Stylo and Handifact: Modulating Haptic Perception through Visualizations for Posture Training in Augmented Reality

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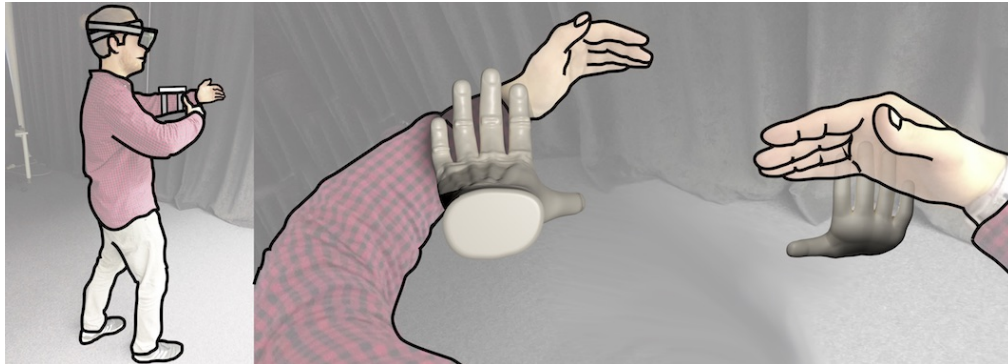
Figure 1: Illustration of Stylo/Handifact in an interactive t'ai Chi training system. The visualization in the right image shows two virtual hands displayed on an augmented reality head-mounted display that indicate motion corrections to the practitioner: the left *Handifact* is pushing the practitioner's arm away from the torso, whereas the right *Handifact* is pushing the arm (from the opposite side) closer to the torso.

ABSTRACT

Stylo-Handifact is a novel spatial user interface consisting of a haptic device (i. e., *Stylo*) attached to the forearm and a visualization of a virtual hand (i. e., *Handifact*), which in combination provide visuo-haptic feedback for posture training applications.

In this paper we evaluate the mutual effects of Handifact and Stylo on visuo-haptic sensations in a psychophysical experiment. The results show that a visual stimulus can modulate the perceived strength of a haptic stimulus by more than 5%. A wrist docking task indicates that Stylo-Handifact results in improved task completion time as compared to a state-of-the-art technique.

CCS CONCEPTS

• **Human-centered computing** → **Graphical user interfaces**; **Haptic devices**; • **Hardware** → Haptic devices;

KEYWORDS

Visual, Haptic, Integration, Multisensory, Sensory, Perception, Posture Training, Wearable, Interface

1 INTRODUCTION

A number of physical activities from the leisure, sport or rehabilitation domain like yoga, t'ai Chi, dance, training or martial arts, depend on carefully controlled posture or motion. Such activities pose challenges for practitioners who often find it difficult to maintain specific postures or execute precisely controlled movements. Typically, such activities are practiced under the supervision of a coach, who corrects the practitioner. However, limited availability of one-to-one coaching is, among other factors, motivation to

support these activities using interactive systems that provide corrective [31] feedback to help practitioners improve their skills.

Our study focuses on a class of interactive systems in which practitioners wear a see-through augmented reality (AR) head-mounted display (HMD). Their posture is analyzed by a motion capture system and suggestions in the form of visuo-haptic feedback are displayed so that the practitioner moves mistaken limbs to the correct position (Figure 1 - right).

In an attempt to improve performance in such tasks we created *Stylo*, a haptic device that mounts on the forearm and anchors on the ulnar styloid process. Stylo is combined with a 3D model of a hand, which we call Handifact*. We evaluate the combination of Stylo and Handifact in two controlled experiments with the goal of answering the following research questions:

- *Is it possible to induce believable visuo-haptic illusions using a see-through HMD combined with a haptic device?*
- *Does the combination of Stylo and Handifact offer tangible performance benefits in a posture correction task?*

2 RELATED WORK

2.1 Visual Feedback in Motor Skill Learning Systems

A number of systems have explored learning movements based on VR avatars [5, 12]. For example, Chan et al. [5] developed a system for learning dance. In their system, learners received three kinds of visual feedback: Score reports, slow-motion replays, and real-time highlighting of the mistaken limb with a high-contrast color. Their feedback type reports that the limb is wrong, but users must still observe a coach avatar to understand how exactly they must correct their movements. Observing a coach avatar on a remote display might make it difficult to understand fine posture errors which is the reason we focus on ego-centric systems in this work.

A number of dance and training games for the Microsoft Kinect offer visual feedback [4, 11, 16, 38]. Feedback in these games is often limited to highlighting or outlining incorrectly positioned limbs, or giving users simple verbal feedback on how well their motions matched the targeted ones with messages such as *good, great, perfect!* etc. However, it is challenging and time consuming to provide precise spatial feedback based on verbal instructions only [5]. Hence, more precise and easy to comprehend feedback methods are required.

Anderson et al. presented YouMove, a system which uses an augmented mirror to give participants feedback about their posture [1]. Although this augmented mirror paradigm is appropriate for identifying mistaken limbs, inferring the direction users need to move in order to correct the posture involves mental rotations, which imposes high cognitive load. Viewpoint-aligned motions pose further challenges (which is why the authors use call-outs that show the scene from a different viewpoint).

