Exploring Individual Differences in Raybased Selection: Strategies and Traits

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Abstract

User-centered design is often performed without regard to individual user differences in aptitude and experience. This experiment is an observation of users performing a selection task using common Virtual Environment raybased techniques and analyzes the interaction through psychology aptitude tests, questionnaires and observation. The results of this study indicate correlations between performance and aptitude test and user behavior performed to overcome difficulties in the task. Future directions for more guided research are discussed.

1 Introduction

Virtual Environments (VEs) have the potential to allow users to work beyond normal limitations in reality. A simple example of this is selecting objects at a distance–VEs give the magical ability for users to work outside of their arm reach. Selection techniques to do this have been created such as Raycasting [Mine95], Arm Extension [Poupurev96], Occlusion Selection [Pierce97], World In Miniature [Stoakley95], HOMER [Bowman97], VoodooDolls[Pierce99], etc. All of these techniques require the user to develop an understanding of the interface and use it to determine which actions will result in their desired outcome. Errors in the task arise due to misunderstandings of the required actions (Norman's Gulf of Evaluation) and mistakes in performing the actions (Norman's Gulf of Execution). Traditionally, these gulfs are considered only with regard to the feedback generated by the interaction technique without controlling for user aptitudes, experiences, and preferences.

The methodology used for this study, because of the large number of unknowns, is an anthropological and observational approach. Quantitative measures have been taken and reported when possible and then interpreted within the human actions observed in situations based upon their scoring of standard psychology tests.

Our previous work focused on the interface and its tunable properties that could be changed [Wingrave02] to mesh with the user's internal model whereas this work focuses on the user and their aptitudes and experiences that make up that model. To date, experience and a few design guidelines have been the major methods of predicting how users will react to virtual environment interfaces, leaving the problem of design still a difficult issue [Herndon94]. Designers and researchers have already observed how certain users learn particular interfaces faster or better than others. This work investigates individual differences as measured by standard psychology aptitude tests, performance data (accuracy and speed), demographic information, and expert observation.

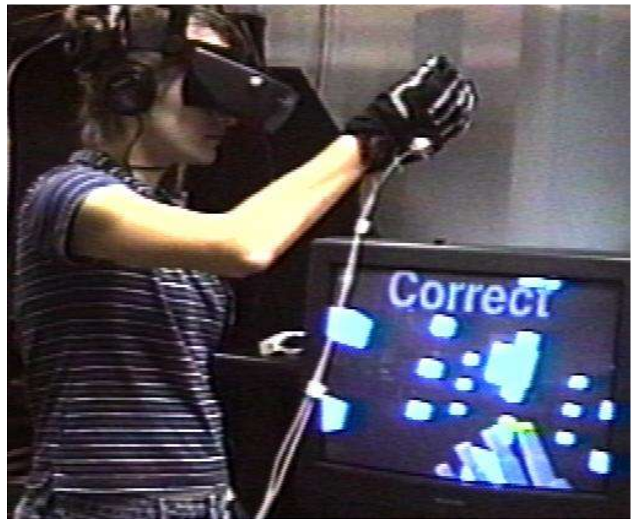

Figure 1. A participant selects a cube correctly.

2 Background

This research drew from two distinct areas: VE interface research and aptitude testing. The domain was strictly a VE problem but we analyzed it with tools and techniques more familiar to experimental psychology.

2.1 VE Background

The task of selection in VEs has been defined in [Bowman99]. In this experiment we used two selection techniques, Raycasting and Occlusion selection. Both of these techniques require aligning a one-dimensional ray to an object in three-space which reduces to a 2D alignment task. Raycasting is where a ray, going to infinity, is projected from the user's finger into the environment and objects that intersect that ray can be selected. Usually a button is pressed to signal that the user intends to select an object but in this experiment, the user was wearing Fakespace PinchGloves™ and pinched their fingers together, either their index and thumb or middle finger and thumb. Raycasting's feedback was the ray coming out from the fingertip and was implemented such that objects are highlighted when the ray falls on top of them. Occlusion selection is much the same as Raycasting in that a ray exists in the environment but that ray originates from the user's eye and continues through a point or bulls-eye, usually the fingertip, to infinity so the ray is not actually seen.

Raycasting and Occlusion selection have been shown to be similar in performance time but Occlusion selection is believed by users to be more accurate yet also more fatiguing

[Wingrave02]. Additionally, both techniques work similarly by aligning a ray and then pinching, and both have tradeoffs between fatigue, accuracy and speed. Because of this, we can then induce from observed behavior the user's internal tradeoffs when dealing with fatigue, accuracy and speed.

