

Background Motion, Clutter, and the Impact on Virtual Object Motion Perception in Augmented Reality

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Abstract

Background motion and visual clutter are present in almost all augmented reality applications. However, there is minimal prior work that has investigated the effects that background motion and clutter (e.g., a busy city street) can have on the perception of virtual object motion in augmented reality. To investigate these issues, we conducted an experiment in which participants' perceptions of changes in overlaid virtual object velocity were tested with several levels of background motion, background clutter, virtual object motion, and virtual object clutter. Our experiment offers a novel approach to assessing virtual object motion perception and gives new insights into the impact that background clutter and motion has on perception in augmented reality.

Categories and Subject Descriptors (according to ACM CCS): H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented and virtual realities;

1. Introduction

A major factor that affects user experience and usability in Augmented Reality (AR) is perception. Although AR can provide a real world context for data and phenomena that are not visible with the naked eye, the user's interpretation of this data is highly dependent on visual perception (e.g., depth perception, color perception, motion perception). For example, White and Feiner overlaid a visualization of pollution data on a city street and qualitatively found that the approach to AR visualization had an impact on the way the data was perceived and interpreted [WF09]. This example highlights two of the major aspects of how AR can affect perception of data. First, aspects of visual representation of data (e.g., color, movement, shape, etc.) can affect perception in AR just as they do in traditional visualization. Thankfully these aspects can be controlled by developers to optimize perception. Secondly, the registration between the real world and the visualization may provide additional context that can change user perception of the data as well. However, in AR the visual feedback from the real world cannot easily be controlled and may include significant background motion and visual clutter, which may hinder user perception.

The perceptual effects of visual clutter have minimally been studied in AR, but there is much research that has focused on effectively quantifying visual clutter in digital images [RLN07]. Generally, visual clutter can be defined as the situation in which a determined number of objects,

features or items as well as their organization prevent a person's ability to easily detect or recognize what is occurring in the scene. The level of visual clutter is analogous to the difficulty for a person notice a note based on its location or appearance on a highly cluttered desk.

Thus, we ask the question – how will motion and clutter affect the user's perception of overlaid visualizations in AR? To answer this, our goal is to identify the perceptual impact of the real background motion and clutter, the virtual object's motion and clutter, and investigate the interactions between these variables that affect perception of virtual object motion.

Towards this goal, we tested perception of visualizations overlaid on backgrounds that contained various levels of motion and visual clutter. Specifically, we performed a within-subjects user study using a mobile AR setup. For the sake of generalizability we used an abstract visualization (figure 1) that consisted of 3D particles moving in different directions on a 2D plane (i.e., to minimize the perceptual effects of virtual object movement direction and depth). This visualization was overlaid on videos of real environments that had similar levels of color contrast, but different amounts of visual clutter (figures 4 and 5). We also varied the amount of motion in the videos by speeding up and slowing down the videos. The color of the particles was constant but velocity of the particles was incrementally increased. To measure motion perception, participants pushed a button when they perceived a change in velocity.

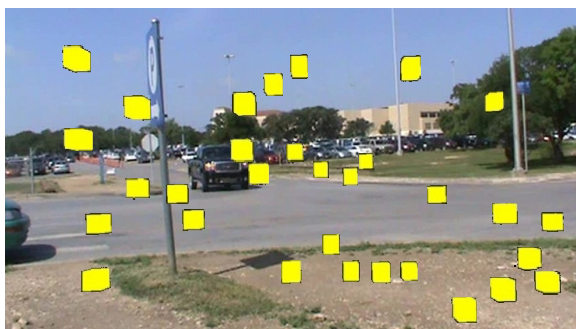


Figure 1. Virtual objects are moving on top of a highly cluttered, medium motion background.

Based on the results of our studies, we offer insight into how background clutter and motion affect perception of virtual object motion in AR. These issues are present in almost all AR applications and could have an impact on usability, acceptability, and future research results. To help mitigate these issues, we aim to contribute a better understanding and quantification of the perceptual impact of background motion and clutter in AR.