These shortcomings further motivate ego-centric systems; One-Body [13] is a system that relies on an Oculus Rift HMD. Though this approach is promising for correcting posture, their method of visualizing corrections (by overlaying a "coach" limb) might not

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*The name *Handifact* is a neologism based on *hand* and *artifact*. As opposed to marking a novel contribution, the name *Handifact* is used in this context to distinguish the virtual hand from the hands of the user.

work so well for viewpoint aligned posture mismatches (especially small deviations, for which it might be challenging to judge the offset of two cylinders in the Z axis).

2.2 Haptic Systems in Motor Skill Learning

Lopes et al. presented a number of works based on Electro-muscular stimulation [20–22]. Electro-muscular stimulation is an approach that can also be used for posture training nevertheless attaching electrodes involves a certain amount of overhead, or discomfort, which might be unsuitable for casual or frequent use.

As illustrated by Spelmezan et al. [33], vibrotactile instructions can be a good alternative to assist in correcting the wrong posture during physical activities, achieving high recognition accuracy and quicker user response than instructions presented over the audio channel. In another approach, Salvado et al. [29] augmented the human arm with a wearable sleeve containing bending sensors and multiple actuators, and corrected arm postures by using different vibrotactile patterns in order to guide athletes or patients arm movements during remote rehabilitation. The flex sensors used in that approach, however, cannot support the necessary accuracy for high-performance posture training.

Luo et al. [23] presented a Yoga training system based on a motion replication technique to correct the user's wrong posture by providing tactile warnings using tactors attached all over the human body. As discussed later in the design of our device, tactors offer high localization accuracies and as such are unsuitable for visuo-haptic integration as required by our proposed system. Finally, van der Linden et al. [39] also proposed a real-time training system to support the teaching of good posture and bowing technique to novice violin players, using a vibrotactile device located on the forearm. Both of these approaches do not explore visuo-haptic integration, and it remains unclear how well these devices would integrate with visual stimuli.

2.3 Modulating Haptic Perception using Visual Stimuli

Crossmodal correspondences are automatic associations between different basic sensory stimulus properties, dimensions, or features. For instance, people often show a systematic tendency to associate moving objects with pitch changes, or to match a large visual displacement with haptic force [34]. People have also been shown to map visual color characteristics to intensity of haptic stimuli [32].

To our knowledge, no study has yet explored how visual depictions of contact affect the perceived intensity of passively received touch sensations.

A few past studies, however, have addressed similar questions. Early seminal work by Lecuyer et al. has shown that manipulating the gain of a mouse pointer can induce a haptic sensation on an isometric desktop device [18, 19]. More recently, Punpongsanon et al. have used a projector to manipulate the haptic sensation of a deformable surface [27]. They projected a pattern that was warped to varying degrees when the participant made contact with the surface. When greater warping was depicted, participants reported the object as being "softer". Although their study was successful in manipulating the perceived hardness of objects, they did not
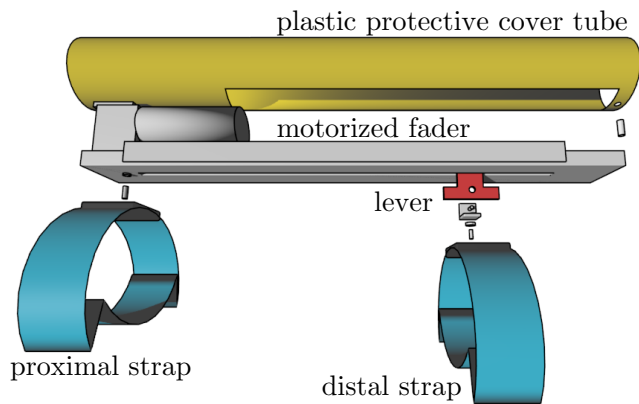
Figure 2: Breakdown of the parts of Stylo. The proximal strap was attached on the fader body while the distal strap (wrist) was attached to the moving component of the fader.

explore how the reverse situation, in which an external object (or agent) makes contact with the participant, is perceived.

The famous "rubber hand illusion" demonstrates how the superior reliability of vision over proprioceptive cues is exploited to give observers the feeling that a fake hand is in fact their own [3]. In this paradigm, a rubber hand is placed above an observer's actual occluded hand; when the occluded hand and the visible fake hand are stimulated in the same manner, the observer assigns body ownership over the fake hand, thus perceiving it to be their real hand. The question remains if visual illusions can induce haptic sensations even when the real hand is not occluded. This is addressed in our work.

3 STYLO-HANDIFACT

Before we explain the reasoning for the design of Stylo-Handifact some terminology must be established: *Sensory cues* are stimuli that activate the different senses e. g. audition, vision, somatosensation, olfaction etc. *Sensory cue integration* refers to whether or not the brain will "integrate" multiple cues. i. e., whether these cues will be judged to originate from the same source, and thus whether the sensory attributes of each cue will be estimated together (cue integration) or independently (cue segregation).

The most widely accepted model of sensory cue integration [8, 9], assumes that when integrating cues, the brain weighs the reliability of each individual cue in order to optimally estimate stimulus attributes. For example, a ventriloquist is producing speech without moving his or her lips. The puppet's mouth is moving. Because the visual system is more reliable at spatial localization than the auditory system, vision dominates the estimate of sound source location. The two sensory cues are integrated and viewers believe the puppet is talking.