In previous experiments [Wingrave 2002], we have used snap-to angles to provide extra feedback to users for these selection techniques: when the user's ray comes within the snap-to angle of an object a snap-to ray is emitted from the origin of the original ray (e.g., the fingertip or the eye), pointing to the closest object within the snap-to angle. For Raycasting a separate ray is drawn and for occlusion selection, a separate bullseye is drawn over the object. Users incorporated this improved feedback into their selection strategies.

2.2 Description of Tests Used

All users of an interface, VE or otherwise, bring to bear their own pre-existing preferences, aptitudes (physical, perceptual, and cognitive), and prior experiences in the world. These attributes can be considered as distinct from, but interacting with, the user's knowledge and skills that result from direct experience, practice, feedback, and training on an interface. By having participants complete a battery of aptitude tests that have potential relations to the skills needed in the VE selection task, we can begin to uncover predictors of performance, as well as highlight attributes of the users that may influence VE design.

Four tests were used, all standard psychology paper tests. They were all timed tests, were given in groups and scored in the standard manner for each test. The tests were chosen for their ability to test widely different aptitudes of the participants, and not specifically for their perceived relevance to VEs. The first test was the Addition Test[1], used to test number facility. The test has users complete as many addition problems as they could in a time limit. This codes for "retrieving appropriate number associations and algorithms from long-term memory and performing serial operations on the stimulus materials using these associations and algorithms." [Carroll74] The second test was the Word Endings Test[1] (WET), used to test word fluency. Participants were given letters and told to write as many words as they could that end in those letters. This test is "a search of a 'lexicographemic' portion of long-term memory for instances fitting the orthographic requirements. Strategies may include the use of an alphabetical mnemonic to systematically search the memory."[Ekstrom76] The third test was the Maze Tracing Speed[1] (MTS) test, used to test spatial scanning. Participants had to trace through as many mini mazes as they could in a time limit. This test has sometimes been used for planning and is "somewhat analogous to … rapidly scanning a printed page for comprehension." [Ekstrom76] The last test was the revised Vandenburg and Kuse Mental Rotations Test[2] (MRT) [Peters95], used to test spatial orientation. Participants observed a CAD drawing of blocks and four similar drawings. Participants had to mark which of the two drawings the original block configuration could be rotated into. This factor is "The ability to perceive spatial patterns or to maintain orientation with respect to objects in space." [Ekstrom76]

2.3 Related Work

There have been many studies involving VEs and various aspects of psychology, but almost all have been towards using VEs to explore human functioning. According to [Rizzo01], VEs are expected to be of "considerable value for better understanding, measuring, and treating persons with impairments due to traumatic brain injury, neurological disorders and learning disabilities." They are being used to assess and treat balance [Jacobson00] and psychological disorders [Hodges01]. VEs have also been used to study visuospatial skills [Rizzo00] and gender issues [Larson99], even to improve spatial rotation among deaf and hard-of-hearing children [Passig01]. VEs have also been considered as a means of not just evaluating but training spatial behavior [Darken00]. More on the VE side, studies have been performed that use psychology paper tests but use them to eliminate a variable in the experiment. That differs from the present experiment which is looking for links between the tests and VEs. The Cube Comparison test [ETS S-2] was used in navigation interface studies for long distance navigation [Pierce01] and evaluating orientation during travel [Bowman99b]. Relevant research also includes comparing spatial information transfer of VEs to the real world [Waller 2001] and even real world studies such as selecting objects with laser pointers [Meyers02]. These studies all show intersections between VE interfaces and psychological research.

3 Experiment

The experiment was divided into two sessions, one hour each. The participants were taken from undergraduate psychology and computer science classes and received course credit for their participation. A total of 25 participants completed both sessions; the data were used from 24 of these participants as the last participant was scheduled but not needed (13 male, 11 female; age range 18-24 years).

In the first session, participants were brought together in groups of sizes from 7 to 11 and administered the paper psychology tests. The tests were ordered so as to minimize mental fatigue on the participants and they were given as much time as they wanted between tests (usually a minute or two). The order was the Addition Test, the WET, the Edinburgh Handedness Inventory [Oldfield71], the MTS test and then the redrawn MRT. The Edinburgh Handedness Inventory was used to provide a pause between these tests[3] and was an untimed test of handedness. This session lasted for about an hour.