2. Background and Related Work

This section is a review of the previous research that is relevant to perception in AR, including some work from visual clutter analysis, motion analysis, and information and scientific visualization. However, note that there is minimal work that has been conducted on how the clutter and motion of the AR background affect perception of virtual object motion.

2.1 Visual Motion Analysis

Chen et al. [CF06] offer some biologically inspired ideas that give insight into human motion segmentation and the perceptual effects. To quantify the motion intensity of the background videos in our studies, we used algorithms to extract motion descriptors. If a human observer watches a video sequence, she can effectively perceive it as slow, fast-paced, or action sequence, etc. For a computer to enable this analysis automatically, motion descriptors of the video must be identified and extracted. There are many different motion descriptors that can be used to quantitatively assess motion, such as intensity of activity, direction of activity, and spatial distribution of activity, and motion trajectory, for example. These descriptors are measured and extracted using motion vectors and then correlated with empirical feedback [JD01].

2.2 Visual Clutter Analysis

Various ways to measure clutter in digital media have been proposed. Some focus on finding the number of objects in an image. Other techniques try to find the number of vertices and lines. Recent techniques analyze clutter based on color, luminance, texture, contrast, the number of items and

objects orientation [RLN07]. However, it has been difficult for previous techniques to assess clutter level based the combination of these variables. Rosenholtz et al. present “featured congestion” [RLN07] to effectively quantify clutter, based on the aforementioned image features, and also takes into account the level of difficulty for humans to perceive an item in a congested image.

Specifically, Rosenholtz et al. addresses the concept of clutter and its negative effects on the detection, recognition, searching and understanding of information in visualizations. The authors compared three different methods for measuring visual clutter: Feature Congestion, Subband Entropy, and Edge Density. All three perform well to predict the mean response time of a user’s visual search. Feature congestion is best at measuring contrast thresholds, color variability and clutter orientation. Subband Entropy can manage gamut limitations. Edge density can measure the spatial distribution of clutter. That is, clutter is a combination of color differences (e.g., contrast, variability, and gamut limitations), and differences in edges’ spatial density, proximity, and orientation.

Although we expect that many of Rosenholtz’s principles likely still apply over a sequence of images, Rosenholtz et al. does not cover issues specific to AR such as virtual object overlay. These are some of the issues that our work aims to investigate with respect to the effect on user perception.

2.3 Reducing Visual Clutter in AR

There have been several methods proposed to reduce visual clutter in AR. Lu et al. investigated ways of reducing virtual object clutter with more subtle cuing [LDF12]. Grasset et al. [GLK*12] presented methods for reducing visual clutter of virtual objects. Veas et al. [VMF*11] investigated how blurring effects applied to the real background can be used in AR to direct the user’s attention. However, we still do not have a fundamental understanding of how clutter and motion collectively impact perception in AR, which is what the present research aims to do.

2.4 Visual Perception in AR

The user’s perception can be affected by many aspects of AR displays such as color contrast, stereoscopy, size, and resolution. This has been studied by many researchers, as reviewed in Kruijff et al. [KSF10]. They identify the main issues in perception in AR as environment, capture, augmentation, display device, and user.

For an example of environment, Livingston et al. [LAS*09] studied depth perception in outdoor vs. indoor environments. They placed physical colored markers along a straight line at various increments. Then they had participants align a virtual target with the physical markers. They concluded that participants under-estimated while indoors and over-estimated while outdoors. The overestimation outdoors was a surprise because previous studies of

depth perception in virtual environments consistently indicate a depth compression in immersive environments.

Although not focused on depth perception, our research is also investigating problems in the ‘environment’ category of AR perceptual research. In fact, Kruijff et al. specifically mention clutter as being one of the main challenges. With respect to clutter, they referenced Rosenholtz et al. [RLN07]. While Rosenholtz et al. is not an AR paper and does not address clutter of videos [CF06], it gives insight into the perceptual effects of cluttered images. In contrast, we aim to investigate how clutter affects motion perception specifically in AR.

