Asymmetry of Grasp in Haptic Perception

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ABSTRACT

In this paper we present evidence that human perception of grasp might be most dependent on the information retrieved during the inward latch rather than the release of objects. This research is motivated by a number of haptic simulations and devices and grounded in perception science. We ran a user study (n=12) with two devices one capable of delivering compliant simulations for both grip and release (CLAW), i.e. symmetric device; the other only capable of delivering adaptive grip simulations (CapstanCrunch), i.e. asymmetric device. We fund that both performed similarly well for realism scores in a grasping task with objects of different stiffness. That similar performance was despite CapstanCrunch release was delivered by a constant spring independently of the compliance of the object. Our results show preliminary evidence that when simulating haptic grasp the release might be less important. And we propose a new theory of asymmetry of grasp in haptic perception.

CCS CONCEPTS

• **Human Computer Interaction**; • **Haptics**; • **Virtual Reality**;

KEYWORDS

HCI, Virtual Reality, haptics, perception

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1 INTRODUCTION

The ability to render haptic sensations in Virtual Reality (VR) is far lagging behind the current state of graphics and audio rendering. A major challenge of haptic rendering is the wide range of sensations involved in touching, grasping, releasing, interacting with dexterity, and feeling the forces of an object. While many devices deliver only a small subset of sensations, there are still many unknowns as to what the basic haptic controllers really need to work in a general way. And when rendering haptics some devices might even create an Uncanny Valley of Haptics if they are not well integrated [Berger et al. 2018].

Recent work on haptics shows great interest in bridging this gap by building hand-held and wearable robotic devices that use motors and other mechanical actuators. This whole line of research actively changes the shapes of the devices to render impressive haptic sensations. These include creating illusions such as the existence of virtual surfaces in mid-air [Benko et al. 2016], grabbing of virtual objects [Choi et al. 2018], simulating weight and forces [Choi et al. 2017; Kovacs et al. 2020], texture shearing [Choi et al. 2016; Choi et al. 2018; Whitmire et al. 2018], bi-manual relations [Strasnick et al. 2018] and more.

However, all such efforts have yet to be implemented in any commercial product. Meanwhile, all that is available to the public, are small vibrotactile feedback that are built into game controllers and mobile devices. And despite there are a number of illusions that they can create, they are very limited for hand object interactions [Berger and Gonzalez-Franco 2018; Gonzalez-Franco and Berger 2019]. One reason for that is that it is hard to reduce the complexity of motorized devices, which increases the cost and reduces the reliability of controllers.

One traditional approach to create better haptics has been to try to focus on matching the functionality of the hand. Haptic gloves or exoskeletons are an example of that. These wearable devices use different mechanical or electrical breaks to stop the fingers from moving when they reach the surface of a virtual object. They can be based on different technologies such as tendons [MacLean et al. 2002], flexible metal strips, or actuators [Bouzit et al. 2002]. Motors that actuate against the force of the user are rarely implemented for safety reasons. Most gloves limit their actuation by braking or resisting the user's finger motion, and only a minority of them apply a force that can open the user's hand by moving the fingers [Blake and Gurocak 2009]. The brake design reduces complexity and increases safety. Nevertheless, gloves usually end up being complex devices since not only they address all the fingers joints, but also they need to mount all the mechanisms on the back of the hand to leave the palm empty [Perret and Vander Poorten 2018].

The use of a braking mechanism in devices enables rendering impressive haptic interactions as the user closes her fingers around a virtual object. When the virtual object is grasped, the breaks engage, preventing the user's fingers to close further, resulting in a believable feeling of a rigid object that presses against the fingers [Choi et al. 2016]. To release the objects, the user may open her hand, distancing the fingers apart. Brakes are passive in nature, using the motion of the user's hands and only applying resistance. Which mean, brakes can be designed to sustain opposing human-scale forces and let go without major damage, or breaking, if a too large a force is applied to them. However some brake systems have no ability to render non-rigid objects, neither elastic nor plastic ones. More advanced braking mechanisms are needed for that, some prototypes have the ability to render compliance using capstans and springs: CapstanCrunch [Sinclair et al. 2019]. CaptanCrunch,

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as well as some of the haptic gloves, may render objects of different characteristics and rigidity. While rigid objects may apply a maximal resistance immediately once the user's fingertips reach the surface of the object, compliant objects may exhibit a resistance that grows linearly while the objects are compressed.

