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Human Foraging in a Virtual World

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Recommended Citation

Martinez, Jose Luis, "Human Foraging in a Virtual World" (2013). *Research Papers.* Paper 429.
http://opensiuc.lib.siu.edu/gs_rp/429

HUMAN FORAGING IN A VIRTUAL WORLD

by

Jose Luis Martinez

B.A., Southern Illinois University, 2003

A Research Paper
Submitted in Partial Fulfillment of the Requirements for the
Master of Science in Psychology

Department of Psychology
Southern Illinois University Carbondale
August 2013

RESEARCH PAPER APPROVAL

HUMAN FORAGING IN A VIRTUAL WORLD

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for a Master of Science Degree in

Psychology

Approved by:

Eric Jacobs, Ph.D., Chair

Graduate School
Southern Illinois University Carbondale
July 4, 2013

AN ABSTRACT OF THE RESEARCH PAPER OF

Jose Luis Martinez, for the Master of Science degree in Psychology, presented on July 4, 2013,
at Southern Illinois University Carbondale.

TITLE: HUMAN FORAGING IN A VIRTUAL WORLD

MAJOR PROFESSOR: Dr. Eric Jacobs

Methods for using the Torque® game engine to test the predictions of three optimal foraging models of human behavior are proposed. Traditional tests of Charnov’s marginal value theorem, the diet breadth model and the effect of energy Budget manipulation on risky choice are translated into a virtual world programmable through Torque®. Use of immersive environments allows participants to interact with experimental conditions that bear a greater functional resemblance to extra-laboratory environments, thereby increasing the ecological validity of the research.

DEDICATION PAGE

I dedicate this paper to my mom, who can always make me laugh….to my dad, thank you so much for everything. I miss you. I love you both so much.

I also dedicate this paper to all those who have traveled far from their homes and have endured unimaginable adversity in an unfamiliar land so that future generations would know a better life.

ACKNOWLEDGMENTS

I would like to thank my advisor Eric Jacobs, this paper would not have happened without his mentorship. He spent a considerable amount of time editing and providing feedback. His commitment to this project is one of the reasons I am so thankful for the many ways he has influenced my life. I've learned so much from him, maybe more than he will ever know.

I would like to thank Michael Young for introducing me to the game engine discussed in this paper and for his feedback on issues of programming and of life.

I would also like to thank my friends, Cathy, Blake and Travis for the moral, intellectual and personal support that has meant so much to me, especially in times when I have needed it the most.

Thank you to the staff and the various friends I've known in the Psychology offices. They often went above and beyond to assure that this process would continue. I am forever in their debt.

I would also like to thank the various friends and acquaintances I've known throughout the years, including my good friends at Windhaven. I could write volumes on the incredibly beautiful diverse range of people I have had the privilege to have met. Each of them is more important in shaping my grander story than they may realize.

I would like to thank my family, starting with my brother, Edward. He means more to me than he can ever know. I admire the strength he has shown in the most adverse of circumstances. I am grateful to have such an incredible role model to look up to. Thank you for all you have done for me and for our family. Also, a heartfelt thank you to his wife Laura for her many delicious home cooked meals and for being an incredible mother to my niece Maddy.

Things haven't been easy for her, but she has demonstrated such amazing resilience. I'm proud to have her as member of our family. Thank you to my niece Jenny. She's an intelligent, funny, compassionate, kind, gentle-hearted, and beautiful (on the inside and outside) person. Thinking of her makes me realize what a wonderful life I've had. Thank you to my mom, Rosa. A woman whose strength of character and warmth of spirit has never ceased to amaze me. She is strong, kind, loving, compassionate, giving, understanding, accepting and intelligent. She is all the things I strive to be and more. The foundational values she has taught me reflect the best of the human heart and spirit. Thank you to my dad, who once rode a bus from Chicago to Washington D.C., and stopped in many cities and towns along the way, in order to lend his voice to those who had none. He inspires me to be a better person. I miss him so much.

Finally, I would like to thank Rocio. Though I will try to do so, the gratitude I wish to express to her can not possibly be articulated in words. This paper could not have come together without her tireless efforts to make sure I never lost sight of the bigger picture. She not only helped with editing and formatting, she helped by reminding me of reasons to keep pressing forward. She accepted who I was and was willing to help despite my limitations. It's an incredible feeling when somebody believes in you, especially at times when you question whether you should believe in yourself. She is a truly beautiful person, a feature easily recognized by those of us who are lucky enough to know her best. I will never forget what she has done for me and for my family. Thank you, you're amazing.

