zoom and pan were difficult to handle simultaneously.

These in-air interactions suffer from a lack of proprioceptive cues, as noted above [16,18]. They demonstrate promising in-air control gestures whose form suggests they could work better with added proprioceptive support. Since real haptic feedback is by definition not available, it is worth looking at how illusory feedback could help.

3 Pseudohaptic Illusion Design

To evaluate the benefits of a PHI, we designed an in-air zooming interaction, *zed-zoom*, that would allow us to compare the usability with and without the PHI. After piloting suggested that PHI effects were connected to the function that relates image scale to finger height, our design process involved exploring this premise systematically.

In the following, we describe our considerations and process for zed-zoom design, and three implemented variants. The first differs from the others by its *scaling function* (linear vs. linearized-log). We eventually termed these Linear and Elastic Zed-Zoom (*LZ-Zoom* and *EZ-Zoom*) respectively (we refer to the log-scaled zoom method as "elastic" for consistency). The third technique is *EZ-Zoom* with auditory feedback.

Simulating Experience with Proxy Technology: While above-surface sensing technology is under development (*e.g.*, EAPs [20]), available prototypes were not mature enough for interaction design development. We simulated anticipated experiences first with sketching methods, then prototyping with alternative existing technology that while less mobile, could simulate EAP strengths (such as transparency, flexibility and low cost) and limits (range, resolution). Our work had the additional role of generating technical application specifications for further above-surface sensor development.

We used a consumer-grade depth sensor, the Leap Motion Controller with Orion hand-tracking software (v3.2.0) [10], which is based on a pair of infrared cameras and three infrared LEDs (60 frames/second sampling). The LEDs illuminate the scene ($\lambda = 850\,\text{nm}$), which is tracked by the cameras to form an inverted-cone-shaped interaction space (150° wide and 120° deep); maximum tracking range is 800 mm [3]. Leap's Javascript API has built-in web sockets, for front-end prototyping with web technologies. The Leap prototype occasionally "glitched" due to internet connectivity, lighting shifts, and Leap loss of finger tracking. In our study, perhaps 3–4 glitches occurred per session.

Zed-Zooming: Zed-zoom mode is triggered with a tap on the intended zoom target, and can be turned off at any time with a second touch anywhere on the screen. In the simplest version, finger height is directly proportional to zoom scale. Content scales linearly with finger height up to a threshold, when content resets to its original position. In pilots, this linear version did not tend to produce an elasticity illusion (Fig. 1c, grey lines).

We chose a 16 cm range of motion to fully utilize the anticipated range of EAP sensitivity. We also wished to ensure that users have ample movement space, given that this PHI derives from a movement artifact. Finally, this height allowed us to observe how users grounded their gestures (*e.g.*, wrist or elbow braced near surface) although ultimately this did not become a study focus.

EZ-Zoom: We searched the scaling function space for relationships that would trigger an illusion, such as accelerating scaling with finger height. We found that decelerating scaling (*e.g.*, a logarithmic scale increase with finger height) makes users feel that the image is harder to pull as the finger is lifted higher (vice versa in descent), and describe this as elasticity or springiness. We believe this is because the finger must travel further per unit of scale change, thus evoking a sense of effort that increases with finger height (Fig. 1d). We posited that this perceived effort could give users a subtle warning about the extent of the interaction space.

This elastic effect seemed strongest when the log shape was accentuated with a "knee", achieved with piecewise linearization (Fig. 1c, red line). As the finger rises, screen content is magnified until the finger reaches the lower threshold (in our study, 11 cm above the display). As it continues to rise, content scales more slowly (0.3X), *i.e.*, harder to "pull up". At 16 cm, the image "snaps" to its original size. We termed zed-zoom with this linearized log scaling function "elastic zed-zoom", or *EZ-Zoom*.

Graphical Cues: We informally tested zed-zooming with many images. Induction seemed strongest with a cartoon image of a soccer ball, which we realized came across as more strongly 3-dimensional (3D) than comparable photographs, which appear relatively flat on a small screen. We wondered if the ball's appearance of volume heightened susceptibility to the illusion, perhaps through its three-dimensionality seeming to amplify image acceleration. To explore this, we chose to compare zoom images which varied in graphical sense of dimensionality (cartoon ball versus photo).

Auditory Cues: To reinforce the graphically induced PHI and convey complementary interaction information [14], the cue which seemed most beneficial evoked a real elastic object, with two parts: a continuous proportional stretching sound during finger movement, and a discrete "pop" at breakthrough.

We created an audio track that sampled a real balloon stretching almost to the point of bursting: rubber stretching sounds get louder with increased finger height. We used two 2-s segments of this track, selected for playback based on finger position. For finger positions from 0–11 cm, we used an early clip (lower frequency and volume; above 11 cm, a louder, higher-frequency clip represented the balloon stretching to its limit. Clips were 2 s, played continuously during finger movement, immediately interrupted when the finger moved between zones, and stopped when the user stopped.

For the pop, at the breakthrough point, we played the sampled sound of a snapping rubber band, to reinforce the image snapping back to its original size.

4 Evaluation Methods

To evaluate the presence, intensity, and benefits of this illusion, we conducted a within-subjects study where we compared self-reported strength of pseudohaptic effects (elicited by *EZ-Zoom*) on a phone screen based on (a) presence or absence

Fig. 2. Setup. Participants zoomed images on a smartphone resting on table; images were the size of a smartwatch screen. Finger height was sensed by a Leap Motion

of auditory feedback, and (b) variations in image content. We also qualitatively inspected how the PHI contributed to the experience and control of zooming. We explained the concept of PHIs to participants, and asked them to self-report any possible illusion and rate its strength.

We used a mixed-methods study (systematic variation of stimuli to elicit qualitative descriptions and subjective ratings), due to the difficulty in obtaining objective measures of illusion strength [12]. We hypothesized that with *EZ-Zoom*:

H1: A large majority of participants (75%) will self-report an illusion with at least moderate (3–6/10) strength averaged on all conditions of audio and graphic manipulation.
H2: Illusions felt will be stronger for the graphically 3D image (ball cartoon) than for the graphically flat image (photo).
H3: Illusions will be strengthened by auditory feedback.

We evaluated H1 with categories generated by qualitative methods on participants' descriptive responses, and H2-H3 with t-tests on subjective illusion-strength ratings.

Apparatus: Both study components were performed on a Samsung Galaxy S7 smartphone with a 14 cm × 7 cm display. Although we were primarily interested in smartwatch-sized screens, the smartphone avoided latency issues we found with smaller devices.

The Leap was mounted on a ring stand to track users' hands and fingers (Fig. 2), within the in-air interaction space directly above the device screen. Finger height above the display was sent to sockets using Leap.JS, to control image scale. To minimize latency, we avoided CSS transitions. Overall system latency was about 2 ms.

Study Design: We conducted a 2×2 $\{audio, no\ audio\} \times \{ball, photo\}$ within-subject evaluation with presentation order randomized, employing *EZ-Zoom* – *i.e.*, the scaling function was a linearized-log relation for all 4 conditions. Each condition appeared once per participant, for a total of 4 trials per participant session. *Ball* and *photo* images are shown in Fig. 3b; and *audio* was as described

Table 1. Procedure, and data collected. Participants repeated these steps for 4 trials.