3.1 Stylo

Stylo was designed with this model of cue reliability in mind. The design goal of stylo was to produce a haptic sensation that is not

simply weak in amplitude, but also qualitatively different and ambiguous, in order to allow the visuals to supersede it and modulate it. At the heart of Stylo lies a motorized fader (ALPS RSAON11M9). This fader is housed in a plastic tube for protection (Figure 2).

There are a number of designs that can produce weak haptic feedback like eccentric rotating mass (ERM) vibration, linear resonant actuators (LRA), electrocutaneous, pressure cuffs, etc. and all have to be mounted on the volar forearm. Our design, conversely, allows for the body of the device to be rotated to the back of the forearm so as to not obstruct the visuals. The fader lever "pulls" the straps from behind but the haptic stimulus is felt across the volar forearm. We opted for a combination of skin stretch and force because ERM and LRA haptic devices have been shown to result in very good localization near anatomical landmarks [6] and perfect pattern recognition when mounted in 2D arrays [25], which is counter to our goal of achieving ambiguous haptic stimuli. Furthermore, skin stretch has been shown to augment the perception of kinesthetic forces [26, 28].

To further increase ambiguity, Stylo attempts to make use of the *Cutaneous Rabbit Effect* [2, 37]. The cutaneous rabbit effect refers to the sensation that a haptic stimulus can be "floating" between two sources depending on the onset timing and distance of the stimuli. In Stylo, there are two straps: A distal strap, on the wrist, anchored on the styloid process and mounted on the lever of the fader and a proximal strap that attaches further towards the elbow, connected to the back end of Stylo. Our pilot tests showed that oscillating the lever forward (pushing against the styloid process) followed by immediately backwards, produces a type of haptic feedback that is uniquely ambiguous. The lever pushes the distal strap against the styloid process and the body of the device carries the force from the distal strap on to the proximal strap. The short time offset with which the two straps are actuated, means that the *cutaneous rabbit effect* could be occuring between the two straps [37], further enhancing ambiguity (Figure 3).
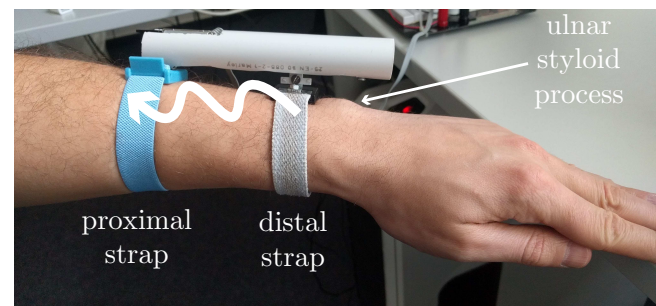
Figure 3: Stylo attached to the forearm. Wave-like arrow shows propagation of the haptic sensation.

It should be noted that this is *one of many* designs that can produce ambiguous haptic forces. A group of tactors or other haptic actuators arranged in a Braille-like array could induce similar effects, including the cutaneous rabbit effect. Nevertheless this design was chosen due to its light weight, low cost, off-the-shelf availability and simple reproducibility.

The fader alone can provide forces between 10g (≈0.1N) to approximately 100g (≈1N). When mounted in the device, the lowest

distinguishable range it can produce is in the region of 30-54g which was used in the experiments. Stylo responds to control signals in real-time, without any delay.

3.2 Handifact

Handifact refers to a rigged and textured model of the human hand. Handifact is animated using an inverse kinematics algorithm [35] to show a pushing pose. The idea behind Handifact was that rather than abstract visualizations, a hand visualization as a virtual "coach" would be immediately understood by participants. Furthermore, although traditional visualization artifacts for motion (like arrows etc.) are good at communicating motions in axes perpendicular to the viewpoint, they would not be as easy to judge in movements aligned with the viewpoint. Conversely, a hand pushing towards a viewpoint aligned axis will be straightforward to judge and the magnitude could be inferred by the skin folds or the geometry of the fingers.

Handifact complements Stylo. Rather than designing a complicated multi directional force feedback device, that can additionally communicate direction, this interface communicates force with Stylo and delegates direction to Handifact, a form of *Multisensory Delegation.*

Figure 4: Setup during the haptic discrimination task.

4 HAPTIC DISCRIMINATION EXPERIMENT

In a posture training application the amount of force exerted communicates the magnitude of translation necessary to correct the posture. A light tap by the coach means the error is small, whereas a strong push means the movement required to correct the posture is greater. As such, the ideal system is one that will be able to render a wide range of forces. An active haptic device like Stylo, however, has limits in the amplitude of forces it can exert. It is important, therefore, to understand whether Handifact can modulate the haptic force perceived so that the range of perceived forces can be increased.

The goal of the haptic discrimination task was, therefore, to explore whether

- Handifact is capable of modulating haptic perception. Specifically, we tested whether pairing a haptic stimulus with Handifact animations, depicting varying levels of contact intensity, was capable of changing the perceived strength of the haptic stimulus.
- participants will feel that the Handifact is perceived as being congruent with the haptic stimulus from Stylo.

4.1 Apparatus

Participants sat comfortably in a chair with their head supported by a chin-rest (Figure 4). Their non-dominant arm was stretched out with the palm flat on the table in front of them. Stylo was mounted on the non-dominant arm, with the distal strap immediately adjacent to the styloid process (Figure 3); the proximal strap was roughly 9 cm from the distal strap. A piece of cloth was draped over the device to occlude its view in order to avoid visual cues from the movement of the lever. Participants additionally wore the Microsoft Hololens see-through HMD, and looked at their left arm to keep the Handifact in view. Their dominant arm was free to move in order to respond with a key press. Participants wore a pair of headphones playing white noise to mask the sound of Stylo's motor.