In the second session, participants returned to the lab and completed the VE test individually. The equipment used was an SGI Indigo 2 with Impact graphics using a V4 head mounted display (HMD). Participants had their head and hands tracked using a Polhemus 3 Space Fastrak magnetic tracker and selections were recorded with Fakespace PinchGloves™. The graphical environment itself was a 3x3x3 array of blue cubes that hovered in front of the user out of reach and wide enough to not all fit on the display at any one time (see Figure 2). Before entering the environment, users were told about what they would see, the equipment they were using and the task of selection that they were to perform. Also explained were the techniques of Raycasting and Occlusion selection and that there were six different configurations of each they were going to be

[1] The Manual for Kit of Factor-Referenced Cognitive Tests can be obtained from Electronic Testing Services at http://www.ets.org/research/ekstrom.html.

[2] Dr. Peters is happy to provide interested researchers with copies of the redrawn MRT used here at cost. peters@psy.uoguelph.ca

[3] People in groups tend not to ask for breaks because they don't want to slow down others in the group so the handedness test gave a break automatically.

using similar to [Wingrave02]. The snap-to effect was also explained as well as their ability to pinch with either their index and thumb or middle and thumb to signal a selection. They were told that they were to use the selection techniques to select the cube colored red when the trial began. There was a training phase where the participants made 10 selections with each configuration and were allowed to ask questions. This was followed by the experiment phase where participants selected each cube in the environment, with the order of selection cued in a random order. They were told to select as quickly and accurately as possible as well as not to step forward, as this would bring them closer to the cubes, but lateral motion was acceptable. Participants were counterbalanced between starting on Raycasting and Occlusion selection as well as the configuration that they started with, leading to a 2x6 within-subject design. Participants were also videotaped with their permission.

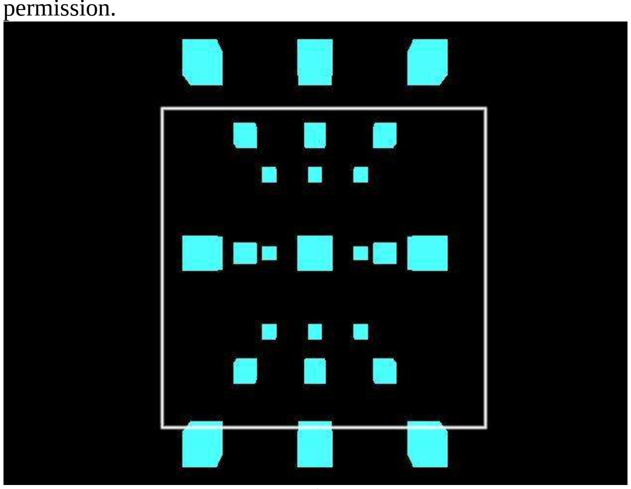

Figure 2. The cube layout of the environment with a box showing the normal viewable area of the user

3.1 Data Collected

Data were collected from both sessions through standard data collection techniques as follows. In the first session, the four tests for psychological factors were scored as appropriate to each test. In the second session, participants were surveyed for demographic information (age, gender, education, etc.) as well as everyday activities (exercise, computer use, music listening, etc.), experience with graphics and physical characteristics (height, arm length, etc.). Before, during and after each selection technique's trials were performed, participants were given comfort ratings forms and at the end, a post questionnaire about their experience with the techniques. The comfort as well as the demographic surveys were administered using seven point Likert-type scales as well as open-ended questions. The VE trials were logged at time of selection and performance data for each selection was gathered, including number of errors, accuracy of each selection, and time to complete a trial.

4 Results

The results of our approach to this study were categorized into effects, gender issues and behaviors. Effects are reported for how the measured factors affect the user. Gender issues are just that and behaviors of the user are reported as participant strategies and hindrances.

4.1 Effects

Raycasting Slower than Occlusion

Overall, Raycasting was slower than Occlusion selection in this environment. The difference most likely comes from the difficulty level of selection in this environment where in the previous comparison studies there were no occluding cubes [Bowman97]. The means for selection of the cubes were 2.60s (std = .488) for Raycasting and 3.03s (std = .792) for Occlusion selection.

User Comfort Correlated with MTS and WET Measures

Part of the post survey asked users to rate the comfort level of each selection technique. Overall, Raycasting was rated as more comfortable than Occlusion selection (reverse-scored on a 7-point scale, mean comfort of 2.67, std = 1.66, and 5.3750, std = 1.24, respectively). This corresponds to prior results in the literature [Bowman01].

