The role of tactile feedback during 2D and 3D target grasping actions in a virtual environment

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Abstract
A possible confound in Ozana and Ganel's 2018 study investigating 2D and 3D grasping tasks is the presence of haptic feedback only in the 3D case. We theorized that sensorimotor adaptation from tactile feedback during repeated trials of grasping tasks could play a stronger role than the dimensionality of the object in determining a participant's resistance to an illusory context. We hypothesized that there would be a significant difference between the illusory effect in haptic and non-haptic repeated grasping tasks and no significant difference between the grasping in 2D and 3D cases. We conducted an experiment where participants performed grasping motions toward both 2D objects and 3D objects with and without haptic feedback in the context of the Ponzo illusion in a virtual environment. There was not a significant difference on the effect of the illusion when dividing data by presence of haptic feedback or by dimensionality of the target. However, the data shows a trend towards greater illusory influence on grasping in non-haptic cases than in haptic cases, suggesting that future research in this area could be crucial to inform appropriate consideration of haptic feedback in future research on the two visual stream hypothesis.

Introduction

In 2008, Ganel, Tanzer, and Goodale published a paper describing the dissociative effect of the Ponzo illusion between grasping tasks and perceptual size estimation tasks. According to the researchers, the results of this experiment indicate entirely separate processing during grasping movements and manual estimation in the context of the Ponzo illusion, demonstrating incorrect manual estimations of bar length in cases where fairly accurate grip apertures remain during grasping. These separate sets of results could indicate separate processing for action and perception, but these results are complicated by a more recent study, also performed by Ganel, that explores the effect of 2D and 3D representations of a bar in grasping tasks.

In this 2018 study, 2D and 3D target objects during grasping tasks were shown to have differential effects in grasping tasks (Ozana & Ganel, 2018). In two back-to-back experiments, Ozana and Ganel studied the difference in effect on MGA during reaches for 3D objects and 2D virtual rectangles on a screen and the difference in effect during reaches for 3D objects and 2D photographs that mimicked the 3D objects without the haptic feedback. They found that 2D grasping was influenced by task irrelevant contextual information in these blocks, whereas 3D target grasping appeared to be immune to context. In other words, the resolution of the grasping was affected during 2D grasping tasks but not 3D grasping tasks. The researchers argue, in the context of the two visual stream hypothesis, that because the 2D cases show variation in the Just Noticeable Difference between different target sizes in accordance with Weber's law, grasping for a virtual 2D object must be processed independently of 3D visuomotor processing. They suggest that 2D objects are processed more holistically than their 3D counterparts, which may be processed more analytically as an isolated motor task. The researchers further contextualize this within the dual-stream hypothesis, claiming support for the notion that within visuomotor tasks, there are cases where the task will be intruded upon by visual context.

Our group will be considering Ozana & Ganel (2018) and testing their conclusion that 2D object grasping is cognitively distinct from 3D grasping. Although Ganel et. al. considered haptic feedback in their 2008 study ten years prior, Ganel and Ozana did not adequately consider the possible confounding variable of haptic feedback in their 2018 study. Haptic feedback was provided in 3D grasping conditions, where the participants could grab the edges of the target object, but such cues were absent during 2D grasping as the participants could only touch the flat surface of the computer screen. The researchers mention this possible confounding factor in their discussion but argue that the nature of the tactile feedback alone does not determine grasp selectivity. In other words, they argued that the dimensionality of the object, not the presence of haptic feedback, is the greater determinant of whether grasping actions will be affected by contextual information, and because of this, they seem to dismiss tactile feedback as a confound altogether. We want to test this effect of tactile feedback using the Ponzo-illusion based test of the two visual stream hypothesis to gain clarity on whether the results of Ozana & Ganel (2018) are the product of varying tactile feedback or if there truly is a difference between 2D and 3D grasping in these motor tasks.