More recently we have seen a trend of devices that do not try to simulate the anatomy and abilities of the hand, but rather try to simulate the object while creating haptic illusions. This line of research has been very successful and even been able to create illusions of compliance on rigid controllers that have no moving parts, like in TORC [Lee et al. 2019b]. This is in part possible because the brain is very good at filling the gap when some perceptual input is missing or only partially complete. And it is also able to integrate different multi-sensory information to create a possible reality depending on the coherence of the inputs [Gonzalez-Franco and Lanier 2017]. While TORC showed that is possible to override proprioception during compliant grasp of objects [Lee et al. 2019a], in this paper, we concentrate on the effect of prediction mechanisms on grasp. The hypothesis is that if you give participants a very realistic inward grasp experience, their brains will automatically predict how the release should feel. Then the release simulation would be much less important than the latching part of the grasp. Which would mean that grasp in VR is also asymmetric. This would be supported by the fact that in the real physical world grasping action is also characterized by asymmetric perception [Johansson and Flanagan 2009]. And that this asymmetry is partially driven by the attention requirements of the task.

In this paper, we are interested in further evaluating the importance of the symmetry between grip and release of the grasp a whether haptic rendering from the human perception is directional: Does human sensing behave the same when we close our fingers to grab an object and when we open the fingers to release the object?

2 RENDERING GRASP FORCES

Objects have different stiffness levels, they can be compliant, rigid, or plastic. When trying to simulate these behaviours on a device it needs to account for those effects during the interaction. Most devices try to implement the latching simulation, some with more success than others. However not all of them produce the releasing simulation beyond a rigid release. That is the case of most devices and gloves [Choi et al. 2016; Perret and Vander Poorten 2018].

Meanwhile, in real life, when a person releases a compliant object from their hand, it opens and spreads her fingers, at that point the compliant object applies the same amount of force that was applied when it was compressed in the opposite direction during the grasp. This is, in real life, grasp might seem symmetric. However, humans perceive it asymmetrically as both neurophysiological evidence and attentional mechanisms contribute to an actual asymmetry in tactile perception in real life. [Johansson and Flanagan 2009].

To be able to simulate that compliant release behaviour a device must either use active motors that can apply such force, like the CLAW device [Choi et al. 2018], or be able to store energy while being compressed by the user's finger force, and then release the energy as a force on the fingers when it is being decompressed, as if it was a spring.

Using a real spring on the controller we can create a compliant release even without the need of motors. However, the spring approach can be restricted by the actual physical innerspring constant (k). That is the case of CapstanCrunch which uses an internal spring to store energy. That energy can later be applied as a force when the fingers are being opened, however this force is capped by the innerspring constant. Using a spring constant that is too high may limit the ability of the device to render objects that have low constant, and vice versa. CapstanCrunch was assigned a spring of constant in the middle of the compliance range it was tested (k=0.6 N/cm). Using a spring to enable grasp simulation can be defined as asymmetric.

3 MATERIALS AND METHODS

3.1 Apparatus

We base our study on symmetry of grasp using the devices presented by Sinclair et. al: CapstanCrunch [Sinclair et al. 2019] and Choi et. al: CLAW [Choi et al. 2018] (Figure 1).

CapstanCrunch device mounts a one-directional break capstan that can highly control for resistance. Using different profiles of resistance, CapstanCrunch is able to render a large variety of objects, as they are being pressed, some can be quite complex. For example, the rendering a button on a keyboard may exhibit some resistance, as the finger touches its surface, which grows linearly as it is being pressed, until some force where the object is not compliant anymore, and the finger feels lack of resistance for a short time until it hits the final position and then stops.

On the contrary for the release of object CapstanCrunch is much less sophisticated and relies on a constant spring. Therefore CapstanCrunch can be considered an asymmetric grasp device.

On the contrary, our second device, CLAW, is capable of simulating both a non-constant latch and release by using the integrated motor. And we will be referring to it as a symmetric grasp device. Despite CLAW's versatility, we opted to use CapstanCrunch for the asymmetric study partially because it uses a 'real' spring instead of a motor. But also, because the motor might also not be ideal when the objects are super compliant, in which case the motor could still apply a bit of a residual force.