2.5 Scientific and Information Visualization

There is surprisingly minimal research in the field of visualization that focuses on empirical study of how people perceive visualizations, let alone particle-based visualizations like in our studies. Lum et al. [LSM03] created algorithms for moving particles along the surfaces of objects. The primary goal was to increase perception of the shapes and features of static 3D objects. They conducted a user study in which they rendered height field data sets using their method and the standard approach. Results suggested that the particles improved users’ perception of depth of the height data. This suggests that particle visualization can have a positive perceptual impact on users. However, this is the only example we could find, and thus illustrates that there is still relatively little known about perception of particle visualizations.

2.6 Visualization in AR

Visualization is an important topic in AR [ZDB08]. User Visual perception potentially has a major impact on visualization in AR. White and Feiner [WF09] give an example case study of a user’s perceptual abilities impacting interpretation of data. Furmanski et al. give another good example of this for x-ray vision [FAD02].

The point is that AR seems to benefit perception of visualization, but there are huge gaps in AR visualization research with respect to how overlaid visualizations will be perceived by users. Thus, we do not know how the uncontrollable aspects of a real world environment in AR will affect the perception of these visualizations.

3. Motivation for Using a Particle Visualization: Generalizability

Here, we review the type of particle visualization that we used in this paper – Brownian motion. The goal of this section is to give insight into what Brownian motion visualizations look like, why they are relevant to AR research, and how we generalize this visualization to other AR applications that include moving virtual objects.

Brownian motion is a particle theory – a mathematical model of how particles move through a liquid or gas [CB06]. Originally Brownian motion was observed in pol-

len particles in water. Despite its botanical origins, other phenomena can be described with Brownian motion, such as the physics of energy conversion and the stock market.

Visualizations of Brownian motion [CB06] usually look similar to many particles colliding inside of a volume (figure 3). To our knowledge, there have not been visual perception experiments with Brownian motion visualization, but visualization and perception literature [Hea07] indicate that there are likely to be some perceptual issues with visualizations of this level of complexity.

Why did we choose this visualization technique for our experiments? We expect it can be generalized to be virtual object movement. Specifically, the objects in our experiments move in many different directions along the x-y plane at a constant velocity and bounce off each other. Thus, perceptions measured in our study are not dependent on direction of virtual object motion or depth. We can then increase velocity and assess whether users can perceive the difference. Overlaying this visualization on real backgrounds with varying levels of clutter and motion enables us to study virtual object motion perception in AR.

4. Methods

We conducted a within-subjects study (approved UTSA IRB #12-144) to determine the impact of background motion, background clutter, virtual object motion (i.e., particle velocity), and virtual object clutter (i.e., number of particles). We were especially interested in analyzing the combined effects (i.e., ANOVA interaction effects) of these variables.

4.1 Hypothesis

Based on the visual clutter and motion literature, our main hypothesis was that a more cluttered, high motion background would significantly hinder perception of the changes in particle velocity, regardless of the number of particles.

Specifically, we aimed to investigate the combined effects of these variables and determine their effects on perception of virtual object motion. This combined effect is closer to what is experienced in practical AR applications. We expected significant interactions between real clutter level, real motion level, virtual clutter level, and virtual motion level and aimed to determine perceptual effects.

4.2 Experiment Setup

We aimed to control for many of the other common aspects of AR that could affect user perception, such as tracking and registration errors, camera motion, viewing perspective, image contrast, and environmental structure and conditions (i.e., the uncontrollable nature of the real world). Thus, there was no tracking enabled, the camera perspective and position was fixed, and instead of a live background, we used an HD video on a large LCD TV to ensure consistency between subjects.

Specifically, the system in our experiment (figure 2) consisted of a mobile phone (HTC Desire HD - 4.3 inch screen, 1Ghz Processor, 768MB RAM, using 1024x768 camera resolution) affixed to a tripod set to eye level for each participant. The phone was facing a 55 in. (139.7 cm) LCD TV, which played the HD videos with varying degrees of clutter and motion.