Research supports the idea that haptic feedback plays an important role in determining object size during grasping. Namely, Hosang et. al. (2015) provide data that support the idea that grasping in cases with haptic feedback is informed primarily by absolute object size, while grasping without haptic feedback is more influenced by relative object size and the context in which the object appears. They were able to test 2D and 3D cases for both haptic feedback conditions as well, and executed the 2D haptic case by placing a block between the fingers of the participant after they grasped at a 2D representation of the object. They found that the 2DH- (non-haptic 2D) case was susceptible to information about relative object size, whereas the 2DH+ (haptic 2D) and 3DH+ case were not affected by relative object size, demonstrating resistance to Weber's Law. They did not test a 3DH- condition.

This research is relevant to our study because it aligns very closely with our research question about the role of haptic feedback as it modulates one's susceptibility to an illusion. It is promising that this study yielded results in line with our hypothesis that haptic feedback will be a significant predictor of whether grasping actions will be responsive to absolute or relative size information. Where our research departs from this experimental design is in our introduction of the non-haptic 3D condition and the comparison of this tactile training effect to the effect of 2D vs 3D grasping.

Elements from the 2015 study and the 2018 study appear in our response to Ozana and Ganel (2018). We aim to bring the essential elements of each of these studies together, along with Ganel's original illusory context, the Ponzo Illusion, to study which variable, object dimensionality or availability of haptic feedback, has a stronger effect in determining MGA during grasping motions. Since haptic feedback has been shown to make a difference in illusion susceptibility, could it have a stronger influence on grasping than the target object's dimensionality, contrary to what the 2018 study proposes? We are introducing the two levels of 2D and 3D blocks in an attempt to follow the experimental design of Ozana & Ganel (2018) as well as two levels to the haptic feedback condition: with and without haptic feedback. Building off of Hosang et. al. (2015), we were able to create the 3DH- condition with a 3D target and no haptic feedback by conducting the experiment in virtual reality. We propose that when comparing the effects of 2D and 3D trials, there will be little difference in illusion effect, but when comparing haptic and non-haptic trials, there will be a significant difference between the two, with a larger illusion effect appearing in non-haptic trials.

Methods

Participants, stimuli and equipment

We chose the Ponzo illusion to test our hypothesis, as it is commonly used in experiments involving the two visual stream hypothesis and it allowed us to compare grip aperture on the two sides of the illusion to determine the illusion effect. We wanted to compare the difference in effect between grasping for 2D objects and grasping for 3D objects, without the necessity of including haptic feedback in the 3D case. To achieve this, we employed a virtual reality setting. All trials except washout trials involved a virtual image of the Ponzo illusion.

To preserve the possibility of sensorimotor adaptation during each block, the orientation of the illusion was switched, rather than the placement of the bar on the illusion. In "near" cases, the illusion was oriented so that the bar appeared on the part of the illusion with converging lines around the bar. In "far" cases, the illusion was oriented so that the bar appeared on the part of the illusion with diverging lines around the bar. The bar always appeared in the same place in the virtual environment. The 2D trials involved a 2-dimensional image of a bar that would appear on the Ponzo illusion background. 3D trials included a visual image of a 3D bar that was one of two sizes. A large bar measured 5mm tall (rising from the table), 10 mm across, and 52 mm tall. A small bar measured 5mm tall, 10 mm across, and 46 mm tall.

Participants were able to see the location of their thumb, but were unable to see the location of their index finger to prevent on-line adjustment of their grip aperture based on visual feedback from comparison of the grip aperture to bar size. Haptic trials included a physical version of the virtual bar, placed in the same place as the virtual representation, to provide tactile feedback to the participant when arriving at the bar. Non-haptic trials did not include a physical bar. The rest of the environment was neutral, but represented the basic layout of the lab room to preserve a realistic sense of the space in which the grasping is taking place.