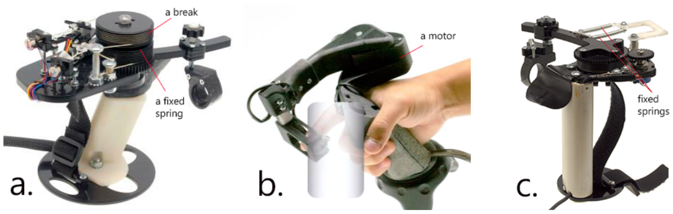

Figure 1: Haptic hand-held devices used in this experiment: a) CLAW: a symmetric device. b) CapstanCrunch: an asymmetric device and c) a fixed spring device (control condition).

Both devices were connected to Unity 3D and the visual experience was displayed inside an HTC Vive. Our controllers were tracked in space using HTC Vive trackers and matched to a virtual hand that was substituting the participant's hand.

3.2 Experimental Design

We design an experiment that compares the realism of perception of grasping objects of different rigidity between CapstanCrunch and the CLAW. The objects to be grasped consisted of 6 balls of different stiffness, ranging from thin air pinch to completely rigid balls. One of the balls was assigned the middle point stiffness in which the k constant of the spring for the CapstanCrunch and CLAW was calibrated to 0.6 N/m. For this object, both devices should render a "perfect" haptic feedback and should rank high by the users. When rendering objects of different compliance, CapstanCrunch, and CLAW, the release fidelity may stray from the expected real physical response. However, the grasp would still be of equivalent fidelity with both devices.

The task was always the same: participants were given a virtual ball in hand and had 5 seconds to pinch it multiple times and thus experience the simulated compliance with the particular device. After each ball participants rated how realistic they felt the touch+visual experience was "From 1 to 7 how realistic was the grasp of the ball". This question was asked inside VR by selecting from a set of options in front of them, right after that the next ball appeared. The main experiment consisted of a randomized sequence of balls with different stiffness with a total of 30 trials (Figure 3). The experiment lasted less than 30 minutes.

In total, 12 participants (2 female, age from 27 to 51) completed the user study. Controllers were presented in a counterbalanced order. All participants were right-handed and gave written informed consent. This study was approved by the Institutional Review Board.

3.3 Spring Simulation

In our experiment, we leverage the ability shown by TORC [Lee et al. 2019b] by which a good visuo-haptic simulation can, at least partially, override the proprioceptive input.

Since two balls were of greater k than the actual spring constant of CapstanCrunch and two were of smaller k (Figure 3). In order to simulate smaller k, we developed a retargeting technique in which the movements of the participants are amplified to make the ball look squeezier than the actual device [Abtahi and Follmer 2018]. The idea being to create illusions of hyper compliance, even when the springs are not able of delivering such small k, a sort of haptic retargeting for compliance. By amplifying the movement effectively, we created an illusion of greater distance (d) and the mental Hook's law equation of F=k*d got distorted, creating the illusion of a smaller k. For the 2 balls with greater k, we did the opposite and scaled-down the movements of the users to simulate larger k.

3.4 Control Condition

Besides the asymmetric and symmetric devices used for the main experiment. We introduced a third mock device that was just a regular spring connected to the finger of the participant in a format similar to the main experimental conditions (Figure 1). But in this case, the participant would perceive only the constant spring no matter the stiffness of the object or if the participant was grasping inwards or releasing the object.

The spring device is therefore symmetric only for an object that has exactly the same constant as its spring.

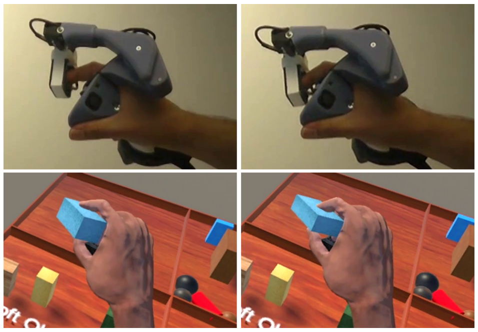

Figure 2: CLAW renders stiffness by applying correct force against the user index finger. In this image the Claw is used to perceive the compliance on a VR object: as the participant presses her finger the VR object compresses.