Figure 2. Experiment setup

4.2.1 Interface

To measure the perception of particle velocity changes, participants pressed a touch screen button when they noticed the change. Then the phone responded with an audible sound.

4.3 Conditions

4.3.1 Real Clutter: RCLUTTER

We recorded two videos (medium clutter, high clutter) as analyzed by the visual clutter analysis algorithm in Rosenholtz et al. [RLN07]. Note that the color contrast, luminance, and brightness of these videos were qualitatively similar. They were also similar quantitatively, as measured by the GNU Image Manipulation Program (<http://www.gimp.org>), medium clutter (figure 1's background): mean: 139.0, standard deviation 47.9; high clutter (figure 3): mean: 137.0, standard deviation 75.4. Thus, we attempted to control for differences in contrast without creating artificial environments.



Figure 3. A still shot from the high clutter background video.

4.3.2 Real Motion: RMOTION

The playback speeds of each of the two aforementioned videos were controlled: still, low, medium, and high as analyzed by motion analysis algorithms in [JD01]. No-motion conditions in RMOTION were made from a still image of each video.

4.3.3 Virtual Object Clutter: VCLUTTER

To control virtual object clutter, there were 3 amounts of particles (1, 16, and 32).

4.3.4 Virtual Object Motion: VMOTION

We used five levels of particle velocity at 172-334 pixels/sec, increasing by approximately 54.4 pixels/second at each interval, based on perceptual thresholds of particle motion determined in pilot testing. In all the conditions the color of the particles was yellow. We chose this color because in pilot testing it seemed to be the most visible color in both conditions without being so high contrast that it caused eye strain (e.g., red). Based on a post hoc analysis, the first interval of data was used as practice and not included in the analysis.

4.4 Population and Environment

The population consisted of 12 undergraduate computer science students with minimal AR experience. The study was conducted in a quiet, air-conditioned laboratory environment with only one experimenter and one participant present during the study.

4.5 Procedure

The study procedure lasted approximately 1 hour.

Training: Participants were trained to use the system with the flat background condition. They went through a few velocity increases and button presses until they felt comfortable with the interface and visualization.

Testing: Participants proceeded through several iterations of the test in random order. Thus, each participant proceeded through 2 (RCLUTTER) * 4 (RMOTION) * 3

(VCLUTTER) = 36 sequences with each sequence having 4 increases in particle velocity (VMOTION). That is, 144 data points per participant. Each particle velocity increase occurred between 10 and 20 seconds so participants could not guess the times between velocity increases. Each of the sequences had different timings, but the sequences remained consistent across participants and across conditions.

Post-interview: participants were interviewed about their experience.

4.6 Metrics

We used the following metrics to assess participant perception of velocity changes:

Number of correct answers: These are the pushed buttons detected that correspond to a real velocity increase in a sequence. An answer was considered correct if it was pushed during a window of three seconds after the real change occurred. The three second window was chosen from post-hoc analysis of pilot studies. It was based on the data frequency – most button presses fell within this window. Treating the first change as practice, the maximum of correct answers per sequence is 4.

Number of false-positive answers: These are button presses that occurred outside the three second window after a velocity change. That is, these are the pushed buttons detected that do not correspond to a real velocity increases in the sequence. These are misconceptions that the user had in thinking that a velocity change happened when it did not or the user took too long to decide (i.e., he or she may have been unsure).

Response Time: The time between the velocity changes and the button presses was measured.

Post-experience interview: At the end of the study the participants were asked to describe the factors that affected their ability to perceive the velocity increases.

5. Results

Analysis approach and justification: Because the data was mostly numerical and we were specifically interested in investigating the interactions between variables, we performed two-way ANOVAs followed by paired samples t-tests with Bonferroni correction. Due to the small sample size, we computed exact p-values when possible.