Tasks and procedures

Participants were verbally instructed to reach for a clearly visible bar and grasp it without lifting it during each trial, beginning with their hand in a static starting position. In haptic trials, participants were instructed to grasp the object. In non-haptic trials, participants were instructed to place their fingers where they think the edges of the virtual bar are, as if they were to grasp it. Trials were separated into 8 blocks with 16 trials each. The thickness of the bar (dimensionality, 2D or 3D), availability of haptic feedback, and orientation of the illusion remained consistent within each block. We blocked these variables to allow for sensorimotor adaptation, as the participant is reaching in the context of only one side of the illusion, so they can, in theory, adjust based on haptic feedback. We blocked the thickness of the bar and presence of feedback for similar reasons, to allow the participant to use the haptic feedback (or lack of haptic feedback) to inform trials with the same conditions.

Following the format of Ozana and Ganel (2018), we did separate the blocks into two groups with 2D blocks always coming first and 3D blocks always coming second. Within these halves of the experiment, the haptic and orientation conditions were assigned a random order for each participant, to avoid any case repeatedly following any other (for example, always performing non-haptic trials right after haptic trials). The size of the bar (big or small) was intermixed within these trials, appearing in a random sequence over the course of the 16 trials in each block. After each haptic block, a series of 10 washout trials without the illusion but with haptic feedback were performed to counteract any adjustment made in grip aperture over the course of the block. The experiment began with 10 haptic practice trials with a random orientation of the illusion to allow the participant to acclimate to the experiment and understand the instructions before experimental blocks began. We recorded the position of the fingers in 3D space throughout each trial until contact with the representation of the bar.

Data analysis

We determined the grip aperture by measuring the 3D distance between the markers of finger and thumb. We subsequently isolated the maximum of this distance (MGA) in the part of the trajectory between movement onset and contact with the target object. In isolating the MGA values, we excluded the practice and washout trials.

Before performing any analyses, we excluded any outliers from the data MGA data, as defined by any trials that fell outside of 2.5 standard deviations from the mean MGA of all trials. Following this refining of the data, there were two subjects that had very few trials left. We analyzed each participant's data individually and found that one had a majority of grip aperture values that exceeded 10 meters, with only 17 observations that were not outliers. The other one only had 12 values that were not affected by technical errors in recording. These two participants were excluded from the data discussed below. Also, we also were not able to run ANOVA on two subjects who did not have enough data sets, so the following ANOVA consists of only 7 subjects' data. The t-tests include the 9 participants who didn't have the issues listed above.

We first performed a within-subject ANOVA on the MGAs across all conditions to see if there was an effect on MGA by any of the conditions. Then, to find a representation of the Illusion Effect (IE), we first calculated the mean of the "near" orientation trials and the "far" orientation trials for each subject separately, grouped by bar thickness, presence of haptic feedback, and bar size. Using these means, we determined the difference between the near and far trials for each combination of the independent variables, as well as for thickness, tactile feedback, and bar size on the whole. To calculate IE in the context of each of these variables, we subtracted the mean MGA of the "near" conditions from the mean MGA of the "far" conditions.

$$IE = (MGA_{far} - MGA_{near})$$

We did not calculate the absolute value of these differences, so any block mean comparisons where the subject was, on average, grasping with a smaller MGA on the "far" illusion would be negative values. We performed a t-test between the IE values for 2D and 3D conditions as well as haptic and non-haptic conditions to test whether there is difference in illusion effect based on thickness or presence of haptic feedback. According to our hypothesis, these t-tests should reveal a significant difference between the haptic and non-haptic cases, but no significant difference between the 2D and 3D cases.

We also performed t-tests between the mean IE values for each of these conditions and zero to test if there is an illusion effect in the first place for any of them. According to our hypothesis, there should be a significant IE for the non-haptic case because there would be no haptic feedback to allow for sensorimotor adaptation and provide resistance to the illusion. However, there should be no significant IE for the haptic condition because sensorimotor adaptation would allow for corrections as the trials went on, counteracting the effect of the illusion and creating less of a difference between the two sides.