4.2 Haptic Discrimination Task

12 participants (3 female and 9 male, aged 18-35 years; mean age 26.4 years) were recruited from the student and staff population. They completed a haptic strength discrimination task, with a two-alternative forced-choice design (2AFC), which is a standard method used in Psychophysics [10].

The task consisted of identifying *which of two haptic stimuli was stronger*:

- a reference tap (with constant intensity of 42g)
- or a comparison tap (of varying intensity: 30, 34, 38, 42, 46, 50, or 54g).

The order of presentation was randomized and the participant had to indicate which of the taps was perceived as stronger, the first or second, by pressing one of 2 keys on the keyboard with their right hand. Each of the 7 possible comparison tap strengths was tested 20 times. This was done for 3 different levels of Handifact animations (light, medium, strong - Figure 6), and one baseline condition without rendering Handifact.

When displayed with the *reference* haptic stimulus, Handifact was projected directly adjacent to the distal wrist strap, and always displayed the "medium strength" animation.

When displayed with the *comparison* haptic stimulus, Handifact alternated between three intensity animations (light, medium or strong - Figure 6). The three poses used were selected in a pilot test in which participants were asked to push an object using light medium and strong force. The strong, anatomically incorrect, rightmost pose was exaggerated because we assumed this level of finger bend would "trigger" the participant's perception of excessive force. In the "none" condition, neither reference nor comparison stimuli were accompanied by Handifact; these trials served as a baseline measurement for participants' ability to discriminate haptic intensity without visual cues.

Figure 5: Participant's view during the haptic discrimination task (cloth cover removed for better visibility). Left: Idle Handifact before touching. Middle: Medium Handifact touching. Right: Medium Handifact touching in the Offset condition.

Figure 6: The three pressure levels used during the haptic discrimination task: Light, Medium and Strong. White point indicates the contact point. When that point "touched" the participants's forearm the haptic stimulus was triggered.

With the comparison stimulus, Handifact was either projected in the same location as in the reference stimulus (no offset condition - Figure 5 - middle) or offset by 9 cm[†] from the distal strap towards the elbow (Figure 5 - Right). This offset condition was introduced to determine if multi-sensory integration will break down as distance from the source of the haptic stimulus increases.

In total, each participant completed 980 trials:

- When Handifact was not shown (*none* condition), there were 7 haptic strengths x 20 trials = 140 trials
- with Handifact shown, there were 2 handifact locations (offset and no offset) x 3 handifact strengths (strong, medium, and light) x 7 haptic strengths x 20 trials = 840 trials.

140 no handifact trials and 840 handifact trials results in 980 total trials.

The experiment lasted roughly 60 minutes; participants were allowed to take breaks at any time, but were encouraged to take a break every 330 trials. All experiments were run with prior, informed and written consent. A short questionnaire was administered following the experiment to determine the participants's age and to ask the participants to rate how realistic the stimuli were.

4.3 Data Analysis

For each level of intensity of the comparison stimulus (30, 34, 38, 42, 46, 50, and 54g), which was compared to the reference 20 times, we calculated the *proportion of trials in which the participants reported the c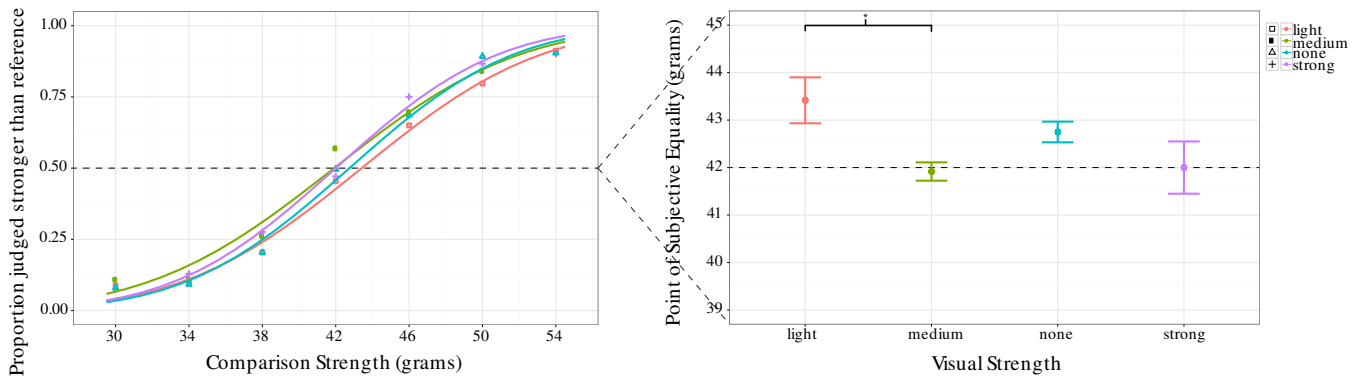omparison stimulus was perceived stronger than the reference stimulus* (Y axis in figure 7-left and figure 8-left). We were specifically interested in estimating the strength of the comparison haptic stimulus that would result in 50% comparison-stronger judgements. That is the strength of the comparison stimulus that is indistinguishable from the reference stimulus (point of subjective equality, PSE). We predicted that, if the "light" or "strong" Handifact animations are successful in modulating the perceived intensity of stimuli, we should see a shift in the PSE from the "medium" visual strength condition. For example, if the "light" animation causes the haptic comparison stimulus to be perceived as weaker, it would then have to be made stronger (up-regulated) to be perceived as equal in strength to the haptic reference stimulus (this amounts to an increase in the PSE).