1.	Zoomed and explored interaction freely for 40 s for current [*image*, *audio*] condition ***Data:*** *Practice not recorded*
2.	Performed a short semi-structured interview, where they were asked to suggest and describe any real-world metaphors that fit that zoom experience, while continuing to access the prototype. (To avoid confirmation bias [12], we did not offer choices) ***Data:*** *(1) Verbal descriptions of any metaphors (audio-recorded)*
3.	Rated the intensity of feeling for each of their self-reported metaphors on a paper survey ***Data:*** *(2) Intensity, on a scale of 0 (no effect) to 10 (very strong/believable effect)*
4.	Demonstrated where they estimated scaling would reset, with their finger in the space above the screen, and explained the cues they used. We logged this point's height (Leap data), relative to scaling function elbow where applicable ***Data:*** *(3) Height-of-reset estimate, and (4) verbal description of cues used (audio-recorded)*

above. Order of conditions were randomized across all participants; data collected are detailed in Table 1.

Sample Size: For this rich-data, mixed-methods exploration, we followed prior PHI studies (*e.g.*, [12]) with n = 12. Based on pilots, we anticipated saturation on psychometrics and an informative range on descriptive measures.

Procedure: Participants were introduced to the study, and familiarized with the concept of zed-zooming and to the Leap Motion Controller. They were instructed in how to avoid blocking its view of their finger during interaction, and to leave the smartphone on the table as they interacted. They then carried out four trials as described in Table 1. At the session's end, participants were thanked and compensated. Sessions took approximately 40 min, and were audio-recorded and transcribed.

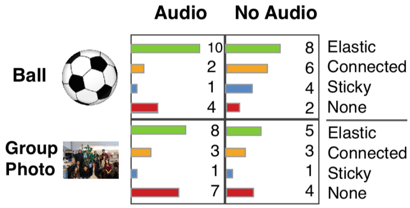
5 Evaluation Analysis and Results

We first detail our process for deriving categories of perceived illusions from participants' descriptions and ratings, and what we found; then share a more open-ended examination of how participants described their experience.

Participants: 12 participants aged 20–30 (five female) received $15 for a 1-h session. They were all right-handed with 2+ years of smartphone experience.

Elastic (74%): rubber, rubber band, hair tie, hair band, stretchy string, balloon, yoyo, chewing gum, spring, stretchy, bouncy, slimy, elastic, harder to move at the top then drop, stiffness, tension, tightness, spring, force, gravity
Connected (30%): yo-yo, rubber bandy string, stretchy string, connected, string, not separated, connected with bar/pole
Sticky (11%): chewing gum, glue, sticky

(a) Phrases used to describe percept, if felt. (%) is items in category, out of 31 unique terms.



(b) Participants reporting a phrase in a given illusion category, by condition (N=12).

Fig. 3. Phrases and illusion categories. Phrases could apply to multiple categories.

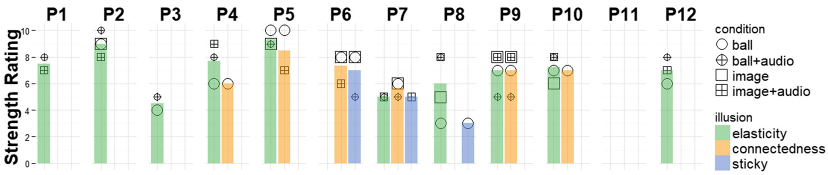


Fig. 4. Illusion strength [0–10] by category and participant. Participants were asked to explain any illusion categories felt, then rate each. Thus for each of P1–P12, this plot shows up to 4 data points (one per condition) for each illusion category. Bar height is the average of multiple values in that condition when present.

5.1 Analysis of Illusion Descriptions

We transcribed and qualitatively analyzed (by condition) participants' self-supplied rich metaphor descriptions and rankings of their strength.

Illusion Categories: We organized the physical sensations that participants described into categories by considering physical properties, metaphors, semantically related words, and sentence context. We identified key phrases in participant transcripts, organized them into clusters with affinity diagramming, and then analyzed cluster contents for its primary theme. We allowed a given phrase to appear in multiple categories: *e.g.*, "stretchy string" appears under both *Elastic* and *Connected*. Categories and word assignments were cross-checked and occasionally adjusted through discussion with two external individuals (haptics-knowledgeable lab members unaffiliated with the project). This process resulted in categories of *Elastic*, *Connected* and *Sticky*. The complete list of participant-supplied terms are shown in Fig. 3a.

Condition Ratings: We assigned participant's ratings for their self-supplied terms to these categories to produce an aggregate set of ratings for each condition and category. For example, if a participant mentioned "stretchy string" and rated the intensity of their experience of a "stretchy string" as 8/10, that rating would be aggregated in both *Connected* and *Elastic* categories for that condition (Fig. 3b).

Table 2. Hypothesis results.

H1: accepted. 11/12 (92%) participants felt at least one illusion with at least moderate strength, averaged over all conditions (Fig. 4). *Elasticity* dominated, manifesting for 10/12 (83%) participants who felt it with an average strength of 7/10 (moderate)
H2: marginally accepted. Image content (3D ball vs flat photo) impacted participants' strength ratings at the significance threshold ($p = 0.046$). We included H2 to verify a minimum level of PHI induction across graphical media. While we chose the images based on a dimensional effect observed in piloting, for realism and economy they also varied in shape and content type. An effect that works on a wide range of image types will be most valuable
H3: accepted. Audio cue presence improved participants' strength ratings ($p = 0.026$) despite being found annoying. Participant descriptions attribute this more to the "pop" than the "stretching" sound. H3's purpose was to identify elasticity PHI strengthening; we can confirm that audio can do this. This cue could be redesigned as more pleasant-sounding, and potentially more informative – *e.g.*, with more smooth audio scaling with finger height

When participants did not mention any term evoking a given category (*e.g.*, *Elastic*), we set their rating for that category to zero, inferring that this form of the illusion did not occur for them. These individuals might have used terms in other categories, implying capacity to feel *some* illusion; or, they might have reported no illusion at all.

As seen in Fig. 3b, *Elastic* was the dominant percept in all conditions. Specifically, *Elastic* was (a) felt by the majority of participants (7.8/12, averaged over all conditions); (b) the most prevalent illusion in every condition (*i.e.*, perceived by more participants than others) and (c) relatively insensitive to the multisensory conditions (auditory feedback, graphic geometry and content) that participants were exposed to.

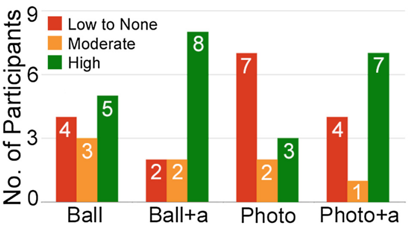


Fig. 5. Participants perceiving elasticity, by condition. Binned by strength ratings for self-supplied descriptions.

Figure 4 conveys individual variation in illusion perception in these three categories. For nearly half (5/12), *Elastic* predominates; for another 6/12, multiple categories are felt (in different conditions) with moderate to high strength. Only P11 reports no illusion.

We thus focused on the *Elastic* illusion. To consider illusion strength by condition, we binned participant ratings as *high* (ratings of 7–10, strong to completely believable); *moderate* (3–6, moderately believable); *low to no effect* (0–2, no or very slight illusion) (Fig. 5).

