ABSTRACT

RETURN TO EARTH: DECAYED RULESETS IN VR

by Nathan James Von Drasek

The focus of this study was to look at how quickly rulesets learned in VR would decay after doing a similar task in reality. Alongside this study is the impact that gender has when tools designed for one gender in mind are used by another gender. Miami students (N = 12) were asked to do both a virtual and real maze inside of the SPoCC lab. They were then compared to themselves on how many mistakes they made from the beginning of the real maze trial versus the end of it. It was found that males made fewer mistakes at the end of the real maze trial than at the beginning. Females did not seem to adjust to the experimental setup at all, which was reflected in them never making any mistakes in the real maze trial. Given these findings, more participants are needed, as well as better tools in the setup, in order to conclusively find the rate of decay for learned rulesets.

RETURN TO EARTH: DECAYED RULESETS IN VR

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This Thesis titled

RETURN TO EARTH: DECAYED RULESETS IN VR

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Dedication

To my wife, Ashley, for all the love and support given to me through thick and thin.

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To all those who helped make this project possible:

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Return to Earth: Decayed Rulesets in VR

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As virtual systems become more and more mainstream in both academic and commercial (home) settings, difficulties in usability continue to be a challenge for researchers and designers (Greengard, 2019; Hale and Stanney, 2017). From nausea, gender differences, to harassment, to triggering traumatic moments, virtual reality has revealed clinical, cognitive, and social issues that psychology is well suited to address. Within cognitive psychology, the recognition that different perception and action relationships can be exhibited by different virtual environments that require a person to learn and adapt to novel constraints present a large domain for research and discovery. Interestingly, from a commercial perspective, this variability in the types of perception-action relationships is one of the key driving forces that generate virtual system sales within the consumer market. It is a part of the experience that one's perceptions can be modified to create a new desired action/perspective. The questions are how might we provide perceptual as well as behavioral support for these new relations as well as will the user be able to detect and exploit these novel relations?

Understanding how users of VR exploit perception and action relationships has been one of the main goals of researcher's who subscribe to James Gibson's (1979) radical view of perception and cognition. Traditional theories of perception assume that the primary function of perception is to organize inherently impoverished or ambiguous stimuli from our senses. Conversely, Gibson asserted that stimulation from the world already contains structured information, thus perception and cognition are not required to create it, but instead employed to guide action allowing one to detect this information successfully. Wagman & Blau (2020) summarize that "Perception is meaningful, on Gibson's account, because there is meaning in the environment that animals perceive" (p.22). From doors, to steps, to user interfaces, what we perceive can give us insights on how to interact with the environment. If a chair is too high, a person will recognize that they can not sit on it. If a door has a handle where you can grip, you're more likely to pull rather than push it. The children's game Bop-It even demonstrates that children are able to see what piece to bop, twist, or pull when the voice in the game commands it. These perceivable opportunities for behavior are known as *affordances* in *ecological perception (Gibson, 1979; Wagman & Blau, 2020)*. In addition, it has been asserted that we are born prepared to explore and are active learners regarding our relationship with our surroundings (Gibson & Pick, 2000). As such VR provides a mechanism for watching that exploration process in real-time with otherwise experienced adults. Smart and his colleagues' (2004) work shows the advantage of examining postural data in this field, "suggest[ing] that postural adaptation involves more than basic reduction or increase of motion; it involves the functional coordination of body segments to achieve a particular goal". In other words, to explore an environment the required adaptation needs more than just an increase or decrease in motion. Coordination of all the body parts is required for goals in VR to be achieved. It is important to recognize that successful interactions in VR depend on the ability of the system to support both perception and action while in the virtual environment. Failure to support both can result in suboptimal behaviors, extended learning curves, and potentially physiological effects (e.g., motion sickness; Smart, Teaford, & Von Drasek, 2020). We see this when we look at new users of VR in comparison to experienced ones. For example, wild flailing of the limbs is more commonly seen in new users who have not figured out the current constraints, whereas experienced users can quickly adjust to keep their coordination regulated and purposeful. While there are some general patterns in behavior that emerge when learning to act in VR, there remain patterns that may emerge from sex related factors that have not been fully addressed.

While perception and action couplings are meaningful to each individual, these couplings may differ by sex. It is known that females are more sensitive to motion sickness (Munafo et al., 2017) yet VR-induced motion sickness can come from a variety of sources, such as interpupillary distance differences (Grassini & Laumann, 2020). It is still not well established how big of an impact gender has on VR. (Grassini & Laumann, 2020). Previous research has not found decisive empirical evidence that can account for the prevalent reports of sex differences in motion sickness susceptibility in virtual environments. The persistence of this issue might also be a consequence of using dependent measures that fail to capture the appropriate changes that would allow for successful differentiation of susceptibility across sexes. In short, the problem of prediction may be exacerbated by methodological and measurement choices. It is possible that these reported differences in susceptibility can be linked more successfully to measurable behavior rather than reported symptomatology.