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INTRODUCTION

In order to survive, a behaving organism requires access to resources which will increase its probability of survival and its opportunities for sexual reproduction. The survival value of an organism's behavior, or set of behaviors, is defined by its ecological context (Krebs & Davies, 1993, p.1). The field of study primarily responsible for the study of such relationships within a larger evolutionary context is Behavioral Ecology. Within this field the relationship between the adaptive utility of behavior and an organism's environment is expressed in terms of costs and benefits and formalized in optimization models. These models are built on a number of assumptions grounded in the evolutionary concepts of variation and selection. Behavioral ecologists assume that organisms within a population vary in terms of morphology and behavior, that resources are finite and that greater access to said resources will increase the organism's likelihood of producing offspring (Hackenberg, 1998, p. 544). They provide testable hypotheses often expressed in algebraic or graphic form and present ecologically valid independent and dependent variables to be manipulated and measured, respectively (Hackenberg, 1998, p. 546). The focus of this paper will be on optimality models in relation to human behavior in controlled laboratory settings. Three optimization models will be discussed and methods for testing the predictions of each within the context of a first person perspective interactive video game will be proposed.

Optimal Foraging: Constraints, Currencies and Decisions

Optimal foraging models provide quantitative predictions of how organisms will behave in relation to the distribution of resources. In order to derive predictions from such models three basic components have to be defined - the currency, constraints, and the decision set (Krebs &

Davies, 1993, p. 108). The currency is the resource that is exploited by the organism (food, water, mating opportunities, nesting sites, etc.). Constraints are limits on possible courses of action that are, imposed by either environment or features of the organism's physiology. For example, the distribution of food is an environmental constraint that imposes constraints on the foraging organism. One pattern of behavior will be useful if the food is distributed evenly throughout the environment (e.g., grazing), whereas other patterns of behavior (e.g. hunting and gathering) will be useful if resources are distributed in spacio-temporal clumps (patches). In the case of physiological constraints, for example, an organism may have only adapted to perceive a certain range of the auditory spectrum therefore limiting the range of available environmental sound that could be used for locating resources. Lastly, the decision variable must be defined for any given foraging model. This is simply the range of behavioral options available to the organism limited by organismic and environmental constraints. Optimal foraging models predict which course of action an organism will take to maximize the net gain of a particular currency, given imposed environmental and organismic constraints.

As stated above, three different optimization models will be discussed. Each predicts behavior given specific ecological conditions. The first of these models, Charnov's marginal value theory, will be discussed in greater detail than the two subsequent ones in order to illustrate, in detail, a procedure adapting current laboratory methods examining human choice in ecologically relevant terms to a first person interactive video game. The two remaining models will be discussed in more general terms in order to demonstrate the potential for such an adaptation.

Marginal Value Theorem

Charnov's (1976) marginal value theorem (MVT) is an optimal foraging model that predicts patterns of searching for and gathering resources that are distributed in patches. When resources are distributed in spatiotemporal clumps or clusters, the resource distribution is said to be patchy. In patchy environments foraging, consists of two constituent behaviors—within patch foraging and between patch travel. While foraging within a given patch the organism will experience a situation of diminishing returns. This means that with each unit of resource consumed within a given patch of resources, the effort and time required to obtain the next unit increases. At some point it is in the forager's best interest to give up and travel to a new patch of resources. Thus, a person picking apples, for example, constitutes foraging in a patchy environment. When a person first begins to pick at an undisturbed tree, the rate of gain is high, but decreases as a function of time foraging at that tree. That is, as the apples are depleted they are harder to get at and you either have to pick higher up on or deeper into the tree. At some point, it is in the picker's best interest to give up and move to a new tree.

The primary dependent variable of interest in the above scenario is the point at which the choice is made to move on to a new patch. Charnov's (1976) marginal value theorem provides us with a means to derive a quantitative prediction of when the organism should leave the current patch. It states that when the marginal rate of return for the current patch falls below the average rate of return for the environment as a whole the forager should move on to a new patch. The optimal switch point is thus determined by two factors: **1)** The rate of depletion at the current patch and **2)** travel time to the next patch.