We analyzed quantitative ratings by (H1) illusion category and strength, and (H2–3) audio or visual condition. To test the effect of image content (H2), we grouped results by image content; for audio effect (H3), by presence/absence of audio feedback. For comparative H2–3, we conducted t-tests on strength ratings by condition at $p < 0.05$. Results are reported in Table 2.

5.2 How Participants Used the Elasticity PHI

Our participants' reports were rich in description of what they used the PHI for, what they liked or disliked about it, and the multisensory cues that induced it. Here, we organize the most salient and recurring of these observations into several themes.

Boundaries Were Evident, Useful and Reinforced by Audio Cues: Height-of-reset was clearly discernible. All 12 participants could correctly specify and describe where the image scaled more slowly: they noticed the elbow, unprompted, and never identified a non-elbow reset point – *"At some point, I don't want to go away any further"* (P12). Some statements specifically indicated reliance on graphical or auditory feedback elements to navigate the interaction space: *"I don't want it to burst so I'm moving more slowly"* (P4); *"The image gets bigger, and you can tell it might be close to exploding. Sound is getting louder"* (P3); *"When the sound gets louder there's more tension in the rubber band because it's about to fall"* (P12).

Multisensory Cues Helped to Crystallize a Physical Percept: Participant statements revealed how auditory and graphic cues sharpened a physical percept. P7 described what they were feeling: *"I can control the size of the picture really well...feels like a rubber band."* When asked how they estimated the spatial extent of the interaction space, 9/12 referred to the illusion: *"[Spring] gets tighter. It moves less as you move further away"* (P10); *"As you get further up it's more effortful"* (P8). Two others said they knew where the boundaries were out of "*intuition*" (P1, P9); but they could not say exactly why.

Auditory Cues Were Annoying. . . : In response to the query "What do you think about the audio?", 9/12 reported that they found it annoying, especially in steady use. Even so, 9/12 indicated value; *e.g.*, "*helpful for getting info about the change in status about whether string is attached*" (P9). Annoyance may have been tied to their perception of the PHI, making them feel more work was needed to pull the image up: "*The stretching sound was not too bad but made me feel like I had to put in more effort*" (P9).

And Perhaps Best as "Training Wheels": Two participants suggested the audio cue's value as an initial learning tool: "*[with audio] the illusion is stronger. But you may not want to listen to balloon popping for a long time. One cool thing is that once I listen to it once I felt the illusion stronger. Make a tutorial with the sound and then get rid of it and it would not be as annoying*" (P8; corroborated by P10).

6 Discussion

To reflect on our results, we consider the existence of and conditions that trigger a pseudohaptic illusion for zooming, and potential utility in the zed-zoom interaction.

The PHI is Real – and Elastic: Participants felt a pseudohaptic illusion – 11/12 with at least moderate strength. The dominant illusion was elasticity.

EZ-Zoom Preference Derives from Control at the Boundary: Participants reported finding control with *EZ-Zoom* at the interaction space boundary. Subjective impression of control *was* improved, based on participant comments and ratings, but further study is required to verify the practical utility of the higher precision relative to illusory effort.

Individuals Vary in Their PHI Perception: While 92% of participants perceived a PHI, they described it in varied ways, and at varying strength (Fig. 4). With further study, we could ascertain if a PHI that proves assistive could be learned.

Audio is Intrusive but Useful... Best in Small Doses: Despite low popularity, the audio feedback we used helped bound the interaction space, and enhanced a sense of control at its boundary. The feedback can be refined in subtlety and frequency. If auditory contributions to the illusion persist after it is disabled (because it has triggered a metaphoric cognitive framework for the interaction), intermittent audio might be adequate.

Limitations: Our Leap sensor simulation was generally effective in rapid experience prototyping, but its occasional glitches (lag, need for resets) could have interfered with PHI perception, most likely under-estimating its strength. In our study, individuals might have centered on one metaphor; some repeated their first stated metaphor in later conditions. Followup is needed to clarify if this was a carryover bias.

7 Conclusions and Future Work

Above-surface interactions lack physical interaction support. We have shown how a crafted pseudohaptic illusion can restore some physicality benefits with an example that can be induced without contact. EZ-Zoom facilitates an illusion of elasticity, which we theorize enhances proprioceptive position cues in the absence of contact. Participants' comments confirmed the illusion's presence, that it conveys information about the above-surface interaction space, and suggest that it enhanced their sense of control.

A damped region near the control range boundary may assist with fine control, but also might add to a perception of effort. We found that realistic auditory feedback on spatial height and breakthrough-point strengthened the illusion, and this facilitation may persist after the audio is disabled.

Applications: PHI has the potential to be beneficial for other above-surface applications. For example, on a small screen that shows multiple selection targets (such as application icons), a nonlinear relation between finger lateral position and speed might induce the illusion of a more *textured* surface. This might, for example, help a person using in-air gestures to navigate a menu of targets as though they are real bumps on a surface.

Panning above a small display is an important complement to zed-zooming. In on-surface panning, finger drag creates a frictional contact between media and finger and thus feedback. Above the surface this is lost; however, the finger no longer needs to maintain lateral correspondence with image movement. Relaxing this constraint allows us to simulate dynamics in the linkage, like elasticity. The speed with which the user "yanks" laterally on content could change pan rate.

For *non graphical wearables* like watch bands, PHIs could be triggered with auditory-proprioceptive coordination, *e.g.*, scaling audio feedback, assisted by an elasticity PHI induced by non-linear audio amplification. Or, an above-surface PHI might be induced with a *remote* graphical image – like zooming on the back of a smartphone to control visual display on a nearby wall.

Summary: We have demonstrated the possibility of integrating a pseudohaptic illusion into an above-surface interaction, and discovered potential benefits: a non-contact PHI can make a common micro-task (here, zed-zooming) more natural by adding an explicit element of imagined physicality, enhancing a user's sense of control. The proliferation of small screens together with emerging sensing technology mean above-surface interactions will soon be a reality. Pseudohaptic illusions may become as intrinsic to them as acceleration is to mouse and trackpad acceleration on graphical cursors.

Acknowledgments. This study was funded by Qualcomm and NSERC, carried out under UBC Ethics #H16-01549. We thank our UBC ECE collaborators Prof. John Madden and Mirza Saquib, and our many helpful colleagues in SPIN lab and the Designing for People research network.