Physical behavior has the advantage of being readily observable, measurable, and relatively independent of the problems that can be associated with self-reports of motion sickness (Stoffregen & Smart, 1998). In addition, there is some evidence that postural motion (variability and velocity) varies across sex (Smith, Ulmer, & Wong, 2012). Of note, recent studies by Koslucher, Haaland, Malsch, Webeler, and Stoffregen (2015) and Koslucher, Haaland, and Stoffregen (2015) found that motion sickness rates were significantly higher for women and that there were pre-exposure differences in postural motion across sexes that were correlated with sickness incidence. The researchers also found an interaction between sex, task, and subsequent incidence rates of motion sickness. Postural sway analyses may allow us to untangle behavior to be used for future analysis. Postural data has long been shown to be a valid measure for a variety of reasons. Stemming from the Postural Instability Theory of motion sickness, postural motion has been shown to be effective at detecting changes in behavior that precede motion sickness (Stoffregen, Smart, 1998). When people do not adjust to their environment correctly, their posture destabilizes and motion sickness occurs (Smart, Stoffregen, & Bardy, 2002). Using postural data for this experiment allows us to collect quantitative data from participants without the inaccuracies of the Simulator Sickness Questionnaire (Sevinc, Berkman, 2020). Postura motion is a tangible and objective means of accounting for individual differences in participants (Littman, Otten, & Smart, 2010). Since many VR settings also require participants to learn a novel ruleset, postural data can allow us to determine when participants are engaged with the environment and receptive to learning novel rulesets.

The motivating perspectives of this thesis are the ecological theory of perception and action as well as expanding the behavioral adaptation research performed at Miami (Littman, 2010;2011). Littman (2010) found that successful VR users needed to detect and consistently employ the rules of the rearranged environment to prevent sickness and have a successful experience. By this we mean that in order for users to successfully navigate, and manipulate a virtual environment, adaptation and control were vital. The faster that a person was able to adapt to these changes, the less sickness and postural instability they experienced. Littmann (2011) shows that measures that characterize postural motion can be useful in other contexts. Specifically, there are quantifiable changes in both magnitude and structure of behavior during the adaptation process when participants are exposed to novel perception and action relationships. This means that when people try to adapt to a new situation, they exhibit changes in their motion that are distinct. This idea isn't new, as both Dolezal (1982/2004) and Harris (1965) have shown that there are behavioral changes that coincide with adaptation, although Harris (1965) focused on phenomenological aspects rather than explicit motion. Dolezal

(1982/2004) reports in his studies that the adaptation period of his prism goggles experiment resulted in numerous wild errors in his movements, making it challenging to accomplish previously simple things. It wasn't until after a period of time that he was able to go about his life, even going so far as to bike and do water sport activities. This example highlights the importance of having consistent perceptual information (even if novel) to support changes in action.

To present a novel perception-action coupling, this study employed Virtual Reality headsets, 360 treadmills, a VR maze in the game Skyrim, and a real maze on the floor to assess how participants physically navigate a maze in different environments under altered rulesets and normative rulesets. The virtual environment, coupled with the 360 treadmill, does two things: dynamically show the link between control and postural stability, and show the first step in the adaptation process. The physical maze shows the speed at which decay of learned rulesets due to previous adaptation occurs. This setup is informed by two of Littman's (2010; 2011) experiments.

Within his 2010 experiment, Littman shows the link between control and postural stability in a VR environment. Participants sat on a chair with motion sensors attached to the head, back, and arms. They were then shown a VR game to either actively play or simply passively watch. Those who were asked to be passive were shown to be more prone to motion sickness than their active counterparts. Part of the methodology taken from this experiment is the use of participants being in control of their avatars in order to reduce sickness and boost learning novel environments. Yet, this only helps in eliminating some factors of sickness and showing the importance of control. Our use of novel rulesets are taken from Littman's other experiment.

Just as Dolezal used prism goggles, Littman (2011) utilized a headset and prism goggles to see how participants moved their head to get through a maze. The experiment focused on the link between novel rulesets and users' adaptation to them. Participants were to view a wall of letters and navigate through them in a pre-defined order. The rules for moving the pointer with their heads were different from what they were used to. Left, right, up, and down movements were opposite with an added angle of degrees to them. This meant that participants had to move their head in ways they had never been exposed to, and hence was a novel concept. As time moved on, participants were able to adapt to the novel rulesets that they were exposed to, even if those rulesets changed abruptly. Littman's work showed that quick learning of rulesets helped with adaptation in participants. We can see that novel rulesets can be used to show postural stability in adaptation to the environment. Ebrahimi's (2014) study also backs up this adaptation phenomenon based on visual and proprioceptive feedback loops. Their study looks at how different feedback loops create errors in actions. Once recalibration in the participants occurs, errors in action cease. Yet, the persistence of these rules after being placed back into a natural setting is closer to what the users experience in reality. Indeed, it is the natural course of events that occur with the user.

The expansion of this experiment is to test a methodology that will allow us to discover how quickly readaptation from a novel ruleset can occur. In addition, this study sought to look at the impact of VR technology that is designed around particular demographics when used by groups outside of that demographic. The first part of the experiment examines the link between control and postural stability. The second part of the experiment expands on previous research by examining the readaptation from the novel constraints presented to 'natural' constraints, in particular, how quickly this occurs.