5.1 Correct Answers

Note that participants could either receive 1 or 0 here for correct or incorrect, respectively. Using ANOVA here might be considered unusual since the correct answers data is binary, and could be considered nominal. Although in this case Cochran’s Q may seem more appropriate (i.e. Cochran’s Q is basically the binomial version of a repeated measures ANOVA), there is not a two-way version, which means that interactions cannot be effectively assessed with

Cochran’s Q. Thus, we used ANOVA here to maintain consistency in our data analysis between main effects and interactions.

We found a significant main effect of virtual clutter on number of correct answers ($F(2,22) = 15.91, p < .001, \eta^2 = .591$) (Table 1). Post-hoc tests showed that were significant differences between 1 and 32 ($p < .001$); 16 and 32 ($p = .03$).

VCLUTTER (# Particles)	Mean	Std.Error
1	.266	.025
16	.326	.029
32	.411	.028

Table 1. The number of correct clicks (min 0, max 1) for each level of virtual clutter

We found a significant main effect of virtual motion on number of correct answers ($F(3,33) = 4.23, p = .012, \eta^2 = .27$) (Table 2). Post-hoc tests showed a significant difference between 226 and 334 ($p = .013$).

VMOTION (px/sec)	Mean	Std. Error
172	.288	.039
226	.295	.032
280	.358	.026
334	.396	.028

Table 2. The number of correct clicks (min 0, max 1) at each level of virtual motion – particle velocity

There was a significant interaction of real clutter and virtual motion ($F(3,33) = 3.75, p = .02, \eta^2 = .25$) (figure 4).

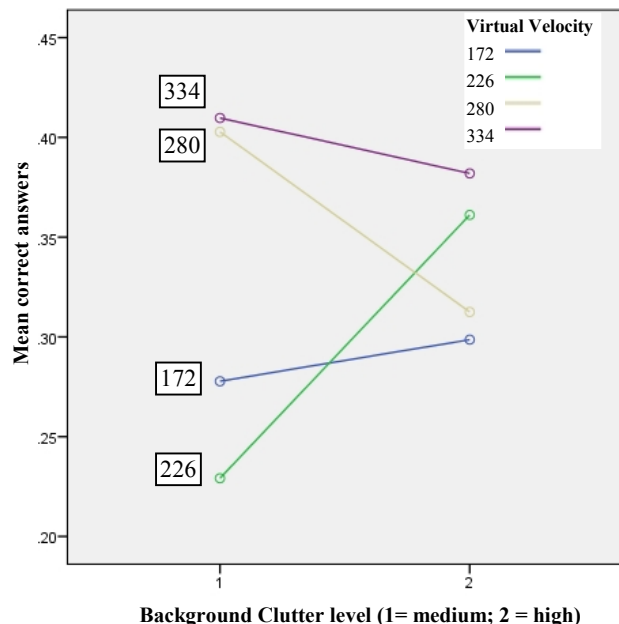


Figure 4. Interactions between # of correct answers at each level of virtual velocity (VMOTION) and real clutter (RCLUTTER)

5.2 False Positive Answers

We found a significant main effect of virtual clutter on the number of false positive answers, ($F(2,22) = 4.7$, $p = .02$, $\eta^2 = .29$) (Table 3), but post-hoc tests only showed near significance between 1 and 16 ($p = .067$).

VCLUTTER (# Particles)	Mean	Std. Error
1	.586	.049
16	.708	.054
32	.596	.044

Table 3. The number of false positive answers (min 0, no max specified) for each level of virtual clutter

We found a significant main effect of virtual motion on number of false positive answers ($F(3,33) = 4.247$, $p = .012$, $\eta^2 = .27$) (Table 4). Post-hoc tests showed a significant difference between 172 and 334 ($p = .026$).

VMOTION (px/sec)	Mean	Std. Error
172	.535	.035
226	.611	.057
280	.660	.068
334	.715	.045

Table 4. The number of false positive answers (min 0, no max specified) for each level of virtual motion

There were significant interactions of (figure 5) real clutter and virtual motion ($F(3,33) = 4.9$, $p = .006$, $\eta^2 = .3$).