Correlation coefficients were calculated between the different comfort ratings, the participants' performance measures, and their scores on the aptitudes tests. Higher scores on the Word Ending Test were highly correlated with higher levels of comfort with Raycasting (r = .538, p = .007). Higher WET scores also highly correlated with Raycasting satisfaction (r = .571, p = .004) and correlated Raycasting accuracy (r = .419, p = .042). WET scores were not correlated with Raycasting time per trial (r = .034, p = .873) or even errors (r = -.092, p = .670). Thus, we can say that participants who score high on the WET test seem to perform well with Raycasting selection, and are more comfortable with that interaction style. However, the reason for such a linkage is not clear at this point and only mentioned because of the multiple significant results.

Higher scores for the MTS were positively correlated with Occlusion selection comfort (r = .454, p = .026). One potential explanation for the MTS – Occlusion comfort correlation would be that MTS scores correlate with reduced time per Occlusion selection trial and thus reduced time per trial would lead to a feeling of greater comfort. However, this was not the case, as MTS scores were not significantly correlated with less time per Occlusion selection trial (r = .209, p = .326). However, [Carroll74] noted that subjects with high MTS scores discovered the strategy of working the mazes in reverse to improve speed. Therefore, we might theorize that in the present study participants with high MTS learned strategies in Occlusion selection to help them improve their performance. If this were the case, there should be a correlation between MTS and Raycasting comfort, which there was not (r = .162, p = .449). This lack of correlation between MTS and Raycasting comfort might be due to two reasons; 1) a significant correlation between MTS and reduced Raycasting time (r = .461, p = .023) and 2) the low levels of fatigue inherent to Raycasting in this study.

Computer Experience

There appears to be a transfer of experience from computer and graphics usage to Raycasting. Such evidence comes from correlations between low Raycasting trial times and user surveys on experience with 2D graphics (r = .488, p = .016), 3D graphics (r = .493, p = .014), familiarity with computers (r = .439, p = .032) and frequency of computers for fun (r = .560, p =

.004). These correlations are even higher for Raycasters (i.e., those who preferred Raycasting) with correlations between low Raycasting trial times and user surveys on experience with 2D graphics (r = .753, p = .003) and 3D graphics (r = .672, p = .012). The usage of computers for fun was marginally significant (r = .543, p = .055). If computer users are better at performing Raycasting, this can call into question past studies that did not control for computer experience. It would also point out that novice computer users may prefer Occlusion selection, which could have implications for the design of interfaces that could be used by large numbers of computer novices, such as, for example, augmented reality guides used in museums.

Addition Test and its Correlated Effects

Higher scores on the Addition Test were correlated with an increased selection time in Occlusion trials (r = .442, p = .030); this was especially true for females (r = .837, p = .001) but not so for males (r = .320, p = .287). For those participants who considered themselves Occluders (i.e., they preferred the Occlusion technique), the Addition Test score was correlated with increased Raycasting time (r=.596, p = .032). Based on observation, participants with high Addition Test scores had difficulty working with the lack of depth control, performing the reaching and pulling actions to be discussed in section 4.3.2. It has been suggested that the Addition Test, in coding for the Number Facility cognitive factor, is "part of an 'automatic process' factor, incorporating both number facility and perceptual speed, which is operant when responding to over-learned material" [Ekstrom76]. This helps explain the measured and observed results here, in that participants with high Addition Test scores were trying to work as if reaching, an over-learned task, which resulted in a decrease in performance. If this is the case, high Addition Test scores might hinder, or at least slow, the ability of users to work beyond reality, a property of many 3D interaction techniques which purposefully differ from reality: as stated by Pierce, "We can create new interaction techniques by breaking our assumptions about the real world" [Pierce01].

Height and Arm Length

The selection techniques were implemented the same for all participants and correlations were found between height and arm length of the participants as reported in the literature [Bowman01]. Taller participants and longer arm length both were significantly correlated with participant satisfaction of Raycasting (r = .435, p = .033 and r = .485, p = .016, respectively) but not with performance. Taller Occluders were more satisfied with Occlusion selection (r = .643, p = .033) and taller Raycasters with longer arms were more satisfied with Raycasting (r = .628, p = .022 and r = .691, p = .009, respectively) but again, no correlation to performance. For males, increased height and increased arm length correlated with faster Raycasting performance (r = .643, r = .018 and r = .646, p = .017, respectively) but no similar effect was found for females. This matches suggestions by [Poupyrev97] which says measurements should be in *virtual cubits*, equivalent to the length of the user's maximum reach in a VE.