Rationale

In this study, we sought to examine the rate of decay of newly learned perception-action constraints acquired in virtual reality used in natural settings and whether these rates were impacted by participant sex. Previous work has shown that rules can be learned by changing perceptions, and that these rules decay if new stimuli 'overwrites' them. However, the time that it takes for a newly learned constraint to decay and be replaced has not been studied in virtual settings. By asking participants to participate in a virtual reality maze that switches their direction of left and right, they learn the new rules of direction through exploration. Using this change in perception (adaptation), they then will be asked to complete a real life maze until they stop mistaking their left and right directional sense and are able to proceed normally down the pathway. Additionally, due to the impact of gender on the field, we also explored the possibility that tools designed for a gender would impact the performance of a different gender. It is our hope in this study that the switch from a virtual to a natural setting will do several things. The first is to simulate user experience in home settings. Many users report still doing actions used in virtual reality after play sessions for a short period of time. Second, the data recorded will allow future designs to implement user guidelines for safety and usability for users of both sexes.

Methods

Participants: There were 5 male and 6 female undergraduate students and 1 female graduate student. No alcoholic beverages or illnesses in the past 24 hours were reported before beginning the experiment. This screening was done to ensure that there were no people who would corrupt the data. All undergraduate students were recruited through SONA and given research credits, whereas graduate students received no compensation. The sample was predominantly white, and participants were on average 19 years of age. All participants gave informed consent with study protocols approved by the Miami University institutional review board (#01726r).

Materials:

360 Treadmill

A 360-degree treadmill (Omni; Virtuix Inc. see Figure 1) was used to allow navigation through the virtual maze. It utilizes a hexagonal walking pad that allows for users to move in a virtual environment with their own two feet. The treadmill connects to the other systems to allow a 1 to 1 ratio of movement for the user. The treadmill is used to allow more immersion in the environment for the player and for the left and right directions to be flipped with ease. This exploration of the environment through this system will help even novel users to adapt quickly to the changes provided in the experiment.

Virtual Reality Headset

A VR headset (Vive, Valve Corp. see Figure 1) allows the user to see a virtual environment. Through a combination of laser trackers mounted on the wall and visual stimuli projected through the lenses of the headset, users can see and interact with the virtual environment through a set of controllers. The virtual space is limited to an area of roughly 6-9 square feet, but within that space users will feel and act like they are actually inside of this novel VR environment.

Motion Capture

A magnetic tracking system (Trakstar; Ascension, Inc.) was used to track postural motion. This system detects motion in six degrees of freedom (3 axes of translation and 3 of rotation). A centrally located emitter creates a low-intensity magnetic field of known strength, extent, and orientation. Receivers (birds) move within this field. The system can detect the position and orientation of each sensor to an accuracy of 1mm. For this study, a single sensor was utilized and was placed on the head (attached to the HMD). Data from the sensor was sampled at a rate of 50Hz and stored on a computer for later analysis.

Figure 1.
Experimental set-up showing 360° treadmill, HMD and motion capture attached to participant's head.

Virtual Maze

The virtual maze (Steam; TiStar Game. see Figure 2) is used to provide limited options for action to the users. Without the distractions of an open environment with many objects to interact with, participants in the experiment will be forced to walk through the maze with their left and right flipped. This will have them adapt their movements to a novel environment, prepping them for the second phase of the experiment.

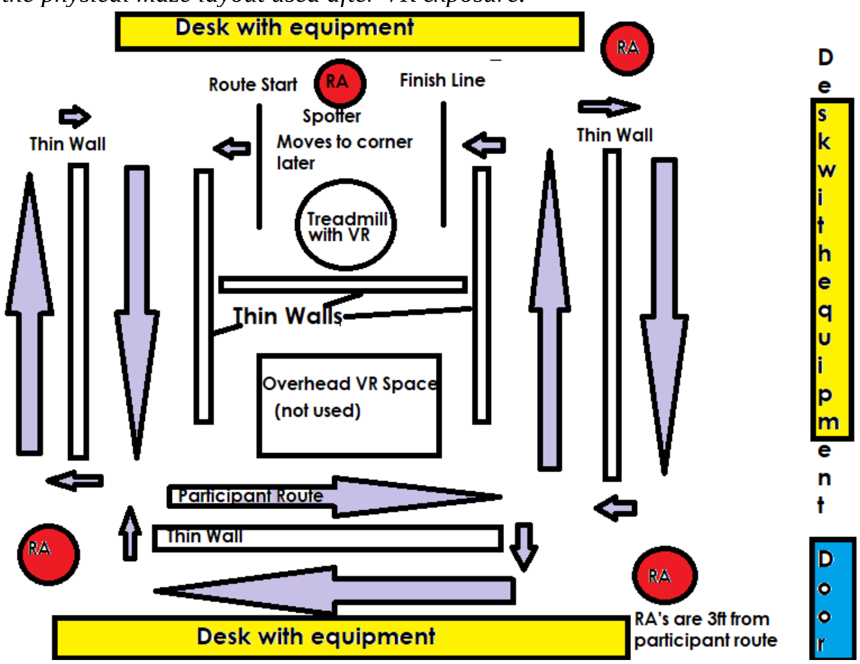
Figure 2.
Example of virtual maze: Shaldor's Maze from Skyrim VR. Link: https://elderscrolls.fandom.com/wiki/Shalidor%27s_Maze