In order to estimate the PSE, for each visual stimulus condition and for each participant, we fit the proportion of trials in which the comparison stimulus was judged as stronger across different comparison strengths with a cumulative normal distribution function (figure 7-8 - left). Fitting such behavioural data with a cumulative normal distribution function (or some other sigmoidal function) is a common method in psychophysics to characterize individual psychometric curves [40]. The cumulative distribution function is characterized by a μ and σ parameter; the μ parameter is equivalent to the PSE (the midpoint), and the σ parameter is a measure of how quickly the proportion of trials comparison was judged as stronger rises as the comparison strength increases (comparable to the slope). During the fitting procedure, the μ and σ parameters could take on values of 1-100 g, in 1 g steps; we found the parameter combination that resulted in the minimum root-mean-square-error (RMSE) between predicted and measured values as the best-fit parameters.

We hypothesized that the PSE depends on the visual stimulus with which we pair the comparison haptic tap. To test this hypothesis, we used a repeated measures ANOVA with the animation strength as the repeated measures factor and the best-fit μ (PSE) values of each participant as the dependent variable; we did this first for the no offset condition, then once more for the offset condition. We then ran dependent sample post-hoc pairwise T-tests to further explore differences between the levels of visual strength.

4.4 Results

As expected in discrimination tasks, increasing the haptic strength of the comparison stimulus resulted in a greater proportion of

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[†]9cm was selected as the first integer value after having cleared the proximal strap (i. e., just outside the device)

Figure 7: Mean performance data with best-fit curves for the no offset condition (left): the more leftward-shifted the curve, the more intense the comparison was overall judged to be. The mean best-fit PSEs for each visual condition in the no-offset condition (right): the haptic comparison strength required to feel like the reference of 42g (dotted line). The haptic stimulus, paired with the "light" intensity animation, had to be made significantly stronger to feel equal to the reference
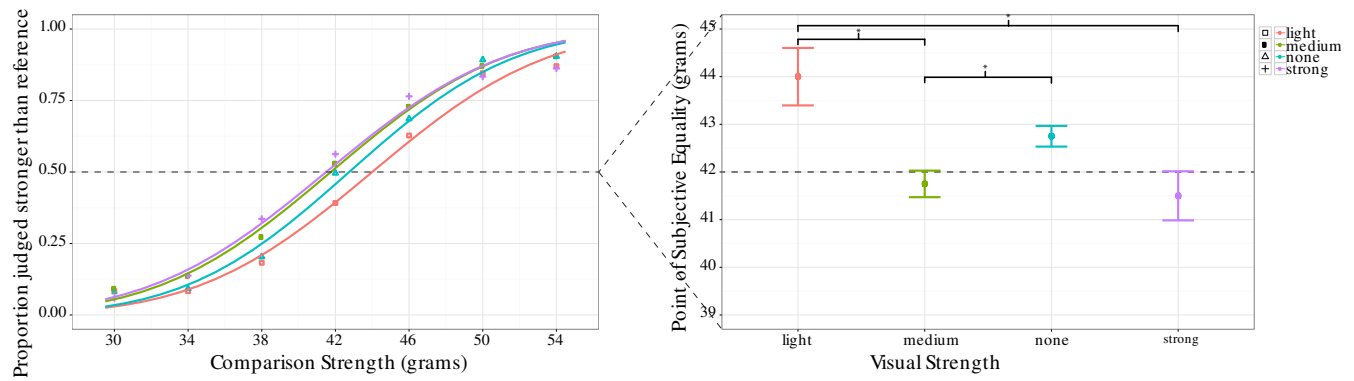
Figure 8: Mean performance data with best-fit curves for offset condition (left):the more leftward-shifted the curve, the more intense the comparison was overall judged to be . The mean best-fit thresholds for each visual condition in the offset condition (right): the haptic comparison strength required to feel like the reference of 42g (dotted line). The haptic stimulus, paired with the "light" intensity animation, had to be made significantly stronger to feel equal to the reference.

trials in which it was judged to be stronger than the reference. This relationship was well fit by a cumulative normal function (the average RMSE was 0.076 with a standard error of 0.002) as seen in figure 7-8 - left. Seeing that the data were well fit by a cumulative normal function, we then tested how the parameter of interest, μ or PSE changed with different Handifact animation strengths.

For the no-offset condition, the one-way ANOVA demonstrated a significant effect of visual strength on the PSEs ($F_{3, 33} = 3.012$, $p = 0.044$). For the offset condition, the one-way ANOVA also showed a highly significant effect of visual strength on the PSEs ($F_{3, 33} = 7.204$, $p < 0.01$). To further explore how the visual strengths affect the PSEs, for the offset and no offset conditions, posthoc pairwise T-tests were carried out.

For the offset condition, PSEs for the light visual stimulus condition were significantly higher than for each of the other visual stimulus conditions (Benjamini-Hocherg adjusted p-values): for light vs medium, $p = 0.012$, for light vs strong, $p = 0.024$ (Figure 8 - right). The PSEs were also significantly different between medium

and none visual conditions ($p = 0.012$, Benjamini-Hochberg adjusted), with PSEs in the medium condition being lower than in the none condition (Figure 8).