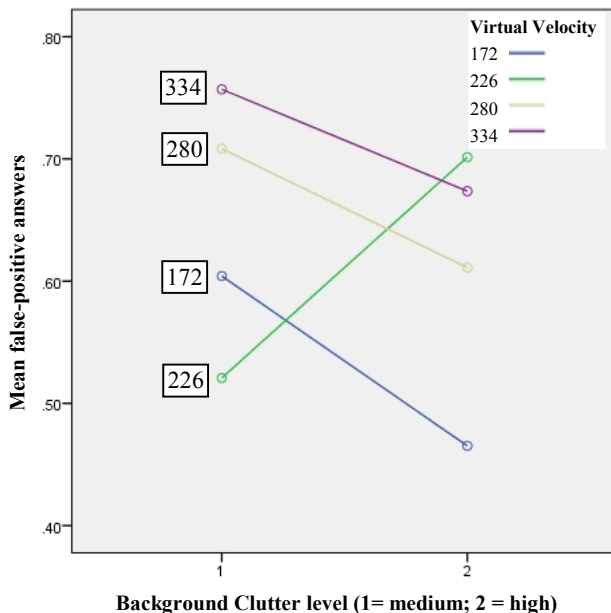


Figure 5. Mean false-positive answers at each level of virtual velocity (VMOTION) and real clutter (RCLUTTER) to show the interactions between these variables

5.3 Response Time

We found a significant main effect of virtual clutter on response time ($F(2,22) = 37.71$, $p < .001$, $\eta^2 = .77$) (Table 5). Post-hoc tests showed that there were significant differences between all levels ($p < .009$).

VCLUTTER (# Particles)	Mean	Std. Error
1	6.178	.259
16	5.642	.256
32	4.899	.234

Table 5. Response time(sec) for each level of virtual clutter

VMOTION (px/sec)	Mean	Std. Error
172	6.189	.451
226	5.581	.285
280	5.276	.241
334	5.246	.177

Table 6. Response time for each level of virtual motion

We found a significant main effect of virtual motion on response time, ($F(3,33) = 3.75$, $p = .02$, $\eta^2 = .25$) (Table 6), but post-hoc tests only showed near significance between 172 and 280 ($p = .09$).

There was a significant interaction of real motion and virtual motion ($F(9,99) = 2.98$, $p = .003$, $\eta^2 = .21$) (figure 6).

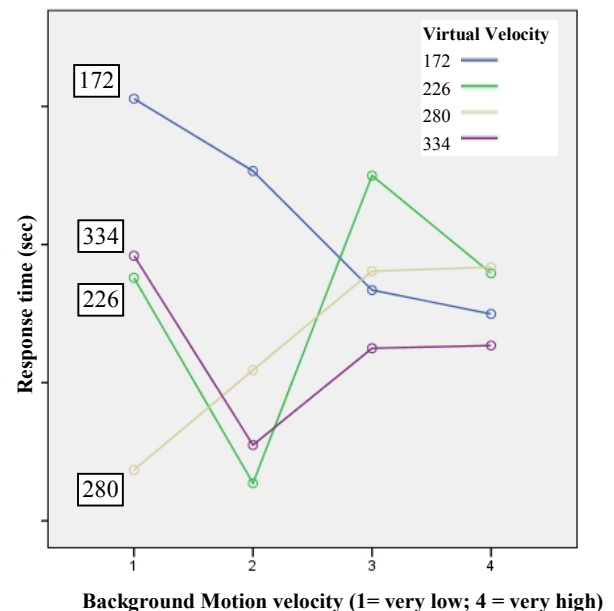


Figure 6. Means of response time at each level of virtual velocity (VMOTION) and real motion velocity (RMOTION) to show the interactions between these variables

5.4 Other significant Interactions

It is important to note that we also found significant interactions between real clutter and virtual clutter ($F(2,22) = 5.34$, $p = .013$, $\eta^2 = .323$), virtual clutter and virtual motion ($F(6,66) = 2.48$, $p = .031$, $\eta^2 = .18$) and significant ($p < .05$) three-way and four-way interactions between the most of the variables. However, these types of interactions lead to a very subjective interpretation. Thus, we limit our discussion to highly significant ($p < .01$) two-way interactions.