Physical Maze

The physical maze that participants used was a combination of tape boxes on the floor as well as a large box partition housing other equipment not used in the experiment. Students started at the 'Route Start' line and proceeded to move around each tape box on the floor. After going around each tape box, they then proceeded to the next one. Each tape box was considered to be one loop. This brought a total of three loops for the participants to go around for the real maze. Participants were recorded as they moved through the maze on how many mistakes they made. By the end of the loops, participants would be back at the starting point and had finished the physical side of the experiment.

Figure 3.

Schematic of the of the physical maze layout used after VR exposure.



Procedure:

Participants would come to the VR room in the SPoCC lab for the study and be given a consent form that asked if they had been sick or consumed alcohol in the past 24 hours. Those that did (or did not wish to disclose) were sent back without doing the experiment but received credit for their participation. After consent was given, participants were told what they would be doing for the experiment. They were then led to the 360 treadmill, got on, and had the motion monitor and VR system attached to them. They then had the VR maze started and proceeded to go through the VR maze 3 times with their left and right directions reversed. Once participants completed the maze, they were then taken out of the VR maze and asked to do a real maze taped on the floor in the SPoCC lab. The tape maze consisted of two blocks inside of a square. The directions were to go to the left at the first intersection, follow the maze back to the starting position, go back to the first intersection, then to turn right at the intersection. Once participants reached the starting point like they did for the left turn section, they were considered to have made a single loop. Three loops were done before the maze was finished. During this time, participants were marked on how often they made mistakes. A participant was considered to have made a mistake if they confused which direction they were supposed to go, crossed their feet over the other, or went out of bounds. There was no limit on the number of mistakes that could be made. They were also timed on how long it would take for them to reach loop 3 in a maze run. At all times, if a participant showed signs of sickness, they were pulled from the experiment and given credit after resting. Once finished, all participants received a debriefing form and participation credit if it was due.

Results

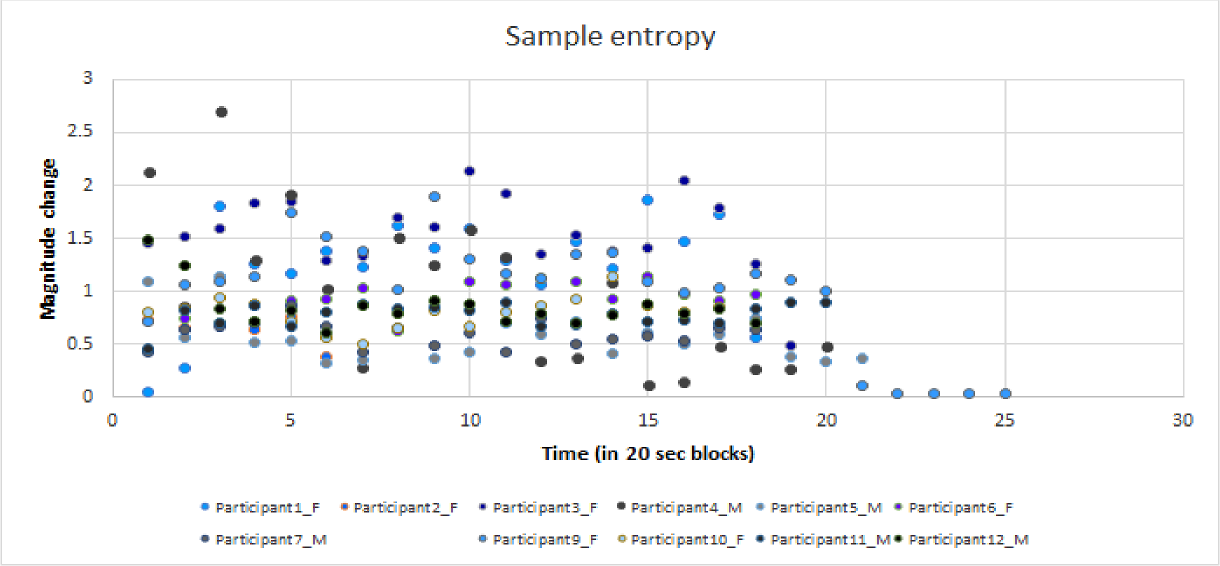
Motion Analysis

In analyzing the postural data, we employed a similar methodology to Littman (2011) and Smart, Teaford, Von Drasek, and Littman (in prep) to look at the adaptation of participants while inside the VR environment. Blocking out the trials into 20 second intervals was done in order to quantitatively look at the changes in behavior of the participants over time while having enough data points for stable non-linear indices. This is because behavior doesn't change in a quick manner, but rather takes a few seconds to go from one behavior to another (Littman, 2011; Hadidon, 2016).