4.2 Gender Issues

The effect of gender was expected to play a role in performance and preference, especially with a spatial task [Voyer95] such as Raycasting. It did but whether it was caused by experience or something innate to gender is unclear here and in the literature. Rizzo et. al. found that training in a VE removed the gender difference between males and females on the MRT [Rizzo2001]. In our study, males were significantly faster at Raycasting trials than females (male trial mean = 2.62s, female trial mean = 3.52s, p=.003). Males were also significantly different from females in terms of self-reported familiarity with computers ($mean_{male}$ = 5.923, $mean_{female}$ = 4.272, F = 23.636, p < .001), frequency of computers for fun ($mean_{male}$ = 6.923, $mean_{female}$ = 5.000, F = 11.294, p = .003), experience with 2D graphics ($mean_{male}$ = 5.5385, $mean_{female}$ = 2.8182, F = 10.915, p = .003) and experience with 3D graphics ($mean_{male}$ = 4.9231, $mean_{female}$ = 2.6364, F = 8.020, p = .010). All of these variables were correlated with improved Raycasting performance (see Computer Experience above). In consideration of the results by Rizzo [Rizzo2001], we would have to suggest that familiarity with computers and computer games is the prime factor, and not gender, per se.

College major has been shown as a factor in spatial ability tasks [Casey 1989] and might play an important role here. The idea is that choice (i.e., self-selection) of college major is correlated with aptitudes, such as those measured by the spatial abilities tests. It is also correlated with experience in the use of computers, partly as a result of the course requirements, and partly as a result of the difference in males and females in the various majors. Though it is purely correlational at this point, it may be the case that college major could be a quick (though definitely not perfect!) indicator of either performance or preference in VE selection tasks. Of course, this is only an initial suggestion and would need to be studied in greater depth. The male participants were six computer science majors, five engineers, one science and one undecided. The female participants were four psychology, two business, one architecture, one engineering, one biology, one chemistry and one undecided.

4.3 Observed Behaviors

Beyond the measurable data in this experiment, participants were observed expressing two types of behaviors during the selection tasks. The first type of behavior included strategies to help them deal with either limitations of the environment, the selection technique or within their aptitudes. The second type of behavior observed were actions users performed that unknowingly hindered their ability to complete the task. This second type of behavior might be due to human nature or experience with the real world. In any event, these hindering behaviors tended to fade with experience as users became more adept at the task at hand and realized the negative effect of the behavior. The ability to measure some of these observations is limited because we were not instrumented to recognize the specific behaviors and additionally because users change behaviors and adapt quickly in response to feedback. Supporting evidence, when available, is noted but video is the best record.

4.3.1 Observed Strategies

Strategies are observed behaviors that certain participants performed, usually as a tradeoff of one aptitude for another so as to increase their overall performance. In some cases, users on their own did not have the ability to perform the task without the strategy. Strategies are listed here with what supporting evidence was possible.

Tracker Lag Strategies

In this experiment, a Polhemus Fastrak tracker was operating at 30 updates a second sending data to the computer at 38400 baud in continuous binary mode. This led to a small but noticeable lag, normal to most VEs. Even in this state, there were two observed strategies dealing with tracker lag for the two selection techniques. The first was the "hover" strategy where users held their pose for a moment before pinching to wait for any type of tracker lag to become apparent in their movements. This increased user accuracy at a cost of speed and was mostly only apparent at first, before users became accustomed to the system. The other strategy used was "work ahead" where some participants, once comfortable in the environment, would pinch before trackers had a chance to catch up, working off their proprioceptive sense. This was usually employed on objects that were easier to select since the feedback of the technique was not needed. This decreased user time at a cost of accuracy and was generally only seen performed by participants that were proficient with the interface.

Strategies Towards Increasing Accuracy

There were two strategies observed by users to increase their accuracy inside the techniques. The first was a "sweeping strategy" in Raycasting where users would align the ray along a row of the cubes, using the feedback of the technique to tell them where the ray was, and sweep across the other unaligned dimension to align with the correct cube. This required extra time but increased accuracy to the point that for those having difficulty, it was possible to complete the selection. Various degrees of this behavior were observed with users scoring lower on the MRT test employing higher degrees of sweeping. Another strategy was to extend the arm into the environment. In Occlusion selection, this was to decrease inaccuracies caused by tracker jitter and user arm unsteadiness. In Raycasting, this brought the hand more inline with the eye and thus easier to work with visually. In both cases, extending the arm traded-off fatigue for increased accuracy. An extreme case of this was users locking their arm in position with their head and moving their arm like a turret around the environment and "firing" at the cubes.