References

1. Agarawala, A., Balakrishnan, R.: Keepin'it real: pushing the desktop metaphor with physics, piles and the pen. In: Proceedings of CHI, pp. 1283–1292. ACM (2006)
2. Chen, X.A., Schwarz, J., Harrison, C., Mankoff, J., Hudson, S.E.: Air+touch: interweaving touch & in-air gestures. In: Proceedings of UIST, pp. 519–525. ACM (2014)
3. Colgan, A.: How does the leap motion controller work? http://blog.leapmotion.com/. Accessed 24 Mar 2017
4. Ernst, M.O., Bulthoff, H.H.: Merging the senses into a robust percept. Trends Cogn. Sci. **8**(4), 162–169 (2004)
5. Goldstein, E.: Sensation and Perception, 5th edn. Wadsworth Publishing Company, Belmont (1999)
6. Han, J., Ahn, S., Lee, G.: Transture: continuing a touch gesture on a small screen into the air. In: CHI Extended Abstracts, pp. 1295–1300. ACM (2015)

7. Hayward, V.: A brief taxonomy of tactile illusions and demonstrations that can be done in a hardware store. Brain Res. Bull. **75**(6), 742–752 (2008)
8. Kratz, S., Rohs, M.: Hoverflow: exploring around-device interaction with IR distance sensors. In: MobileHCI, pp. 42:1–42:4. ACM (2009)
9. Kuchenbecker, K.J., Fiene, J., Niemeyer, G.: Improving contact realism through event-based haptic feedback. IEEE Trans. Vis. Comp. Graph. **12**(2), 219–230 (2006)
10. Leap Motion: Windows VR development (2017). https://developer.leapmotion.com/windows-vr. Accessed 28 Mar 2017
11. Lécuyer, A., Burkhardt, J.M., Coquillart, S., Coiffet, P.: Boundary of illusion: an experiment of sensory integration with a pseudo-haptic system. In: IEEE VR, pp. 115–122 (2001)
12. Lécuyer, A., Burkhardt, J.M., Etienne, L.: Feeling bumps and holes without a haptic interface: the perception of pseudo-haptic textures. In: Proceedings of CHI, pp. 239–246. ACM (2004)
13. Lee, J., Baek, S.: Elastic cursor and elastic edge: applying simulated resistance to interface elements for seamless edge-scroll. In: Adjunct Proceedings of UIST, pp. 63–64. ACM (2015)
14. MacLean, K.E., Schneider, O., Seifi, H.: The diverse tasks of haptic and multimodal design and how to support them. In: Handbook of Multimodal-Multisensor Interfaces, pp. 97–142. Morgan Claypool (2017)
15. Mandryk, R.L., Rodgers, M.E., Inkpen, K.M.: Sticky widgets: pseudo-haptic widget enhancements for multi-monitor displays. In: CHI Extended Abstracts, pp. 1621–1624. ACM (2005)
16. Marquardt, N., Jota, R., Greenberg, S., Jorge, J.A.: The continuous interaction space: interaction techniques unifying touch and gesture on and above a digital surface. In: Campos, P., Graham, N., Jorge, J., Nunes, N., Palanque, P., Winckler, M. (eds.) INTERACT 2011. LNCS, vol. 6948, pp. 461–476. Springer, Heidelberg (2011). https://doi.org/10.1007/978-3-642-23765-2_32
17. Mine, M.R., Brooks Jr., F.P., Sequin, C.H.: Moving objects in space: exploiting proprioception in virtual-environment interaction. In: SIGGRAPH, pp. 19–26. ACM (1997)
18. Nancel, M., Wagner, J., Pietriga, E., Chapuis, O., Mackay, W.: Mid-air pan-and-zoom on wall-sized displays. In: Proceedings of CHI, pp. 177–186. ACM (2011)
19. Pusch, A., Lécuyer, A.: Pseudo-haptics: from the theoretical foundations to practical system design guidelines. In: International Conference on Multimodal Interfaces, pp. 57–64. ACM (2011)
20. Sarwar, M.S., Dobashi, Y., Preston, C., et al.: Bend, stretch, and touch: locating a finger on an actively deformed transparent sensor array. Sci. Adv. **3**(3), e1602200 (2017)
21. Sridhar, S., Markussen, A., et al.: Watchsense: on-and above-skin input sensing through a wearable depth sensor. In: Proceedings of CHI, pp. 3891–3902. ACM (2017)
22. Srinivasan, M.A., Beauregard, G.L., Brock, D.: The impact of visual information on the haptic perception of stiffness in virtual environments. In: Haptic Symposium, vol. DSC:58, pp. 555–559. ASME (1996)
23. Wu, W.C., Basdogan, C., Srinivasan, M.A.: Visual, haptic and bimodal perception of size and stiffness in virtual environments. In: Haptic Symposium, vol. DSC:67, pp. 19–26. ASME (1999)

Pseudohaptic Feedback for Teleoperated Gripping Interactions

Sarah Anna Wojcik[1], Carsten Neupert[1,2], Johannes Bilz[3], Roland Werthschützky[1], Mario Kupnik[1], and Christian Hatzfeld[1](✉)

[1] Measurement and Sensor Technology, Technische Universität Darmstadt, Merckstraße 25, 64283 Darmstadt, Germany
hatzfeld@must.tu-darmstadt.de

[2] ITK Engineering GmbH, Im Speyerer Tal 6, 76761 Rülzheim, Germany

[3] Microtechnology and Electromechanical Systems, Technische Universität Darmstadt, Merckstraße 25, 64283 Darmstadt, Germany

Abstract. We present a proof-of-concept for pseudohaptic feedback in gripping interactions. This paper includes a review about known applications of pseudohaptic feedback in virtual reality and teleoperation as well as the results of an identification experiment in a gripping task. In this experiment, 16 subjects identified five stimuli with different compliances. Independent factors were the visual condition (side or top view of the gripper) and the compliance of the human-machine-interface (stiff or compliant). A mean information transfer of 1.09 ± 0.25 bit (mean and standard deviation) in 60 trials was achieved by the participants. However, a large and significant habituation effect was found. It leads to an increased information transfer of 1.47 ± 0.29 bit in the last 15 trials of the experiment. The visual condition exhibits a small effect with a mean difference of 0.14 bit for all trials, no effect was found for the compliance of the HMI.

Keywords: Pseudohaptic feedback · Gripping interaction Compliant interfaces

1 Introduction

Pseudohaptic feedback is a well-known haptic phenomenon, where visual feedback is used to generate different haptic impressions with human-machine-interfaces (HMI) without an actuator. First introduced by Lécuyer in [11], isometric interfaces, i.e. stiff interfaces without perceivable compliance [25], are used in a pseudohaptic setup. Interaction forces of the user are determined as input measures. The reaction of the proxy, i.e. the movement on the screen or of the end-effector in a teleoperation system, depends on these input measures and the interaction of the proxy with the (virtual or real) environment. This reaction is conveyed to the user via a visual channel. Since visual impressions are

D. Prattichizzo et al. (Eds.): EuroHaptics 2018, LNCS 10893, pp. 309–320, 2018.
https://doi.org/10.1007/978-3-319-93445-7_27

valued more reliable than haptic impression [1], more or less force is imposed on the interface to achieve the intended outcome. The different amounts of applied force are interpreted as different force reactions by the user.

The large advantage of pseudo-haptic feedback is the generation of haptic feedback without actuators. This is cost-efficient and improves stability of haptic systems, since no closed-loop control is used that includes the user. The user's control loop is closed via the virtual feedback and therefore intrinsically stable.

This paper investigates using pseudohaptic feedback for the display of gripping forces. The work is motivated by a minimally invasive robotic surgical system designed by the authors (Fig. 1, [9]), incorporating five intra-corporal degrees of freedom (DoF) for Cartesian motion, rotation, and gripping of the end-effector. Haptic feedback is conveyed by a Delta mechanism with constrained kinematics, matching the parallel kinematic capabilities of the slave robot. For this system, pseudohaptic feedback for the gripping degree of freedom does not only minimize stability issues, but increases the fidelity of the overall haptic feedback due to a lower moving mass.