To look at the adaptation strategy of participants over time, sample entropy, elliptical area, path length, and normalized path length were used (see Smart et al, 2014 for a description of these measures). Due to the setup of both the virtual and physical tools, the scatterplots below are the best representation of the data collected. In addition, inferential statistics were not computed given the small sample size, so characterization of movement was made based on descriptive indices.

Figure 4.

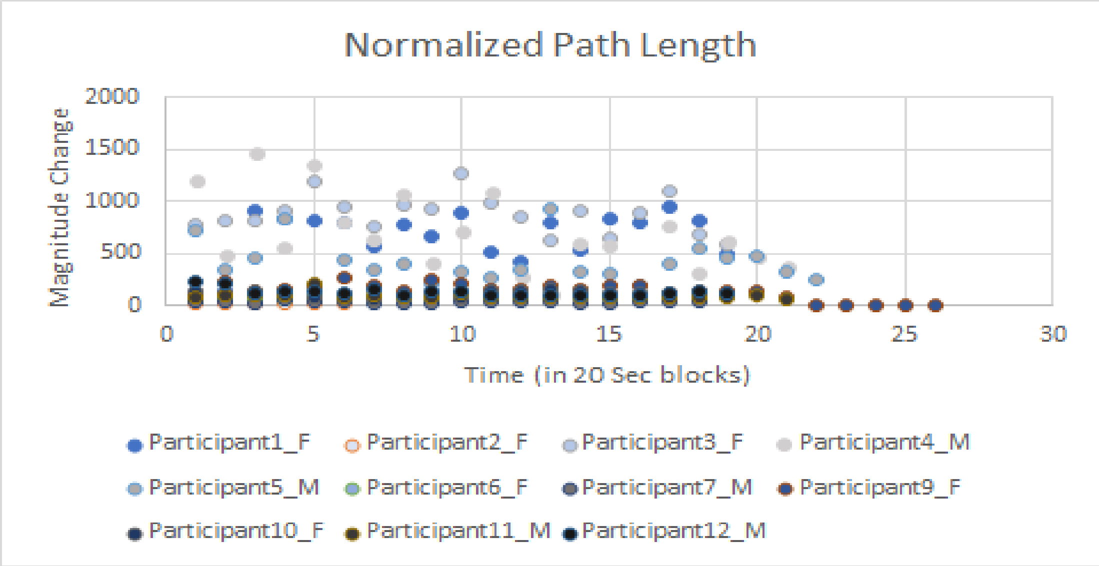
Sample Entropy rate of change (scalar) as a function of Time (20 second blocks) for each participant. Female participants in blue, male participants in grey.



Sample entropy allows us to determine if movement strategies are stable/change over time. Higher values indicate that previous motion is less predictive of later motion. This is often interpreted as either exploratory or unstable, with lower numbers indicating persistence in movement strategies or stable motion. From the chart, we see that generally females did not adapt overall (*M*=-0.021, *SD*=0.049), whereas males either had a slight to moderate adaptation strategy (*M*=-0.024, *SD*=0.038). While the means are close to each other, the greater spread in strategies over time indicated by the standard deviation suggests that there is more variability in the females compared to the males over the course of the task.

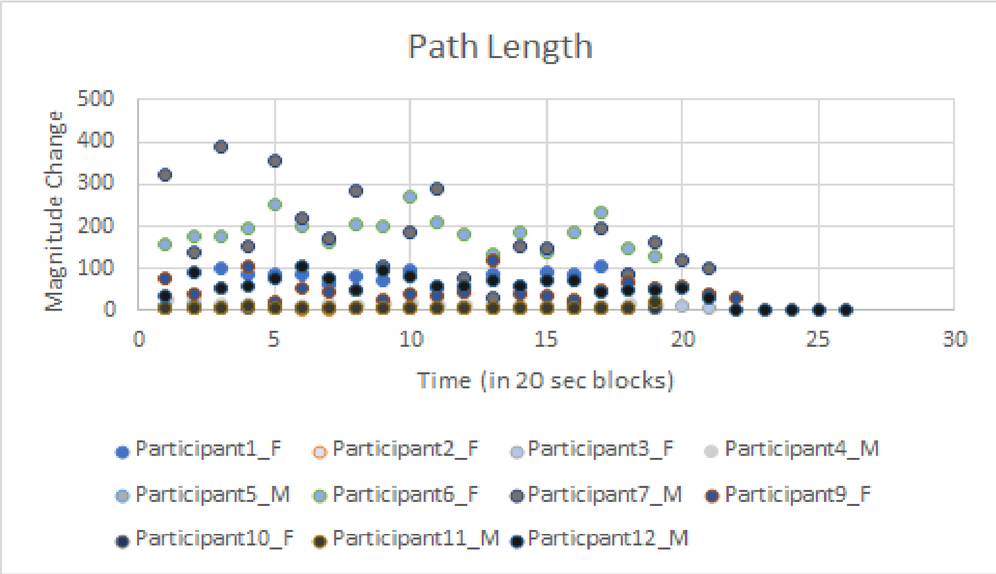
Figure 5.