Results

From our ANOVA of the MGA across all conditions, we found that there was not a significant difference

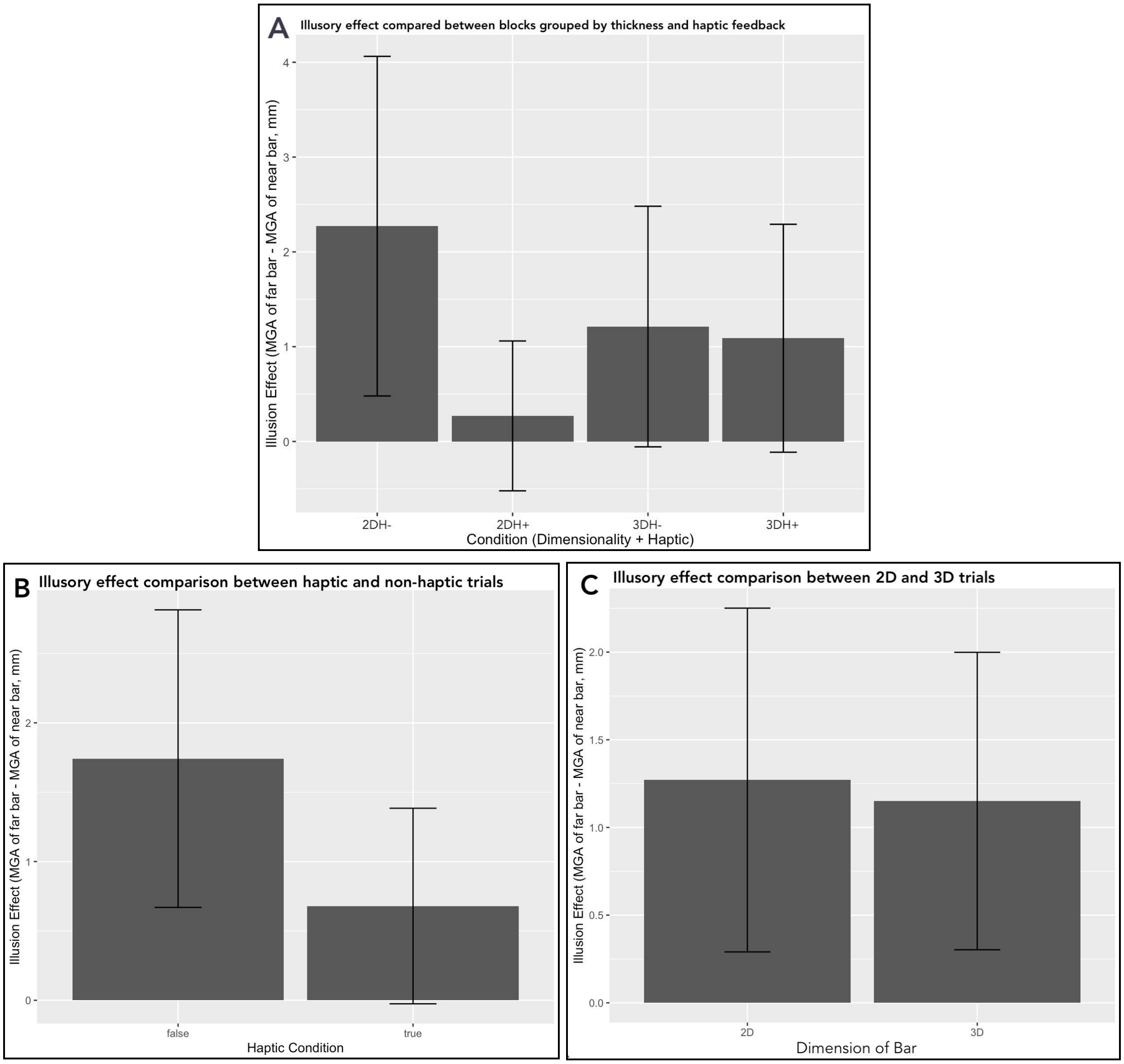

Fig. 1 Results. All values are averages across participants. **a** IE across all participants for each of the following sets of blocks: 2D blocks with no haptic feedback (2DH-), 2D blocks with haptic feedback (2DH+), 3D blocks with no haptic feedback (3DH-), 3D blocks with haptic feedback (3DH+). **b** A comparison of the IE across all non-haptic trials and all haptic trials. **c** A comparison of the IE across all 2D trials and all 3D trials.