study.png

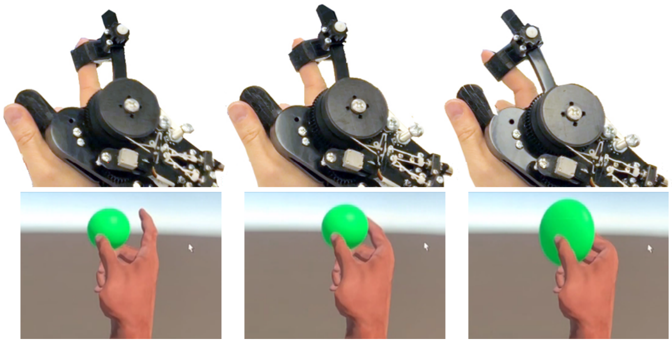

Figure 3: Sequence of participant using the CapstanCrunch with a compliant ball. As the participant reaches for the ball this will squeeze.

4 RESULTS

Through our user study, we compared the perceived realism on stiffness rendering of CapstanCrunch and the CLAW. Overall both devices were capable of providing a good rendering of compliance across the board (Figure 4).

With all the data we first run a Wilcox test that shows no significant differences in perception between the two devices p-value = 0.7832. To better understand the implications of this result we then run a TOST equivalence test using the TOASTER library (Two One-Sided Tests for Equivalence in R) and dataTOSTtwo function in R as proposed by [Lakens et al. 2018]. The results shows that both devices were equivalent in realism. Significant equivalence was found t(140) = -1.8, p = 0.037, given equivalence bounds of -0.752 and 0.752 (on a raw scale).

Our results suggests that having a constant spring on CapstanCrunch for the release of the grasp did not impede participants from achieving as high degrees of realism as with CLAW.

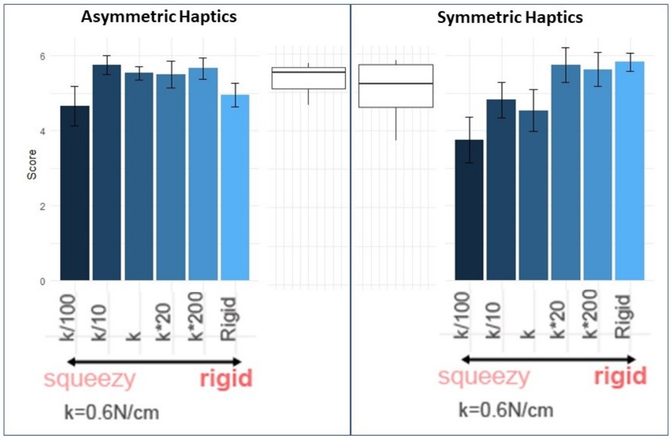

Figure 4: Barcharts with standard error scores of perceived realism for the different simulated stiffness in the two devices. The boxplot represents the distribution of scores across participant for each device.

4.1 Control Condition

To explore the importance of the inward grasp simulation we further compared both devices the symmetric and the asymmetric to a third one that had a constant spring.

The realism scores for the fix spring were quite good for when the k simulated was close to the k of the actual spring (Figure 5).

But beyond these objects, the scores for this device were very low (mean = 4.10, sd=1.9) compared to the scores of the symmetric (mean = 5.05, sd=1.7) and asymmetric (mean = 5.34, sd=1.1). Wilcoxon Test showed that the differences were significant between the fix spring and the asymmetric device (p=0.0001), and with the symmetric device (p=0.003).

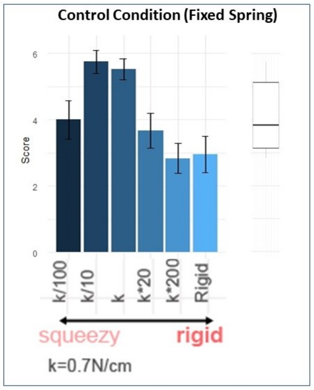

Figure 5: Barcharts with standard error scores of perceived realism for the different simulated stiffness in the fixed spring control condition device. The boxplot represents the distribution of scores across participant for each device.