Normalized Path Length rate of change (scalar) as a function of Time (20 second blocks) for each participant. Female participants in blue, male participants in grey.



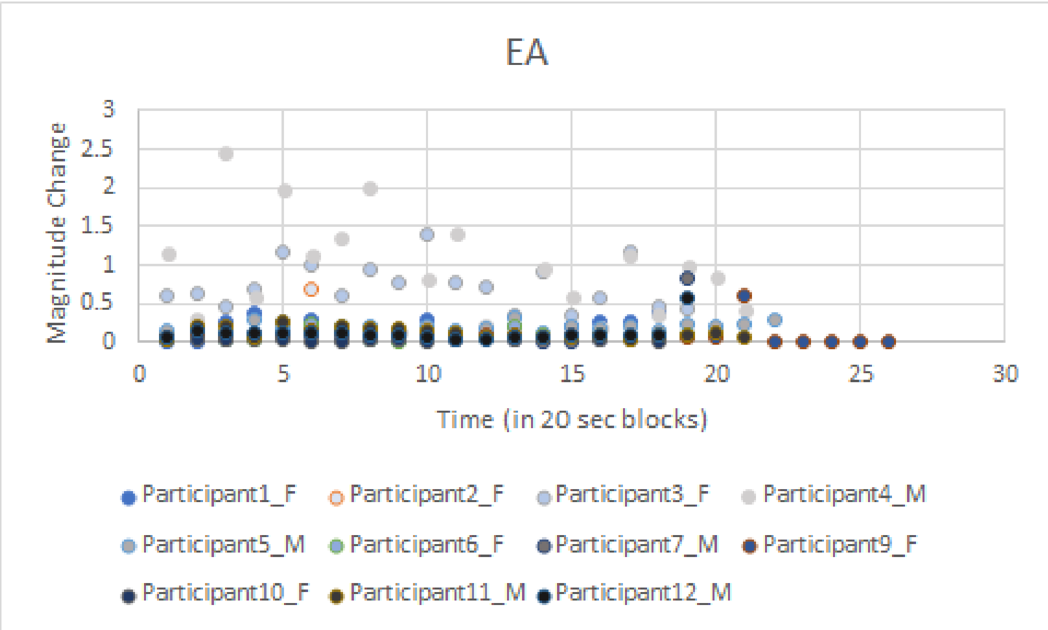
Normalized Path Length is used to assess the complexity (literally twisting and turning) of movement with higher values indicating more complexity. Since participants are trapped in a small circle for the treadmill, it was expected to see these values to be high. Males twisted less over time (*M*=-9.119, *SD*=14.684) than females (M=-3.942, SD=12.854) on average. These high values were expected and reflect the tools (i.e. the 360 treadmill) constraints rather than participant behavior.

Figure 6.
Path length rate of change (m) as a function of Time (20 second blocks) for each participant.



Path length is used to indicate the amount of movement that participants are exhibiting, with larger numbers indicating more movement. Males moved less on average (*M*=-4.999, *SD*=6.008) over time than females (*M*=-0.551, *SD*=1.482). This shows that males physically moved more than female participants during the study. However, the high values reflected here may be more due to participants moving out of the emitter field rather than actual physical movement.

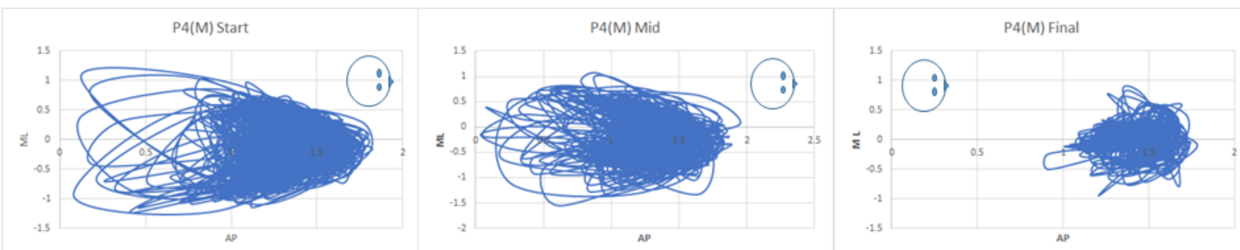
Figure 7.
95% Elliptical area rate of change (m^2) as a function of Time (20 second blocks) for each participant.



Elliptical area gives us another means of assessing the magnitude of movement that the participants are exhibiting with larger numbers indicating bigger movement that has often been associated with instability. Our elliptical area graphs show a similar story. Male participants showed less area being covered over time, indicating adaptation (*M*=-0.005, *SD*=0.021). Female participants on the other hand stayed in a tight area, showing rigid posture without the freedom to explore and adapt in the first place (*M*=-0.010, *SD*=0.070). We see this story played out in individuals' path lengths as well.