between the near and far conditions across all MGAs from the experiment *($p = .14$)* meaning that overall, the illusion did not necessarily have an overall effect when all blocks are considered together. There was, however, a significant difference between the MGAs for the small bar and the big bar across all participants ($p < .01$). There was also a significant difference in MGA between all haptic and all non-haptic trials *($p = .01$)*. This indicates that both bar size and availability of haptic feedback was influencing the way people grasped the target objects.

We performed a t-test to determine whether the IE for the big bar trials was significantly different from the IE for the small bar trials, and that t-test yielded a *p*-value of *.83*, leading us to conclude that there is not significant difference in how much the grip aperture changes from far to near depending on the bar size. Because of this, we did not analyze the data from each of the bar sizes separately after the ANOVA.

In graphing the mean IE for each combination of thickness and presence of haptic feedback (Fig. 1a), we find a large but non-significant difference between the IE in the 2D haptic and 2D non-haptic blocks. There is less of a difference between the 3D haptic and 3D non-haptic conditions, but nonetheless, in both the 2D and 3D cases, haptic trials show a non-significantly lower IE than haptic trials.

Considering our null hypothesis, which is based on Ozana and Ganel (2018) and their claims about the importance of dimensionality in determining susceptibility to irrelevant contextual information during grasping, this graph should show two taller bars that are similar in height for the 2D cases, and two lower bars that are similar in height for the 3D cases. The fact that the 2D bars are so different in height suggests that there is something more than thickness of the bar influencing these subjects' susceptibility to the Ponzo illusion. The haptic cases, with their visibly lesser illusory effect in both the 2D and 3D contexts, align more closely with our hypothesis that haptic feedback will reduce the illusory effect of the Ponzo illusion.

We compared the overall effect of the presence of haptic feedback by comparing the mean IEs for all haptic and non-haptic trials (Fig. 1b). A t-test of these two means revealed that they are not significant ($p = .35$), but the graph suggests that these results tend toward a higher IE for non-haptic trials and lower IE for haptic trials. This non-significant tendency aligns with our hypothesis that haptic trials would have a lesser illusion effect than non-haptic trials. We performed a t-test to see if there is an actual illusion effect in either of these cases, and neither the haptic blocks *($p = .17$)* nor the non-haptic blocks *($p = .06$)* showed a significant difference from zero.

Lastly, we also compared the overall effect of the thickness of the bar by comparing the mean IEs for all 2D and 3D trials (Fig. 1c). The t-test for these two means did not reveal a significant difference *($p = .91$)*, and the bars are visibly closer in illusory effect than when comparing haptic and non-haptic trials. Again, neither of these means is significantly different from 0 *($p_{3D} = .10$; $p_{2D} = .11$)*, but the fact that these two means are not significantly different aligns with our hypothesis that there would not be a large difference between the 2D and 3D trials, as Ozana and Ganel (2008) would suggest.

We attribute our lack of significance to our small sample size, which was made smaller by errors in recording data during two participants' trials. With a total of 9 participants, we believe that a larger sample size would yield more significant results.

Discussion

Our experiment aimed to address the importance of considering haptic feedback in experiments about the two visual stream hypothesis. Without significant results for our analysis comparing IE means by thickness and by haptic feedback, we cannot reject the null hypothesis and claim support for our alternative hypothesis. We did not find a significant illusory effect across the board, and we do not have significant evidence to support the idea that haptic feedback plays a larger role in mediating illusion effects during grasping than thickness does. Nonetheless, our experiment does present interesting results regarding the role of haptic feedback and object dimensionality.

First, despite no significant illusion effect being recorded, all of the means for illusion effect in each of our methods of dividing the data were positive (Fig. 1). Because we defined IE as MGA_{far} - MGA_{near} without finding the absolute value, our results indicate a trend for these participants toward grasping larger when the bar is in the far context, which aligns with the expected illusion effect heavily recorded in prior research on the Ponzo Illusion.