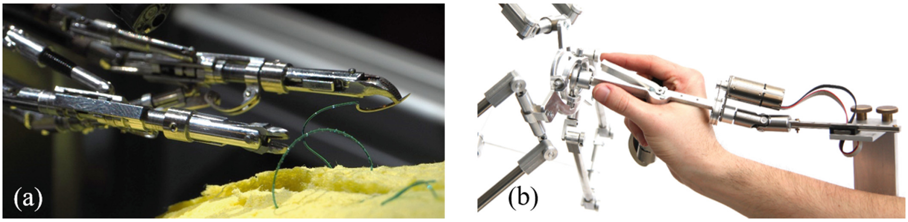


Fig. 1. FLEXMIN System [9]. (a) Slave robot with two endeffectors (five DoF each), (b) user interface for a single endeffector.

In this paper, we describe the capabilities of pseudohaptic feedback in virtual environments (VE) as well as our own previous work about pseudohaptic feedback in teleoperation systems. In Sect. 2, we describe the experiment performed for this work and discuss the results. The paper concludes with possible next steps to integrate pseudohaptic feedback for gripping interactions in teleoperation.

1.1 Pseudohaptic Feedback in Virtual Environments

Pseudohaptic feedback is used to display a variety of haptically perceivable properties. In general, the intensity of pseudohaptic feedback is controlled by the so-called control/display relation (C/D) [11], linking the real interaction of the user with the HMI C and the reaction on the visual channel D. Changing the C/D relation will yield different haptic impressions.

Lécuyer et al. investigate the alteration of cursor velocity in order to display different amounts of friction with isometric and isotonic interfaces (interfaces with a perceivable compliance) [11]. Further works include the perception of compliances with an isometric device [13]. For base compliances of 1.8 mm/N to 4 mm/N, Weber fractions of 6.15% were determined, which comply with direct interaction values (8% according to [22]). Dominjon et al. [7] as well as Yamamoto et al. [23] show the possibility of displaying different masses in independent experiments. By altering the virtual behavior of a mass, a pseudohaptic impression that is different from the actual manipulated mass, can be achieved. Pusch et al. as well as Lécuyer show that pseudohaptic feedback can alter the perceived amount of hand movements [11,13,17]. Real movements of 5 mm are interpreted as movements of up to 40 mm (mean interpretation 27 mm). Further work by the group of Lécuyer uses pseudohaptic techniques to display different surface properties such as texture [12] and curvature [3]. Curvature is also discussed in [6]. Hachisu et al. present an approach to intensify the pseudohaptic feedback by adding tactile information [8]. Further applications include training applications for technical processes [21], and medical simulation [2].

Argelaguet et al. find increased realism of pseudohaptic feedback depending on the physical work of the user [4]. Pseudohaptically rendered compliances are perceived as more realistic, when a small amount of movement is allowed by the human-machine-interface. The amount of movement is not as relevant as the general requirement to perform a movement – and therefore work – when interacting with the HMI. The same effect is reported for pseudohaptic rendering of torque [16] and serves as an inspiration for this work.

The works of Lécuyer [13,18] give a broad overview of the capabilities of pseudohaptic feedback in virtual environments. The authors of this paper extended the pseudohaptic approach to teleoperation tasks (see next section). In this work, we focus on gripping interactions with pseudohaptic strategies, since to our knowledge this has not be addressed before.

1.2 Pseudohaptic Feedback in Teleoperation

In two previous studies, we proved pseudohaptic feedback to be feasible for feedback in a single DoF in a compliance discrimination task (Fig. 2). A mean channel capacity of 0.72 bit for pseudohaptic feedback and 1.48 bit for direct interaction with a spring beam in an experiment with a theoretical maximum capacity of 1.58 bit was determined [14].

In a second experiment, reported in [15], effects of several parameters (maximum displacement of the spring beam, offset force, scaling factor, alteration mode of Control/Display-ratio) on the channel capacity were investigated. The channel capacity for an experiment with six different, logarithmically distributed compliances ranging from 0.4 mm/N to 13 mm/N was determined to be in the range of 0.68 bit to 1.72 bit (theoretical maximum of 2.6 bit). The altering mode of the C/D-Ratio had a significant, large effect on the channel capacity. Furthermore, the maximum displacement of the spring beam had a significant effect on the results, because of the spatial resolution of the visual channel. Other parameters such as offset forces did not show a significant effect. Learning effects were identified for training over several days with a channel capacity increase of up to

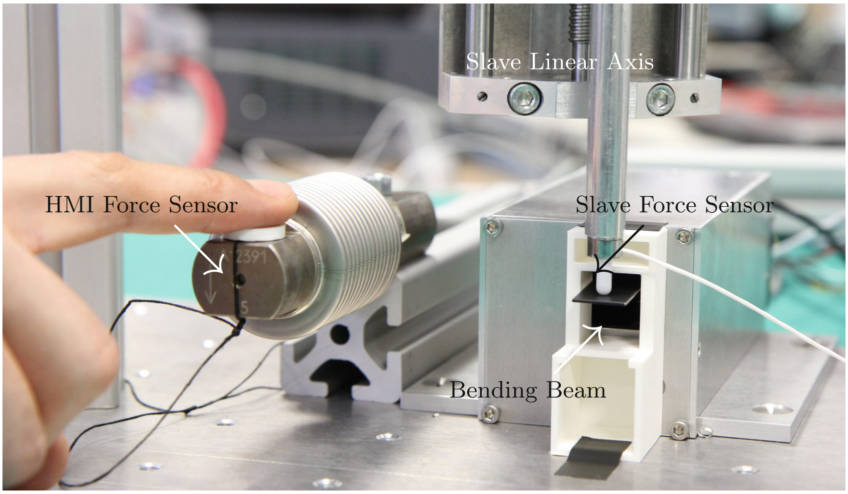


Fig. 2. Experimental setup employed in [14,15]. The HMI consists of a force sensor (model Z6FD1, Hottinger Baldwin Messtechnik, Darmstadt, DE), the slave is build from a linear axis and a force sensor (model KM10z, ME-Messsysteme, Hennigsdorf, DE). The slave acts on a bending beam, which compliance is altered by adjusting the free length of the spring beam by a stepper motor.

0.8 bit, but not necessarily for several training sets on the same day. The results of this previous work form the basis of the experimental design of this paper.

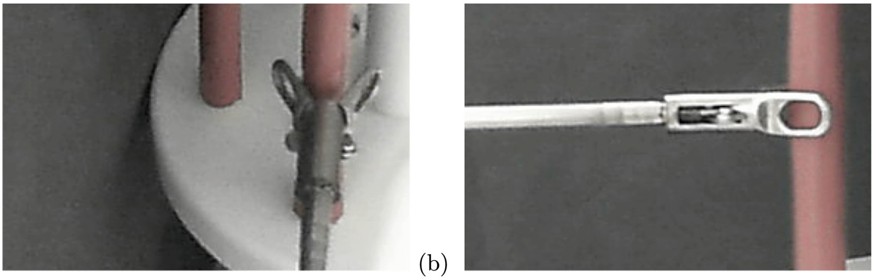
2 Methods

This section describes the experimental design, the setup and the subjects taking part in the experiment.

2.1 Experimental Design

Goal of this study is the evaluation of pseudohaptic feedback for gripping interactions in general as well as the effect of actual physical movement of the HMI on the channel capacity of a pseudohaptic gripping task. Putting mechanical energy into the HMI showed beneficial effects in pseudohaptic setups in previous studies [4,16] as well as a more accurate perception of stimulus intensity in rotatory controls [19,20]. Therefore, an investigation for pseudohaptic setups promises further improvement of channel capacity. The experiment is conducted with two different human-machine-interfaces one enabling a physical movement against a defined compliance, the other one as a stiff interface. These are further described in Sect. 2.2.