For the no offset condition, there was only a significant difference between the PSEs of the light and medium conditions ($p = 0.041$, Benjamini-Hocherg adjusted p-value) (Figure 7 - right).

In summary, we found that the haptic stimulus was perceived to be approximately 3.6% weaker when paired with the "light" Handifact animation in contrast to when it was paired with the "medium" Handifact animation. When Handifact was projected further from the haptic source (offset condition), the haptic stimulus felt approximately 5.4% weaker when paired with the "light" Handifact animation than when paired with the "medium" Handifact animation. Lastly, the offset "medium" Handifact animation was successful in making the haptic stimulus feel 2.3% stronger than without the Handifact.

Furthermore, the post-experiment questionnaire revealed that all participants judged the combination of visual and haptic stimuli to

be congruous (seemingly arising from the same event): 83.3% of participants judged them to be convincing, while 16.7% of participants judged them to be *very* convincing. This occured both through the questionnaire responses, but also during the post-experiment interviews, where participants revealed that Stylo and Handifact felt congruent. "I felt like the virtual hand was touching me".

4.5 Discussion

In this study we demonstrate, through the use of Handifact, that a visualization of a virtual human hand making contact with an observer's arm can affect the perceived intensity of a real haptic stimulus on that arm. We tested participants in a haptic intensity discrimination task in the presence of Handifact. We used 3 different animations of Handifact making contact with the arm, each with varying degrees of apparent intensity: light, medium and strong. In addition to the different animations, we tested the effect of projecting the animation to a site that is offset (more proximal) from the reference stimulation. We found that the light touch animation was effective in altering the perception of the intensity of the real haptic stimulus, such that a resulting touch was perceived as weaker. This effect was further enhanced when Handifact was projected to a location slightly offset from the reference tap location.

In the offset condition there was a statistical significance between the "none" comparison condition and the reference stimulus (Figure 8 - right). This means that because the reference trials were numerous, they most likely led to the recalibration of participants' sensory system. i.e. The 42g+medium Handifact became the baseline, so then when Handifact was not present, in the "none" condition, 42g felt weaker than 42g with medium handifact.

We postulate that the "light" animation was more succesful in manipulating haptic stimuli because of the angle from which it was seen by participants (Figure 5). The differences between light and medium were more easy to distinguish than medium and strong. Since medium was most likely recalibrating the baseline, there was very little modulation by the strong animation. Adding more "intensity" cues to Handifact would most likely help alleviate this effect.

An explanation for why the offset condition produced stronger multisensory effects could be due to differences in spatial resolution along the volar forearm. It has been found that localization resolution is better near anatomical landmarks (i.e the wrist) and worsens towards the center of the volar forearm [7][6]. During the offset condition, the visual stimulus was presented closer to the proximal strap, and since haptic localization is less reliable around the proximal strap, visuohaptic integration should be more effective here. As mentioned earlier, sensory stimuli with lower reliability are more influenced by stimuli with higher reliability [9].

In addition, it has been postulated that multisensory integration, especially visuohaptic integration, is more effective in the region immediately surrounding, or on, the body (the peripersonal space) than more distal locations [17]. This is an intuitive expectation as many of our physical interactions with objects occur in the peripersonal space, whereas sights and sounds from far away are less likely to be accompanied by haptic stimulation.

It should be noted that this is the first instance of such sensory manipulation reported in the literature. Although earlier works

have manipulated the perception of stiffness [27], there are no reports in the literature of manipulating the strength of a haptic stimulus with a paired visual stimulus on the volar forearm. Additionally in most visuo-haptic illusions the participant's arm is hidden from view [3], or the source of the haptic stimulus is hidden [14]. In this work, despite the source of the haptic stimulus being known to the participants and the device firing in their field of view, the illusion still worked. We postulate this integration occurs because of priors. Participants have prior experience of hands touching them whereas they have no experience of such a haptic device exerting forces on them. Such contextual priors have been shown to strongly influence perception [30].
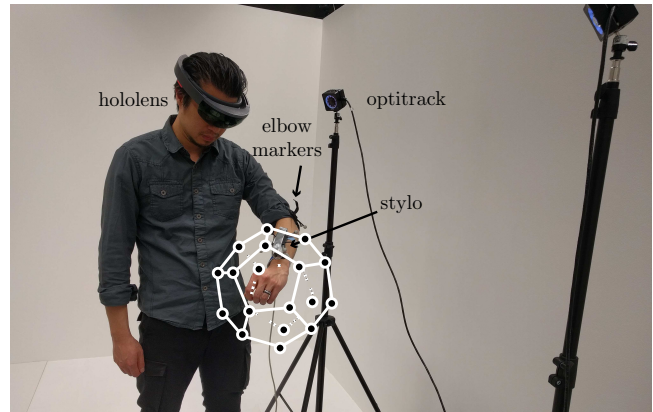

Figure 9: Setup during the docking experiment. Black dots represent the target locations.

5 DOCKING STUDY

The results of the previous exeriments have shown that Stylo-Handifact is perceived as realistic visuo-haptic feedback by participants. In this study, we wanted to determine whether such a device-visualization pair can offer tangible benefits in a posture matching task. We ran a forearm docking study to simulate a posture correction situation. We expect the findings from a forearm docking task to extend to other body parts.