6. Discussion

Main effects of false positive answers suggest that increasing virtual motion increases user error. However, this is not obvious when looking only at results of correct answers and response time. Participants had more correct answers at higher virtual motion and higher virtual clutter. Similarly the results also indicate a faster response time at higher virtual motion and higher virtual clutter. However, the number of false positive answers seemed to increase consistently with an increase in virtual motion, which likely increased number of correct answers and shorten response time. That is, at high virtual object velocities, participants were more likely to perceive a velocity change when there was no velocity change.

On the other hand, increasing virtual clutter did not seem to consistently increase error. Post-hoc tests indicated that there was a difference between low virtual clutter and medium virtual clutter but the mean of false-positives at high virtual clutter was close to the low virtual clutter. That is, the medium virtual clutter condition participants falsely perceived more velocity changes at the medium level of virtual clutter than at the low level, and anecdotally than at the high level. This was surprising to us.

It was also surprising that we did not find any main effects based on background motion or clutter. We wondered how these variables may have influenced the main effects we saw with virtual clutter and virtual motion. Thus, to investigate this further we analyzed the interactions of the four independent variables: virtual clutter, virtual motion, background clutter, and background motion.

In the analysis of correct answers, we found significant interactions between virtual motion and real clutter (figure 5). At lower virtual motion (172-226 px/sec), increasing clutter increases correct answers. However, at higher virtual motion (280- 334 px/sec), increasing clutter decreases correct answers. Thus, at lower virtual motion, increasing clutter can have a positive effect on virtual object motion perception.

We also found significant interactions between virtual motion and real clutter for false positive answers (figure 5). Increased clutter almost always decreased the number of false positive answers, except at the 226 px/sec, where increasing clutter increased error. To explain this, consider both correct and false positive plots (figures 4 and 5) together as total click frequency. The main difference between the shapes of the plots is at the lowest velocity (172

px/sec). Thus, at the lowest virtual object movement velocity, real clutter increases correct answers and decreases false positive answers. We hypothesize that a cluttered background shown under slow moving virtual objects actually gives users additional cues that serve to improve virtual object motion perception.

Results suggest that real background motion influences virtual object motion perception in terms of response time (figure 6). At low virtual object velocity (172 px/sec), increasing real motion appears to decrease response time. At moderately high virtual object velocity (280 px/sec), increasing background motion appears to increase response time. At the moderate low (226 px/sec) and very high (334 px/sec) virtual velocities, increasing background motion does not have a consistent effect on perception. Thus, it is unclear how to characterize the combined effects of background motion and virtual object motion. However, there does seem to be a complex combined effect of background motion and virtual object velocity on perception response time.

7. Conclusions

At the beginning of this article we posed the question - how much will motion and visual clutter affect the user's perception of virtual object motion in augmented reality? Our study results offer some insight into the answer. Perception of virtual object motion depends on the velocity of virtual objects, the level of virtual clutter, the clutter in the background, and the motion in the background. However, one unexpected result of this study was that high background clutter can sometimes have an augmentative impact on virtual object motion perception, when the virtual objects are moving at slower velocities.

But what does this imply for AR application developers and researchers? The take home message of this paper is: Consider that background motion and clutter from the real world may impact perception of virtual objects' motion.

This may seem obvious to some, but it has typically not been addressed in practice. Most previous AR work used relatively simple, low motion backgrounds, which was often due to tracking constraints. However, these constraints are quickly becoming less stringent. Thus, the AR community needs to consider how background motion and clutter may affect user perception in future AR applications and research studies.

In the future we plan to conduct more empirical studies on perception in motion-cluttered AR and develop overlay and layout techniques to mitigate ill effects on perception.

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