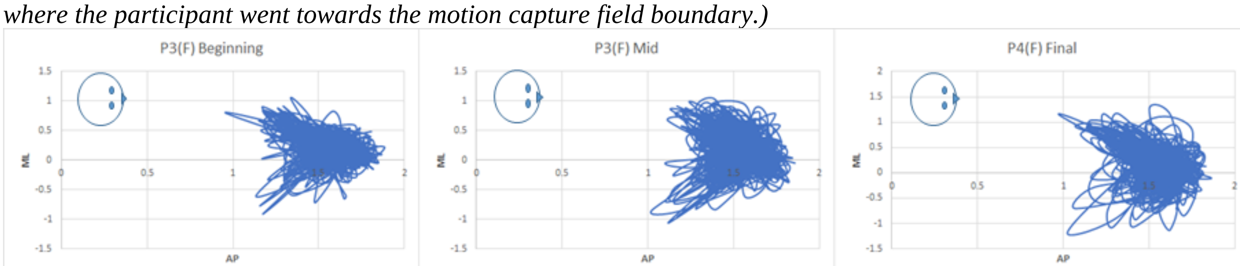
In addition to these quantitative measures, we also examined state space plots (AP v. ML) of the participants' head motion to provide some insight into their adaptation process. From these exemplar plots, we can see that our male participant started off with wild motion that would have indicated motion sickness if no changes occurred.

Figure 8.
Representative state space (AP v. ML) for male participant's head movements. (Note: excursions to the left are where the participant went towards the motion capture field boundary.)



This large path length indicated that the participant wasn't familiar with the ruleset that was given and was trying to figure out what was going on. Smaller areas are what we are looking for. From the beginning of the trial to the end, we see changes in the participants behavior in their path length. This is evident from the shrinking of the area that is seen from the beginning of the trial to the end. Within 10 minutes, the male participant successfully adapted to the new virtual environment, represented by the stable and tight posture of the path length. Normally this is what we want to see. Initially wild paths that gradually become smaller over time. Contrast this with a female participant from the same experiment.

Figure 9.
Representative state space (AP v. ML) for female participant's head movements (Note: excursions to the left are where the participant went towards the motion capture field boundary.)



We see relatively tight posture from the beginning. Certainly, a smaller area than our male participant, but this behavior stays consistent for the rest of the trial. What we see here is that the female participant is not changing behavior and it is relatively smaller compared to the male participant. Something is preventing the participant from feeling free enough to attempt to explore the VR environment in order to adapt to it.

Performance Analysis

The averages showed a similar story. Mistakes were counted as participants went around the tape maze. Overall, females showed 0.28 mistakes on loop 1 and 0 mistakes on loop 3. Males showed an average of 1 mistake on loop 1 and 0.2 mistakes on loop 3. This large difference in performance skewed the paired t-test results.

Table 1.

Directional Error rate for each participant.

Participant					Participant				
2	0	0	0	Female	5	2	1	0	Male
3	0	0	0	Female	6	0	0	0	Male
4	2	1	0	Female	8	0	1	0	Male
7	0	0	0	Female	12	3	2	1	Male
9	0	0	0	Female	13	0	0	0	Male
10	0	0	0	Female					
11	0	0	0	Female					
Average mistake	0.29	0.14	0		Average mistake	1	0.8	0.2	

A paired-samples t-test was conducted to compare the number of mistakes made in Loop 1 and Loop 3 for the entire participant pool. There was a significant difference in the scores for Loop 1 (M=0.69, SD=1.11) and Loop 3 (M=0.08, SD=.28) conditions; $t(12)=2.31$, $p > .05$. These results suggest that there is adaptation that occurs between the beginning and end of the real maze test. Participants make fewer errors as the test goes on, showing readaptation to the environment after a VR training session. This happened at a rapid pace, never taking longer than 150 seconds.

Discussion

The purpose of this study was to look at the decay rates of learned rulesets in virtual spaces as well as to see if a sex effect occurred in the experiment. It does appear adaptation and recalibration occur between the virtual and physical mazes. However, a closer look at the data reveals a distinct gender effect on both movement and performance. The gender effect that occurred can be summed up as follows: Participants performed differently because they moved differently. Despite having similar movements between sex groups, the movement that occurred showed that females did not adapt to the VR environment as males did. This means that, even though both groups were walking, twisting, turning, and proceeding in the maze in similar fashions, females did not pick up on a strategy to become more efficient in the VR maze over time. This is seen in the difference in magnitudes of movement between groups for the VR maze and the mistakes made in the real maze. The large movements seen in the male’s VR maze indicate that they felt free to explore the environment to create a strategy that would allow them to be more efficient in the VR maze. This efficiency shows adaptation and is reflected in both the decrease in movement measures for the VR maze and the decreases in mistakes made in the real maze. Females showed the same motion from the beginning of the VR maze to the end of it, signifying no adaptation. Because no adaptation occurred in the VR maze, no readaptation was needed for the real maze. This was reflected in the real maze portion showing females making no mistakes the entire time. This lack of adaptation could be explained by errors in the toolsets used during the experiment.

The first indication of errors in the tools comes from the scatterplot data. Path length, normalized path length, and elliptical area all have values that shouldn't have been possible in the experiment. Looking at the data showed that participants may have left the boundary of the emitter field as they were performing the VR maze. This arose due to the constraints of the size of the VR space. Leaving the emitter field created a data point that went back to a zero value, tricking the machine into thinking that a participant traveled meters in a fraction of a second. This greatly inflated measures dependent on distance traveled, like the ones mentioned above. So while there may be some indication for adaptation in the VR space on some measures, more accuracy would be able to point to a clearer picture of what is occurring to participants inside the study. The emitter box is also not the only point of tool error that could have occurred.