As a baseline for comparison we implemented OneBody by Hoang et al. [13]. OneBody is an egocentric posture training system in which the practitioner sees a cylindrical skeleton superimposed on his or her limbs. Alongside the practitioner's skeleton, the translucent skeleton of a coach is rendered and the participant can then judge whether the posture is correct based on the colour of the limbs. A limb in the correct position is coloured green, whereas a limb in an incorrect position is coloured red (Figure 10). We extended OneBody to assess the effect of Stylo, Handifact and the combination of both, i. e., Stylo-Handifact.

In the following sections and diagrams OneBody is referred to as **OB**. The following four conditions were tested:

- OneBody: We implemented OneBody exactly like Hoang et al. i. e., Limbs turned green when the joints came within 5cm of their respective counterparts.
- OB+Stylo: Same as vanilla OneBody but with a haptic "nudge" when the trial begins.
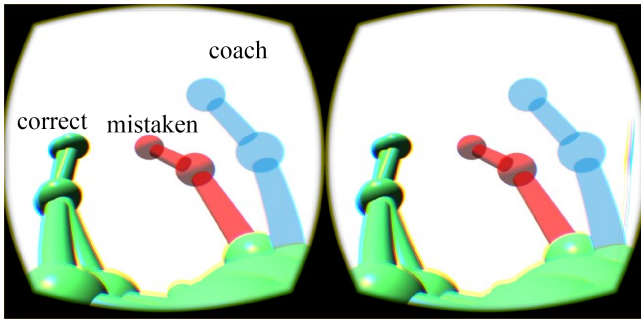
Figure 10: OneBody: Coach limbs in blue, correct limb in green, mistaken limb in red (used with permission[13]).
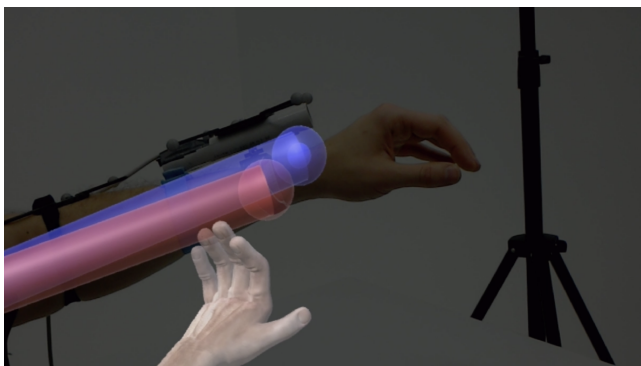

Figure 11: Docking Experiment Screenshot (OBHandiStylo condition). Handifact is pushing the participant's forearm (red) to dock with the virtual coach (blue).

- OB+Handifact: Same as vanilla Onebody but with Handifact pushing (medium intensity) the forearm towards the correct position. At the 5cm threshold, Handifact would relax its push and the fingers would guide the user for the final 5cm of the docking (see Video).
- OBHandiStylo: This technique combined all the above techniques. Handifact pushing in addition to Stylo nudging.

14 participants from a different pool than the first experiment (5 female, 9 male, ages 25-34) took part in the study. In the Stylo conditions, Stylo was attached on the forearm of their non-dominant arm.

The task was to dock the forearm to a location indicated by the forearm of the OneBody "coach" using all four techniques in randomized order. Participants began the task by placing their forearm in front of their abdomen in a comfortable position. That was going to be the forearm "home" position for the rest of the task. After this position was recorded by the system, the task began and targets appeared. As soon as the forearm entered a threshold of one centimeter from the target position the trial was deemed successful, time was logged and participants were shown the home position indicated by a blue sphere to return to, before proceeding with the next trial. Returning to the home position reset the trial timer (not shown to participants) and displayed the next target.
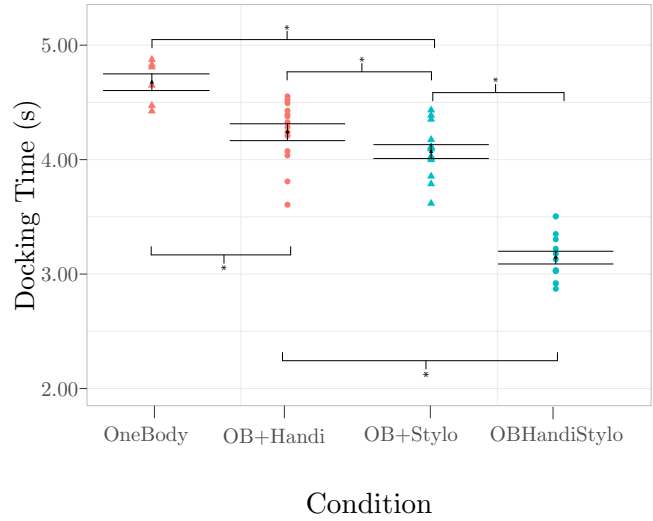

Figure 12: Results of the docking experiment with std. Error. Time (s) on Y axis (lower is better).

Participants tested 20 target positions (vertices of a dodecahedron centered at the home position). Target distances were 10cm. This was found in pilot tests with a professional Karate coach, as an average error wrist offset in Karate postures for beginners. Each participant ran 2 stylo conditions (present or not) x 2 handifact conditions (present or not) x 20 positions for a total of 80 docking trials with the experiment lasting approximately 35 minutes.