In addition to the effect of a physical movement of the HMI, we also investigated the effect of the visual angle on the gripping tool by using two visual conditions with side and top view of the gripper (Fig. 3). The latter provides a good view on the closing angle of the tool, while side view only provides movement information via the visual channel. No other alterations of the visual channel were employed in the experiment. Table 1 sums up the experimental conditions.



(a) (b)

Fig. 3. Magnified screenshot of visual conditions. (a) Top view, (b) side view. Red tubes exhibit an outer diameter of 6 mm. (Color figure online)

Table 1. 2×2 full factorial design for the conducted experiment

Factor / Level	I	II	Remarks
Visual condition	Top view	Side view	See Fig. 3
HMI	Stiff	Compliant	See Fig. 7

Considered output measures are the Information Transfer (IT) [10] as a measure for the channel capacity and the reaction time of the subjects.

The Information Transfer metric is calculated from identification experiments and allows for unconditional comparison of information transferring channels. In contrast, a measure such as the percentage of correctly identified stimuli depends on the number of stimuli and is prone to possible confusion of labels by the participant. IT can be estimated by

$$IT_{\text{est}} = \sum_{j=1}^{K} \sum_{i=1}^{K} \frac{n_{ij}}{n} \log_2 \left(\frac{n_{ij} \cdot n}{n_i \cdot n_j} \right) \text{bit}, \quad (1)$$

with K as the number of stimuli; n as the total number of trials; $n_{i,j}$ as number of occurrences and n_i and n_j as row- and column sums of the confusion matrix indicating the subject's response category for each stimulus category, in this case the compliance of the sample.

We also recorded the time from the start of stimulus exploration until the input of a stimulus identification by the subjects. This is intended to deliver a measure for task difficulty [24], i.e. we expect longer exploration times for experimental conditions that are perceived as more complicated by the subject.

2.2 Experimental Setup

The experimental setup consists of an electromechanical gripper, two human-machine-interfaces, and a rotating setup for changing stimuli. The setup is controlled by via a LabVIEW program (National Instruments, Austin, TX, USA). Figure 5 provides an overview of relevant signals and components of the setup. A micro controller (Arduino Uno R3) calculates the set position of the gripper based on the user force F_U and the gripping force F_G to control the manipulator. Based on the results in [15], a division scheme is used to alter the control/display-ratio according to

$$x_\mathrm{e} = \begin{cases} \frac{a(F_\mathrm{U} - F_\mathrm{U,offset})}{1\,\mathrm{N} + b \cdot F_\mathrm{G}} & \Big| \; x_\mathrm{e} \leq x_\mathrm{e,max} \\ x_\mathrm{e,max} & \Big| \; x_\mathrm{e} > x_\mathrm{e,max} \end{cases}, \tag{2}$$

with x_e as set position for the gripper and $F_\mathrm{U,offset}$ as force threshold that has to be overcome to use the gripper. The variables $a = 0.5$ and $b = 0.1$ are dimensionless scaling factors to adjust the different parameters with values determined in preliminary experiments. Figure 4 gives an example of a control/display-ratio alteration.

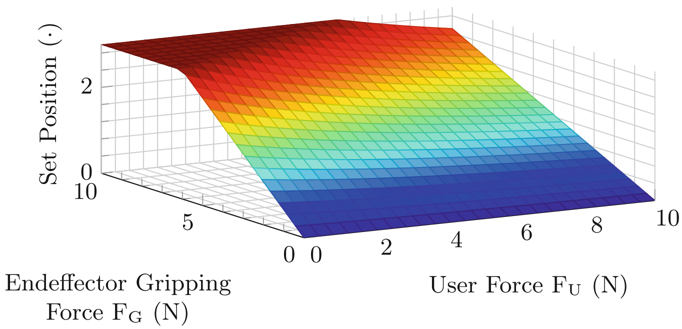


Fig. 4. Gripper set position x_e depending on different values of user force F_U and gripping force F_G based on Eq. (2). Set position is limited to $x_\mathrm{e,max} = 3$ and no offset force is considered in this example.

The output position is coded as a pulse-width modulated signal (PWM) and fed to the motion controller. The motion controller controls the gripper branches' position as described below. The force sensor reading from the gripper sensor is fed back to the micro controller and the position is adjusted according to the measured force.

The **electromechanical gripper** is based on a commercial, laparoscopic instrument that opens and closes the gripper with a toggle lever actuated with a translational motion. Using a push rod and a screw gear, a DC-motor (model

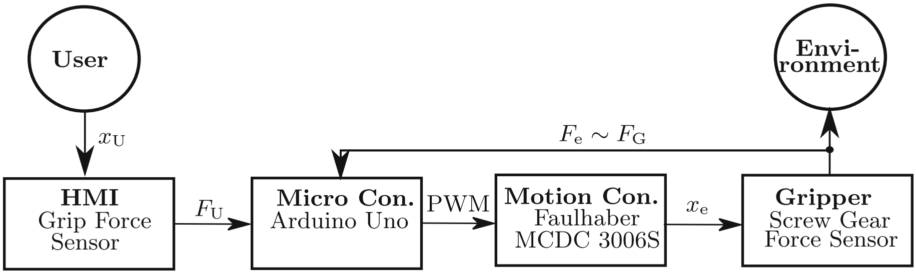


Fig. 5. Block diagram of relevant signals and components of the pseudohaptic gripper. Serial connections are used to connect micro and motion controllers to the control computer.

1741U012CXR with encoder model IE2-1024, both Faulhaber, Schönaich, DE) opens and closes the gripper driven by a motion controller (model MC3006S, Faulhaber). A force sensor (model KM10z, ME Messsysteme, Henningsdorf, DE) measures the force F_e acting in the push rod. The force between the gripper jaws F_G is calculated from F_e based on the kinematic properties of the toggle lever (Fig. 6).

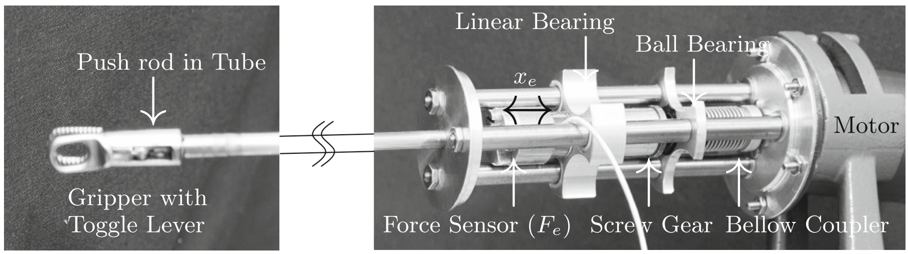


Fig. 6. Electromechanical gripper used as end effector in the experiment. The gripper is actuated by a toggle lever attached to a push bar. The push rod is actuated translational by the motor with attached screw gear. Axial force is measured via a force sensor to enable the calculation of the gripping force at the end effector. All mechanical parts are beared in such a way, that no parasitic forces get induced to the force sensor.