It has been noted that improperly calibrated interpupillary distance can cause discomfort (Saredakis et al., 2020). This discomfort could lead to motion sickness, which could lead to less optimal participants. As the Vive headset used in the experiment had non-adjustable fixed lenses, which are only optimally used by less than 50% of both male and female participants (though the information comes from a non-peer reviewed scientific journal), this could have impacted performance on the participant. As more consumer headsets allow for lens adjustment, it would behoove the literature to intentionally look into experimentally designed studies to see the rates of motion sickness on a gender basis.

Another piece of the setup that may have impacted the study for female participants is the 360 treadmill itself. Peer-reviewed literature is scarce for the equipment, but the fact remains that the tools were designed for males in mind. The shoe sizes included in the treadmill were all in male shoe sizes, meaning some female participants were not able to find the right shoe size to fit them for the trial. Height adjustments for the treadmill, as well as the safety straps, inner ring circumference, and Velcro belt were all designed with a male body in mind. On several occasions a small physical therapy ball was placed in between the belt and female participants to ensure they could move properly on the treadmill. This may have prevented adaptation to occur in the virtual environment with so many different exterior stimuli for the female participants.

The safety of the treadmill ensuring that participants would not fall out of the equipment changed behavior as well. While some participants stayed in relatively similar behavior to their normal walking, others took a posture they would not normally employ. This change in behavior for walking could also account for some individuals' change in rates of adaptation. However, not enough participants did this to be certain about it.

Culminating all the tool differences between genders possibly made female participants feel physically unsafe. Without the security that the tools were able to give to male participants, female participants became rigid in their posture, leading to several consequences. For the participant that the system was designed for, they had higher starting EA and sample entropy value, meaning that they explored what behaviors worked. For the participants that the tools were not designed for, they didn't feel physically secure and thus didn't explore what behaviors would be best for the environment, resulting in the restriction of motion. Essentially, any movement that females did was done in an abundance of caution. Small careful steps, slow turning, and mindful use of the body was typically seen in female participants. Males, as noted earlier, would be more likely to take much more risk in their movements. Much more intense postures, quick turning, and others once they learned the rules to the environment.

There is no definitive answer on the rate of decay of learned rulesets acquired in VR settings that can be derived at this point given the constraints of the current study and data. In particular, the possible gender effect arising from erroneous tools and a smaller *n*, makes a conclusive statement on the null hypothesis difficult to make. While it is well documented that altered rulesets can be learned and used in various settings and the decay does occur, the actual documentation of how long this decay occurs over time doesn't exist. For the participants that did show adaptation from one environment to another, the decay that occurred was quick, with all occurring in under 150 seconds (2 and a half minutes). The uses of this knowledge would help inform designers and users about what to do after a play session. The most obvious example would be driving on the opposite side of the road in a game, then driving in real life quickly after a play session on the wrong side of the road. Knowing how long these rulesets last would allow for warnings to be made for users during play time.

The study has further implications with the persistence of learned abilities. Within the perception action loop, perception is the first step that is needed for learning and adaptation to occur. If perception does not occur, the entire system of perception and action falls apart. This means that any learning due to adaptation breaks down and decays quickly over time when perception of the novel environment is removed. In essence, if one doesn't use an ability, they will lose the ability. For virtual environments, any training or adaptation that occurs may need repeated sessions for a longer lasting effect to be seen. Decay begins immediately after the removal of the environment, with full decay occurring in less than 150 seconds for this experiment.

Limitations:

As noted with the errors that occurred in the study, this obviously led to limitations. We discovered that this is the first action-based adaptation study when we are used to standing posture experimentation. This means the standards used for the experiment were not calibrated with movement kept in mind. While the system can be adjusted for this, some of the behavior of the participants exceeded expectations, resulting in this mistake. We also saw that participants would run out of the emitter field due to the active participation that the experiment required of participants. Future studies would have us place the EM box above the participant in order to fully capture all movements and potentially remove the treadmill if it is found that it cannot be adjusted to female participants.

Conclusion:

From this research as well as findings in the literature, it is imperative that further studies looking at the effects of gender and various tools used in VR setups be performed. This would allow for the discovery of what is preventing females from adapting to VR spaces (as well as think about accessibility issues in the broader sense). With multiple generations of head mounted displays, treadmills, and controllers on the market, taking a more in-depth look at where the effect is occurring would help with future build designs and instructional setups for consumer VR. Looking at the persistence of learned rulesets with longer VR training periods, as well as translational effects of the training would also be something to explore. This would not only help with improving VR standards but also ensure the safety of the user as well. With VR becoming a more and more prevalent form of entertainment, as well as the market eyeing the general remote workforce due to the pandemic, knowing the effects of both long- and short-term effects on the consumer is paramount to ensuring future success of the technology.

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