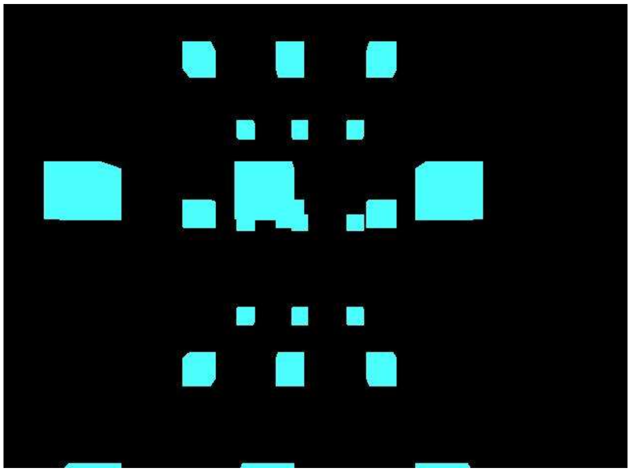

Figure 3. The typical user view was to the side so they could see objects further in the back that would normally be occluded. Notice all cubes do not fit on the screen at the same time, creating a need for searching strategies.

Strategies Assisting Cube Finding

Since the cubes did not all fit in the view at once, there were strategies used in finding the cubes faster (see Figure 3). The first was to tilt their head at an angle so as to fit the entire scene, not completely in view, but requiring a glance along only a single dimension. This can be fatiguing for the neck and disorienting for the user. A second technique was to glance across the scene through all four corners and then narrow-in on the red cube. Participants using this strategy might even glance past the red cube at first but as they process the scene, they will return to the original location and select the object. This technique leads to disorientation but a faster rate of finding objects by making use of visual memory. The last strategy, used by all participants, was to step to the side of the original position so that the middle row was not fully occluded.

Snap-To Angle Strategies

There was a continuum of how participants used the snap-to angle feedback of Occlusion and Raycasting selection. User behavior at one end was focused on using the feedback to narrow in on the object to be selected. In this sense, the feedback gave a direction to move in order to increase accuracy. The other extreme was to use the snap-to angle as the ultimate line between which object was selected. If users were at this extreme, they would not focus on increasing accuracy if the snap-to feedback told them they were correct, they would simply pinch. The tradeoff was that tracker jitter, arm unsteadiness, and the act of pinching the finger (sometimes referred to as the Heisenburg effect [Bowman01b]) was enough to result in a selection error. If users used the feedback to narrow-in, they would have less of a chance of this occurring but at the cost of time spent increasing the accuracy.

Strategies to Alleviate Fatigue

There are two strategies that users employed to reduce fatigue with these two experiments. For Occlusion selection, users would pull their arm in closer to their face since extending their arm required exerting more physical effort. For Raycasting, users held their arms lower to "shoot from the hip" [Bowman99]. Both of these strategies trade off fatigue with accuracy and have been well documented in the literature.

Multiple Successive Pinches

As already mentioned, many participants pinched their fingers multiple times in succession while trying to select a difficult cube. Since there was no penalty for incorrect pinches to the user's goal of finishing the experiment, this strategy can be seen as reducing the aiming time of the technique at a cost of accuracy and follows a binomial distribution, increasing the overall chance of success with each pinch.

Task Specific Error

The selection techniques, as implemented in this environment, detected the object closest to the ray at the time when the user pinched, and considered that object to be the "selected" object. Because of this lack of a minimum accuracy for selecting an object, users only had to select well enough so as to not be confused with another cube. As a result of this, there was no reason not to err so long as the correct object to be selected still had the lowest err. In the top of Figure 4, a cube that was harder to select was selected with higher precision selections. In the middle of Figure 4, a cube that was relatively easy to select had very low precision selections. In the bottom of

Figure 4, purposeful errs in accuracy were given, by aiming above the cube, to steer away from a cube nearby in the background. Users work with an interface and give accuracy and precision at levels that are required of the task.