The **human-machine-interfaces** used in this study were manufactured from PLA material using a 3D-printer (model Ultimaker 2+, Ultimaker B.V., Geldermalsen, NL, Fig. 7). The design is derived from typically used grips in laparoscopic instruments. Two variants are manufactured, one stiff and the other with a mechanical compliance of 0.43 mm/N and a maximum deflection of 11 mm. The force exerted by the user F_U is measured by force sensors (model FlexiForce A201, Tekscan Inc., South Boston, MA, USA) in both interfaces.

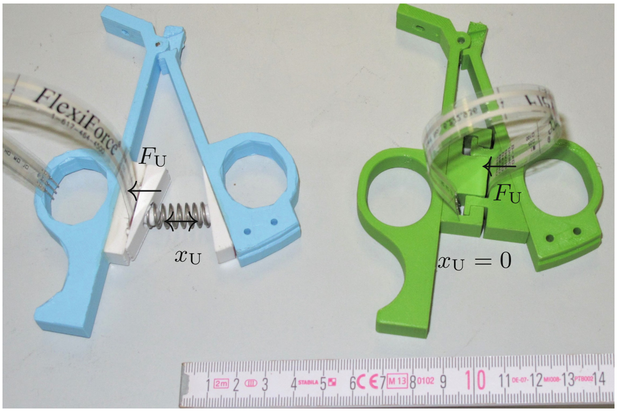


Fig. 7. Compliant (left) and stiff (right) Human-Machine-Interfaces. Scale in cm.

2.3 Subjects and Stimuli

16 subjects (25.4 ± 2.3 years, 15 m/1f, all but two right-handed) took part in the experiment. They gave prior informed consent and were monetarily compensated for their participation. Subjects were seated in front of a computer screen and the experimental setup (Fig. 8). For each of the four experimental conditions (HMI × visual condition), the subjects were requested to test the five different stimuli employed in the experiment without time restrictions. Stimuli consist of silicon rubber and PVC tubes with 6 mm outer diameter and different wall thickness (1 mm and 1.5 mm), thus exhibiting different compliances. Stimuli were covered with adhesive tape to ensure a uniform visual appearance and mounted on a 3D-printed mount that was moved out of sight for change of stimuli.

After learning the different stimuli, subjects performed 60 trials identifying randomly presented stimuli for each condition. Subjects were instructed to decide quickly and trust their intuition. After every 20 trials, a short brake was automatically enforced by the setup. In addition, subjects could take a break whenever they wanted. The entire experiment lasted approximately 1 h for each participant.

3 Results and Discussion

We analyzed the obtained information transfer values with respect to the treatment factors (HMI type and visual condition). Furthermore, we looked at four blocks with different numbers of trials in order to assess habituation and learning effects. The overall recorded 60 trials were analyzed as first block, the other blocks included the last 45, 30 and 15 trials of the experimental run. In each block, the same number of each stimulus was presented to the subjects.

The results (Fig. 9) exhibit a strong tendency for increasing IT in the course of the experiment. A repeated-measures analysis of variance (ANOVA) was conducted with GNU R (version 3.4.3) with the IT values calculated according to

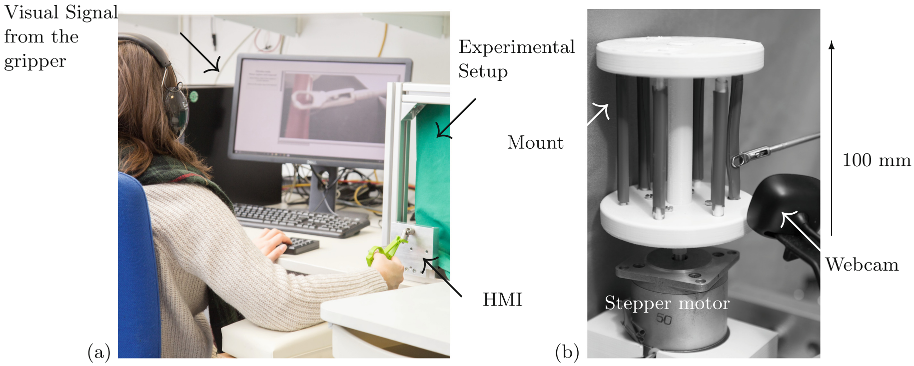


Fig. 8. Experimental setup. (a) The subject uses the HMI with the dominant hand to test the stimulus and enters the recognized stimuli (coded with a number) via a keypad. The monitor shows the interaction from the gripper and the current stimuli. (b) Stimuli in 3D-printed mount controlled by a second Arduino Uno micro controller.

Eq. (1) as dependent variable and visual condition, HMI type, and trial block as independent variables. The analysis yielded a significant effect of the visual condition ($F_{(1,15)} = 9.68$, $p = 0.007$, $\eta^2_G = 0.08$) with a small effect size (η^2_G according to [5]). The analyzed trial block also had a significant, large effect ($F_{(1.46,21.8)} = 114$, $p < 0.001$, $\eta^2_G = 0.23$, after Greenhouse-Geisser correction for sphericity). Post-hoc tests show significant differences between the IT values obtained from the last 15 trails and all other conditions, and for the values from the last 30 trails compared to the last 15 as well as the values from all trials. There were no significant influences of factor interactions.

The analysis of the information transfer shows a strong **habituation effect**, that was also observed in other pseudohaptic feedback experiments. For five stimuli, the maximum attainable IT is 2.32 bit, corresponding to perfect identification of all stimuli. In this experiment, this maximum was achieved by a single participant in the last block of 15 trials. In this block, the mean IT value is 1.47 bit, corresponding to almost 2.8 identifiable stimuli. This value is in line with the current state of the art, which normally finds two or three reliable identifiable stimuli for each signal parameter (ISO 9241-910)[1].

Next to the habituation, the **visual condition** has a significant impact on the amount of information transfer. This also holds for the later trial blocks, therefore we conclude that learning will primarily take place in the haptic sensory system, not in the visual.

Although we could not find a significant effect of the **HMI type**, the results provide helpful insights for the design of haptic systems. If the compliance of the interface is not affecting the performance of pseudohaptic feedback, less expensive force sensing elements can be used, for example photo-electric sensors that

[1] With exemption of frequency - in this case, up to seven different stimuli are discernible.

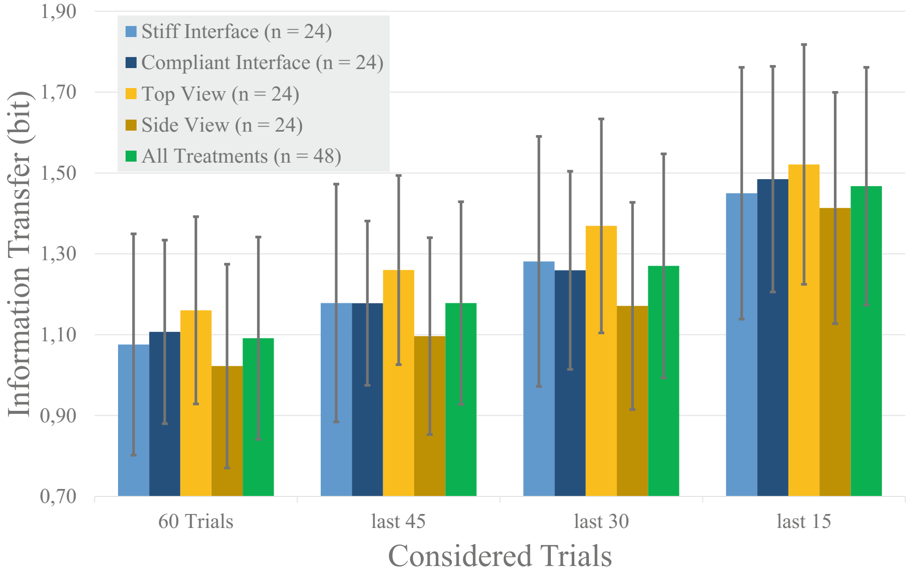


Fig. 9. Information transfer (mean and standard deviation) for different treatments and trial blocks.

measure the deflection of the interface against a known compliance. However, the compliant HMI used in this study exhibits a fairly high stiffness. The effect of more compliant systems should be investigated with regard to previous studies as described above.