4.2 Limitations

There are a couple of limitations to our study. One is the rendering of very low spring constants. For very elastic objects the CapstanCrunch asymmetric rendering got even higher scores for realism than the CLAW (Figure 4). We found the source for this effect in the limitation of the CLAW control system based on motors. At very low spring constant, the user expects to close and open his hand with almost no resistance, yet some latency in the control system does generate small resistance by the motor, while CapstanCrunch break was able to generate much smaller resistance in both directions. Furthermore, this need for CLAW to be always actuated by the motor when moving was also what prevented us from using CLAW for all the conditions, as it could not be really "turned off". If that caveat could be overcome, it would eliminate a source of variation in this experiment..

Nevertheless the scores in realism were high for both devices. Another is that our study did not implement any further control condition nor device to test what happens when only the release is truly simulated. But we anticipate that the effect of the asymmetry here observed is reliant on the fact that most characteristics of the objects are given during the latching part of the grasp, therefore the brain can fill the gap during the release.

Additional limitations come from the fact that the results might be driven by this task and it is yet to be know how would this transfer to all grasp and or dexterous manipulations.

5 DISCUSSION

Our results support the existence of an asymmetry of haptic perception while grabbing objects for our specific squeezing task. When we grab an object, the immediate haptic sensations enable us to evaluate the nature and properties of the object material. With that in mind we take decisions and make predictions about how the object will behave in the future. This makes anthropological sense, humans would need to rapidly evaluate whether an object should need to be dropped immediately, or if it was a possible food, what use could it fit, etc. Much of that information would come during the latching part of the grasp and in fact continuous exposure to a touch percept tends to reduce our awareness over time and even decreases in neural responsiveness have been reported overtime on thermal touch [Jones 2016]. Humans are therefore mostly driven towards touch in an attention and exploratory way, and once there is no more to be learned from the object we start ignoring the signals to be able to focus on the next one.

This means that finally by the time when we are ready to release the object, there are two concurrent processes driving the release at the same time:

- Attention reduction, in many cases, we have no longer any interest in the object.
- Top-down predictions [Gonzalez-Franco and Lanier 2017]. By the time of the release, our brain has pretty elaborated predictions on the behaviour of the object and even if the actual sensory input does not correspond it will likely override or fix it with the predictions.

The types of illusory experiences generated by prediction mechanisms are common on humans, one example being the phantom phone vibration [Rosenberger 2015], or how after talking about lices some people fill the urge to scratch their hair, despite their sensory input is clearly not sending that information [Ullman et al. 1996]. Of course top-down predictions are also existing at the moment of latching the object, our previous life experiences drive many of our day to day interactions. However we tend to be mostly sensory and bottom-up dominated during that moment of the grasp interaction [González Franco 2014].

However, as we mention in the limitation section future research should determine whether this asymmetry transfers to all types of grasp, beyond squeezing, and or dexterous manipulations.

5.1 Implications for the design of haptic devices

Our results have shed light on the possibility of a perceptual asymmetry of grasp in haptics, that would be expanding previous research on physical world grasping action that is characterized by asymmetric perception [Johansson and Flanagan 2009]. And that this asymmetry is partially driven by the attention requirements of the task. However this theory will need to be further backed by future research. Our current experiment only first introduced the concept by comparing two devices but this would need to be tested across more devices and tasks. As maybe this specific task that itself promotes more attention cues at the onset than at the end of grasp. However if our findings are corroborated with future experiments it could have very important consequences in the creation of future haptic devices. For once it reduces the number of simulations that need to be implemented in grasping controllers. In the same way that because the human eye is not able to detect further than 90Hz we do not create screens with a higher refresh rate, haptic controllers could focus on delivering a very realistic grasp latch, and worry less about the fidelity of the release. In practice this asymmetry of grasp theory here presented is not only supported by our results but also by the many gloves that do a decent job with restive systems in creating the inward brakes while not actuating the forces on release.

This is even more important if we think that the rendering of resistance to the user motions as they grasp an object is fundamentally easier than rendering the object force on the fingers as the hand opens up. While the former can be implemented by passive breaks, the later needs the energy to move the device and keep it pressing against the fingers. Which can also become a safety concern. Furthermore, while breaks may be small, as electrostatic friction strips on the back of each finger, generating hand grounded actuation as opening the hand currently requires mechanical contraptions from the inside of the fingers or rather large exoskeleton levers on the outside of the palm, both are complex and may reduce the mobility of the hand if there are real-world obstacles around.

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