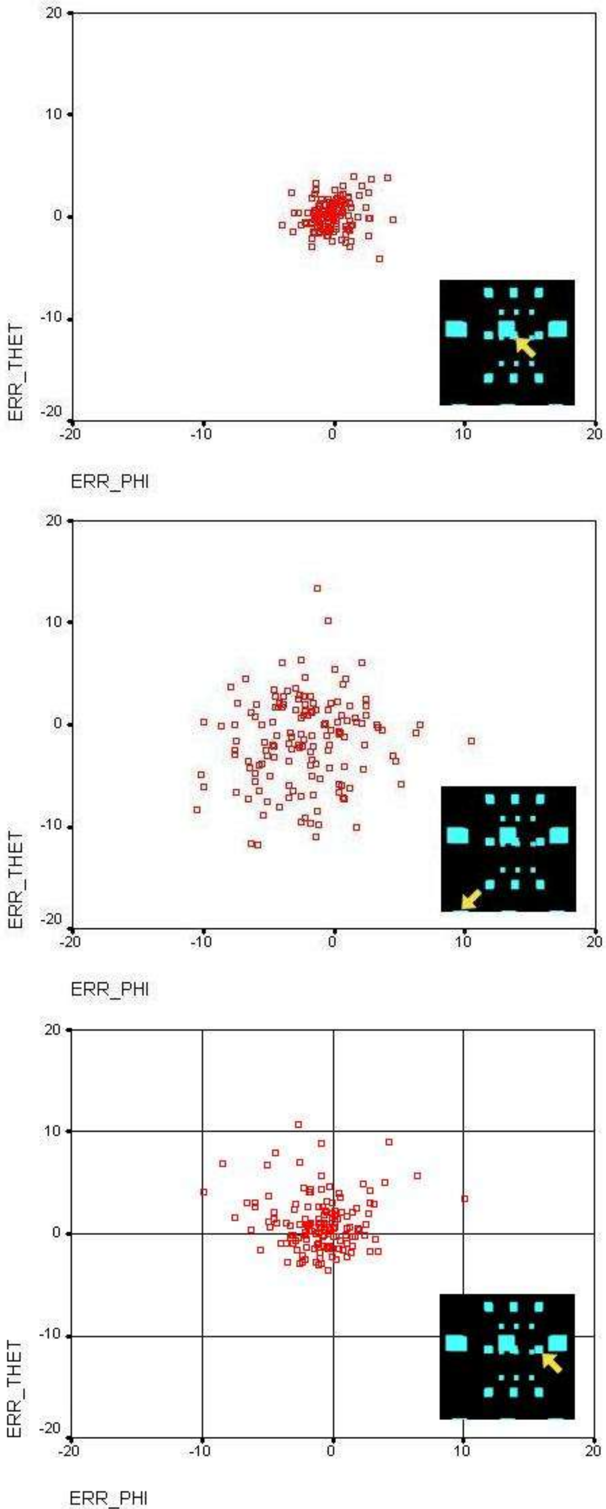

Figure 4. Participants vary their accuracy distributions per cube depending on the amount of accuracy required. Shown are the accuracy of selection of three cubes using Raycasting. Error is in spherical coordinate degrees.

4.3.2 Observed Hindrances

Hindrances are behaviors that participants expressed that either served no performance improvement, and thus was considered wasted effort, or behaviors that actually impeded performance. Experts of an interface can be trained to not perform these actions and remove hindrances as an interaction problem. Interfaces for novices will need to support these behaviors or break the user the habit quickly. Supporting these hindrances could increase interface accuracy since users encode information about their intent in the hindrance.

Speed-Accuracy Tradeoffs after Errors

Users tended to become familiar with the selection techniques after a few trials and then slowly increase their speed over time as they created strategies and became more familiar with the environment. However, users made occasional errors, some more than others, and this took them out of their routine and caused them to tradeoff slower performance in favor of improved accuracy. This is a well-known occurrence in cases where there is a speed-accuracy balance, and it often causes a dip in speed, until the participant regains confidence. This is precisely what was observed here, and was described as a period of “bad vibes,” during which selections were generally slower but more accurate, until users ramped back up to pre-error speeds.

Looking Up In Occlusion Selection

Arguably an implementation issue, this hindrance occurs in Occlusion selection when users are selecting cubes high in the environment and look up higher and higher to select the cube. Since the rotation of the head occurs at the neck and the starting point of Occlusion selection is the eyes, the motion of tilting the head back lowers the occlusion ray making selection harder. After a few trials most users adapted, by not raising their head high, though whether or not this was a conscious decision is unclear.