Ozana and Ganel (2015) claim that grasping toward 2D and 3D objects are differentially affected by irrelevant context, without sufficiently addressing or testing the possibility that haptic feedback could be a confounding variable. Haptic feedback was present during all blocks that yielded results showing resistance to the illusory context, and haptic feedback was absent in all trials that yielded results that showed evidence of illusory influence on grasping. Despite the fact that the difference between haptic and non-haptic trials is not significant in our experiment and the fact that none of these means are significantly different from zero, we can see from the graphs that the mean illusory effects of haptic and non-haptic trials are further apart than those for 2D and 3D trials. This may indicate that, with further study and a larger sample size, we would be able to attribute the difference in susceptibility to illusory context to the availability of haptic feedback, rather than object dimensionality.

The trends in our results align more closely with our hypothesis that sensorimotor adaptation from the availability of haptic feedback during grasping tasks leads to a lesser illusory effect than in non-haptic trials, regardless of whether the target object is 2D or 3D. The difference in illusory effect between haptic and non-haptic trials may indicate that the immunity to illusory context demonstrated in experiments that don't separate dimensionality and haptic feedback could arise from a motor reaction that allows for easier grasping based on actual length more than relative length. Haptic feedback could provide a more reliable interaction with the target object and may be used to calibrate and to refine visuomotor interactions in repeated trials. Future research could confirm these results with a greater number of subjects and longer blocks that would allow for more sensorimotor adaptation.

Although we see this trend when analyzing all of the haptic trials together, the results from Fig. 1a of the individual block combinations tell a more complicated story. These results are not dissimilar from those in Hosang et. al. (2015) which demonstrated a difference between 2DH+ trials and 2DH- trials. As seen in Fig. 1a, we also found a large difference in the means between these two groups. However, we were able to test both 3DH+ and 3DH- grasping, expecting to see a comparable difference between haptic and non-haptic trials to that of the 2D cases. Although there is a very slight trend toward a lesser illusory effect for the haptic case, there is not a clear difference in illusory effect between the 3DH+ and 3DH- grasping tasks. Also, the haptic trials still show means above zero for the illusory effect, indicating that there is still some influence by the illusion even when haptic feedback is provided. These unexplained results likely indicate that there are other factors that contribute to the effect of the illusion, and the dimensionality of the object could play a role in how much an illusion affects the way we use our vision for action.

This presence of an illusory effect during haptic trials could also be a result of our analysis of each of the blocks as a whole, rather than isolating the first few trials and comparing them to the last few. Analysis of this sort may indicate that near the end of the haptic blocks, sensorimotor adaptation does dispel the effect of the illusion, meaning that these haptic results show an illusion effect only because they include the trials before adaptation occurs. Further analysis that we were not able to complete is needed to draw that conclusion. This is an area of interest that would be useful to analyze in a follow up study.

Further confounding variables beyond a small sample size and low amount of trials performed could be a lack of consistency in our verbal instructions, misalignment of virtual reality visuals and real world bar placement, and the fact that we only presented a bar on one side of the illusion at a time. The first two could have contributed to increasing the noise in our data, and the use of only one bar could have reduced the effect of the illusion that is usually shown with two bars.

Despite the apparent ambiguity in our results, significant findings that resembled these results would still be notable and important to consider in future studies of the two visual stream hypothesis because they would indicate that resistance to illusory context during grasping tasks may be attributable to the availability of haptic feedback. Considering that grasping tasks often include tactile feedback and perception tasks (such as manual size estimation) often do not include tactile feedback, research in the field of vision for perception and vision for action may disproportionately show support for grasping being immune to illusory context because it is so often confounded with the presence of haptic feedback. Results such as these, demonstrating a stronger influence on immunity to irrelevant context by haptic feedback than object dimensionality would indicate that researchers should deeply consider the role of haptic feedback in testing the two visual stream hypothesis to avoid letting it skew their results.

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