Participants took 4.7 s ± 1.4 s (mean and standard deviation) to input an answer. No effects of trial block or stimulus could be found in another repeated-measures ANOVA for that output measure. Although there is a difference in performance (i.e. different channel capacities for certain factor level combinations as described above), the lack of an effect on the exploration time indicates no increase in the perceived task complexity.

4 Conclusion and Further Work

In this paper, we presented a proof-of-concept for pseudohaptic feedback in a teleoperated gripping task. According to this study, the visual representation should be selected in such a way, that the closing angle of the gripper can be closely monitored for best performance. In contrast to several other references, we cannot find an effect of slightly compliant user interfaces on the performance.

In the future, we will investigate the effect of more compliant user interfaces as well as conduct experiments with a more close resemblance of typical tasks from minimally invasive surgery. Furthermore, the force measurement of the gripper from this experiment is affected by friction of the push rod in the surrounding tube. Although offset forces did not have an effect on performance in our previous studies, the effect of a variable gripper force due to friction has to be investigated for a successful use of pseudohaptics in gripping tasks.

Acknowledgements. The work was supported by the German Research Foundation under grant no. WE 2308/13-2. We also thank Dr. Fritz Faulhaber GmbH for supplying motors and motor controllers and Martin Schilling for conducting the experiments.

References

1. Aldridge, R.J., Carr, K., England, R., Meech, J.F., Solomonides, T.: Getting a grasp on virtual reality. In: Human Factors in Computing Systems, pp. 229–230. ACM (1996)
2. Ammi, M., Ladjal, H., Ferreira, A.: Evaluation of 3D pseudo-haptic rendering using vision for cell micromanipulation. In: 2006 IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 2115–2120 (2006)
3. Argelaguet, F., Jáuregui, D., Marchal, M., Lécuyer, A.: A novel approach for pseudo-haptic textures based on curvature information. In: International Conference on Human Haptic Sensing and Touch Enabled Computer Applications, pp. 1–12 (2012)
4. Argelaguet, F., Sato, T., Duval, T., Kitamura, Y., Lécuyer, A.: Collaborative pseudo-haptics: two-user stiffness discrimination based on visual feedback. In: Auvray, M., Duriez, C. (eds.) EUROHAPTICS 2014. LNCS, vol. 8619, pp. 49–54. Springer, Heidelberg (2014). https://doi.org/10.1007/978-3-662-44196-1_7
5. Bakeman, R.: Recommended effect size statistics for repeated measures designs. Behav. Res. Methods **37**(3), 379–384 (2005)
6. Ban, Y., et al.: Modifying an identified curved surface shape using pseudo-haptic effect. In: Haptics Symposium (HAPTICS), pp. 211–216. IEEE (2012)
7. Dominjon, L., et al.: Influence of control/display ratio on the perception of mass of manipulated objects in virtual environments. In: Virtual Reality, pp. 19–25. IEEE (2005)
8. Hachisu, T., et al.: Pseudo-haptic feedback augmented with visual and tactile vibrations. In: 2011 IEEE International Symposium on VR Innovation (ISVRI), pp. 327–328 (2011)
9. Hatzfeld, C., et al.: A teleoperated platform for transanal single-port surgery: ergonomics and workspace aspects. In: WorldHaptics Conference (WHC), pp. 1–6. IEEE (2017)
10. Jones, L.A., Tan, H.Z.: Application of psychophysical techniques to haptic research. IEEE Trans. Haptics **6**(3), 268–284 (2013)
11. Lécuyer, A., et al.: Pseudo-haptic feedback: can isometric input devices simulate force feedback? In: Virtual Reality, pp. 83–90. IEEE (2000)
12. Lécuyer, A., Burkhardt, J.M., Etienne, L.: Feeling bumps and holes without a haptic interface: the perception of pseudo-haptic textures. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 239–246. ACM (2004)
13. Lécuyer, A.: Simulating haptic feedback using vision: a survey of research and applications of pseudo-haptic feedback. Presence Teleoperators Virtual Environ. **18**(1), 39–53 (2009)
14. Neupert, C., et al.: Investigation of the usability of pseudo-haptic feedback in teleoperation. In: WorldHaptics Conference (WHC), pp. 488–493. IEEE (2015)

15. Neupert, C., et al.: Pseudo-haptic feedback in teleoperation. IEEE Trans. Haptics **9**(3), 397–408 (2016)
16. Paljic, A., Burkhardtt, J.M., Coquillart, S.: Evaluation of pseudo-haptic feedback for simulating torque: a comparison between isometric and elastic input devices. In: Haptics Symposium (HAPTICS), pp. 216–223. IEEE (2004)
17. Pusch, A., Martin, O., Coquillart, S.: HEMP–hand-displacement-based pseudo-haptics: a study of a force field application and a behavioural analysis. Int. J. Hum.-Comput. Stud. **67**(3), 256–268 (2009)
18. Pusch, A., Lécuyer, A.: Pseudo-haptics: from the theoretical foundations to practical system design guidelines. In: Proceedings of the 13th International Conference on Multimodal Interfaces, pp. 57–64. ACM (2011)
19. Reisinger, J., Wild, J., Mauter, G., Bubb, H.: Haptical feeling of rotary switches. In: Proceedings of the Eurohaptics Conference (2006)
20. Tan, H.Z., et al.: Manual detection of spatial and temporal torque variation through a rotary switch. IEEE Trans. Haptics **1**(2), 96–107 (2008)
21. Tatezono, M., et al.: Effect of haptic feedback on pseudo-haptic feedback for arm display. In: ICCAS-SICE, pp. 4332–4337. IEEE (2009)
22. Tan, H.Z., Pang, X.D., Durlach, N.I.: Manual resolution of length, force, and compliance. Adv. Robot. **42**, 13–18 (1992)
23. Yamamoto, Y., Nakakoji, K.: Designing pseudo-haptic feedback mechanisms for communicating weight in decision making tasks. In: AAAI Spring Symposium: Shikakeology (2013)
24. Yokota, Y., Igarashi, Y., Okada, M., Naruse, Y.: Estimation of the reaction times in tasks of varying difficulty from the phase coherence of the auditory steady-state response using the least absolute shrinkage and selection operator analysis. In: 2015 IEEE Engineering in Medicine and Biology Society Conference (EMBC) (2015)
25. Zhai, S.: Investigation of feel for 6DOF inputs: isometric and elastic rate control for manipulation in 3D environments. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting, vol. 37, no. 4, pp. 323–327. SAGE (1993)