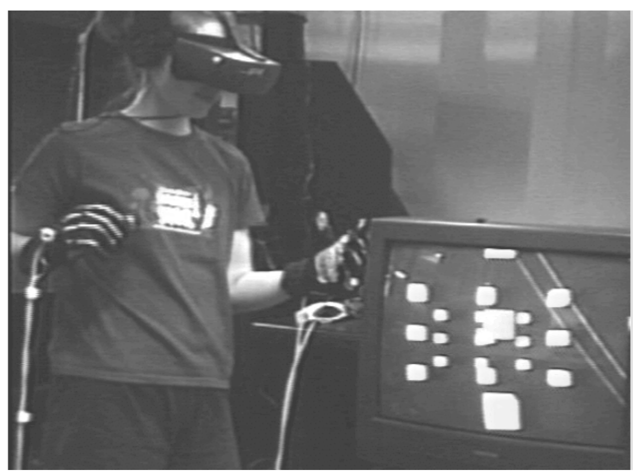

Figure 5. When using the selection techniques, participants pulled their arms back, hindering accuracy and comfort.

Reaching and Pulling

Many users attempted to “reach” or “pull” their arms forward and backward to select objects that were far or close to the user. Since both techniques were raybased selection techniques, the utility of such actions was minimal in the case of distant objects[4], and actually detrimental in the case of close objects. Users went so far as to rotate their shoulders back (see Figure 5) and bend their wrists as their hands moved behind their backs, which was clearly an uncomfortable position. These behaviors fell off with practice, though at faster rates for some participants. Participants with higher Addition Test scores tended to perform these behaviors more.

4.3.3 Supporting these Behaviors

Supporting these behaviors will be future research work but a few design concepts come to mind to better incorporate these strategies and hindrances.

Many types of behaviors could be supported by choosing an error function that changes based upon context. For the "hover" strategy, interfaces could provide more intense feedback when users are performing these actions in the hope that more feedback will reassure the user. For "work ahead" interfaces when determining overall error, the interface could weight heavier the alignment error not along the dimension from which the user traveled. This would select for objects more in line with the user's arc. "Sweeping strategies" are due to users not having an understanding of where their ray exists in space and work off cues given by the interface's feedback. The interface could be improved by weighting for objects that are in line with the sweeping action. "Reaching" and "pulling" behaviors can emphasize objects closer or further from the user that exist on the ray, creating a 2 1/2D selection technique. Task specific error could be managed by identifying a function of how users purposefully commit errors based upon near and overlapping objects.

Other behaviors could be improved by automatically scaling or changing the interface based upon context as has been done for context sensitive flying [Ware97]. When users extend their arm into the environment to increase accuracy, they are increasing the distance between the occlusion ray's start and bullseye which makes the interface more accurate. This action could be augmented in Occlusion selection by moving the start of the ray further behind the user's eyes as they reached so as to further increase accuracy and reduce the amount of reach required. In Raycasting, users bring their ray more inline with their eye to increase accuracy but an interface could recognize this and move the virtual hand up faster. Elevating the user's hand has been unnoticeable even up to as much as a foot and a half in elevation [Bowman01c]. User viewpoint can also be scaled to assist in finding objects in a scene.

Using better or more feedback at certain points in the interface can be used to support the behaviors and reduce the hindrances. "Reaching" and "pulling" behaviors can be supported with graphics showing what the interface believes to be selected and the value of that belief. When users feel "bad vibes" after an error, immediate supporting feedback on the next task can help the user regain confidence in their abilities and disappear once the user has returned to normal. To alleviate fatigue caused by overextended hands, the interface could tell the user directly or even enter jitter as a function of the distance the hand exists from the body being careful to not cause them when the user truly DOES want to extend their arm.

Modifying user actions, when done properly, can increase the usability of an interface. Machine Gun pinches could be supported by averaging multiple temporally close pinches into one average pinch. Supporting behavior by modifying user actions can be very annoying to the user but useful when done properly.

5 Conclusion

This study observed participants performing a selection task in an occluding environment and correlated data with standard psychology paper tests to discover behaviors and aptitudes of different user types. Important correlations to comfort, experience, aptitude tests, body size and gender were noted between various measures and performance as well as observed strategy and hindrance behaviors of participants. In particular, Techniques in this study also are applicable to analyzing other techniques for other tasks.

This work sets the stage for future research by showing fruitful veins of research. The psychology tests chosen scored for only a fraction of the various aptitudes recognized in the psychology literature. Each observed behavior requires research to recognize it and then to discover ways to deal with it. Each technique dealing with each behavior then requires a study itself to determine how it interacts with other techniques and so on. To manage all this, the results must be put into some control structure to organize the new and complex findings. Future research will pull this and other studies together into a cohesive theory of raybased selection techniques.

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[4] As previously stated, holding the arm out does increase accuracy but this relates to cases where participants either did not move their arm from side to side to select a distant object but instead reached as if reaching past the occluding object, or in even some extreme cases opened their hands as they reached to try and grab objects.

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