5.1 Results

We analyzed the effect of stylo and handifact on the docking time using a within subjects 2x2 analysis of variance. Dependent variables were Stylo (present or not) and Handifact (present or not). Analysis found a highly significant effect of Stylo on docking time ($F_{1,13} = 54.3$, $p < 0.01$ $eta^2 = 0.73$) and of Handifact on docking time ($F_{1,13} = 87.12$, $p < 0.01$ $eta^2 = 0.64$). Post-Hoc analysis using pairwise T-tests revealed statistical significance between *all* techniques (Figure 12): OneBody vs OneBody+Handifact ($p < 0.01$), OneBody vs OneBody+Stylo ($p < 0.037$), OneBody vs OBHandiStylo ($p < 0.01$), OB+Handifact vs OB+Stylo ($p < 0.024$), OB+Handifact vs OBHandiStylo ($p < 0.01$). Mean docking times can be seen in Table 1.

It is noteworthy that the combination of Handifact and Stylo (OB-HandiStylo) resulted in slightly better docking time improvement (2.04 sec) over vanilla OneBody than the sum of Stylo or Handifact alone (1.91 sec).

5.2 Discussion

In line with our expectations extending OneBody using Stylo and Handifact resulted in time decreases across all conditions. The performance improvement from the OB+Stylo condition most likely came from the increased reaction time, in line with the findings by Spelmezan et al. [33]. Surprisingly, the improvement in performance with OBHandiStylo as compared to the sum of the individual parts suggests that a visuo-haptic synergy is taking place [24].

Table 1: Mean docking times per technique.

Technique	OneBody	OneBody+Stylo	OneBody+Handifact	OBHandiStylo
Mean (sec)	5.02	4.19	3.94	2.98
Standard Deviation	0.40	0.36	0.38	0.27
Improvement over OneBody (sec)	-	0.83	1.08	**2.04***

Due to the limited field of view of the Hololens participants needed to constantly move their head/neck in order to locate targets. As a result in post-experiment interviews the majority of participants commented that Hololens was rather uncomfortable. The limited field of view of the hololens must be taken into account when interpreting these results. When using a HMD with a wider field of view like a video-see-through device[36] the results might be different. Participants additionally noted that due to the limited field of view (FOV) of the Hololens, having handifact present pushing their forearm gave an immediate clue as to how the posture needs to be corrected, as opposed to the vanilla OneBody technique where users needed to pan around the FOV to find the coach limbs.

A limitation of our implementation is that when handifact was pushing from the far side of the forearm, towards the user, it was occluded by the OneBody cylinders but not by the participant's arm/hand. Achieving this could arguably further improve user experience because occlusion is an important monocular depth cue [15].

Unlike the haptic discrimination experiment, in the docking study, participants did not wear headphones and could therefore hear the motor inside Stylo firing. Despite the sound levels produced by the motor being very low, one could, if attentive enough, associate the sound of the motor with the intensity of the haptic feedback which could, theoretically, lead to the illusion breaking down. We did not observe such a pattern in our participants. Care should be taken when designing future iterations of such haptic devices so that noise levels be kept to a minimum.

6 LIMITATIONS - FUTURE WORK

In the haptic discrimination task, the "strong", exaggerated level of Handifact animation when seen from the side (Figure 6) is clearly distinguishable. However, when seen from a 3/4 angle as the participants saw it during the experiment, the difference between the medium and heavy animation was not so salient. We postulate that carefully tuning these animations could lead to stronger modulation effects, as mentioned in the discussion section of the haptic discrimination experiment.

Another limitation of this study is that although the forces produced by Stylo were measured when the device was not worn, the real applied forces when wearing the device might not completely match and measuring these forces is less than trivial.

The reference stimulus, against which the comparison was judged, was not only constant in true haptic intensity, but also consistently paired with Handifact's medium intensity animation. Future studies should explore the use of different intensity animations for the reference stimulus as well as different tap strengths for the reference stimulus. The effect of projection location relative to haptic stimulation should also be more systematically studied in the future; specifically, the range of spatial disparities between visual and haptic cues that result in multisensory effects should be identified. We have shown here that an overall offset of 9 cm between haptic and visual stimulation on the forearm is capable to produce appreciable multisensory effects; however,we postulate that eventually multisensory integration would break down given a large enough disparity between cues. Understanding the conditions in which multisensory integration is enhanced or diminished is crucial in developing immersive augmented and virtual reality applications involving multiple senses.

7 CONCLUSION

We presented Stylo and Handifact. A haptic device - visualization pair for posture training applications. Despite the main focus of this work being posture training, we believe that Stylo/Handifact can be used in other applications such as learning musical instruments, sports (golf, billiards, racket sports, archery) and other activities that rely on correct posture.

We contributed a rigorous analysis of how Handifact modulates the haptic sensations from Stylo and demonstrated that participants felt Handifact and Stylo to be congruent and realistic despite knowing that it is an illusion. A light-looking animation tricked participants into perceiving a smaller haptic sensation. This is the first time an on-body haptic perception has been modulated using visualizations on a see-through HMD. This has implications on the design of future wearable devices and allows for light-weight, low-energy designs.

In a posture docking task the Stylo/Handifact pair improved performance of a state of the art technique and showed more improvement than the sum of its components. These findings can be used by designers of posture training applications for enhancing performance.

Future studies of form factors and visualizations will identify the specific attributes that lead to more effective visuo-haptic modulation and more congruent integrations.

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