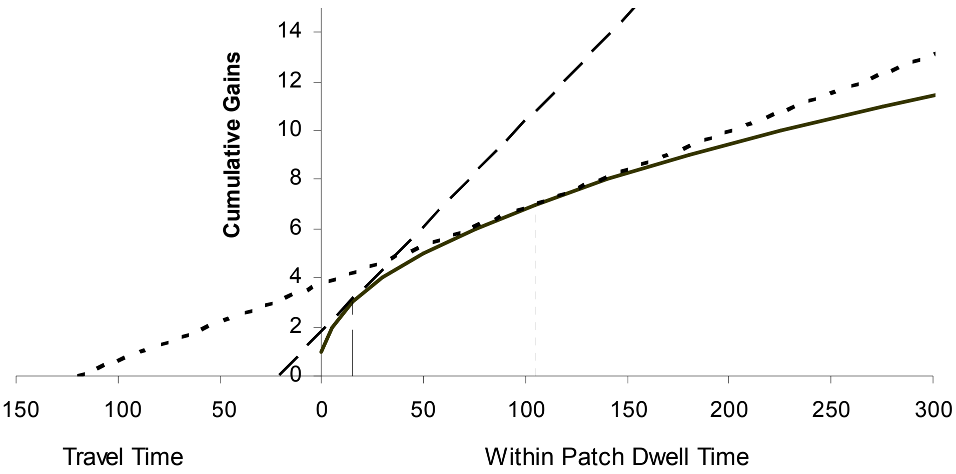

Figure 1. Cumulative gain as a function of within patch residence time. The two lines represent two travel time requirements. The short-dashed line and the dashed line represent a 120 s and a 20 s travel requirement, respectively. Optimal switch point is determined by drawing a line from the required travel time tangent to the cumulative gain curve.

The predictions of the marginal value theorem are depicted graphically in Figure 1. The figure shows a cumulative resource gain as a function of within patch residence time. This relationship is well described by a negatively accelerating curve. Also shown in Figure 1 are two theoretical travel times and predicted optimal switch points. Travel times are shown on the abscissa to the left of the ordinate. The optimal cumulative gain is determined by drawing a line from the travel time tangent to the gain curve. The point at which they touch determines the point at which switching to a new patch will result in maximum resource gain. The optimal within-patch dwell time can be determined by dropping a vertical line from the point of tangency to the abscissa. The MVT predicts that as the travel time between patches increases, the optimal switch point also increases. This prediction is illustrated by comparing the points at which each of the two lines, representing the two travel times, come in contact with the gain curve. Thus, as travel time between patches increases (i.e., overall resource density decreases), the forager should persist within a patch for a longer time before searching for a replenished patch of resources.

Simulating Patchy Environments in the Laboratory

Kacelnik (1984) tested four different versions of a model of central place foraging, where animals collect food from an artificial patch and deliver it to a central place location within the foraging area. The models were based on Charnov's (1976) marginal value theorem and differed only in that they defined currency differently. In this experiment starlings, a medium sized bird found mainly in Europe and Asia, had to forage for food to deliver back to its young. In its natural environment, starlings forage for prey (individual insects), that are clustered in patches. The starling collects the insects in its beak while foraging within a patch. Thus, as the beak fills with prey it becomes more difficult to carry the load. The constraints are the distribution of patches relative to the nest, the depletion rate of insects within a patch, and the handling costs of carrying the insects back to the nest. The decision set of interest is what load size will occur under these constraints.

To reproduce this in the laboratory Kacelnik (1984) trained the birds in a foraging environment in which they were required to travel from a home nest to a food dispenser that delivered mealworms on a progressive interval schedule. This schedule simulated a situation of diminishing returns by increasing the interval in which each successive prey was delivered. When the bird flew back to its young to deliver the food, the progressive interval schedule was reset to its original value, simulating travel to a new patch. The rate of prey depletion was held constant, but the distance the bird had to travel form its home nest to the foraging site was varied across conditions. Time within the patch was found to be a function of how far the feeder was placed from the nest. As the travel time (to the feeder + back to the nest) increased, so did time within the patch.

The four models calculated currency as: **a)** maximization of resource extraction or yield, calculated as the energy collected per total round trip time, **b)** maximization of delivery rate, calculated as total yield minus parent's metabolism, **c)** net energy gain for the family, calculated as the total delivery minus the metabolism of the brood, with energy costs of begging for food considered or **d)** maximizing thermodynamic efficiency, calculated as yield/parents metabolism. Of the four models, the one that best fit the data was one that defined currency as the net energy gain for the family.

Traditionally, behavioral ecologists test predictions of optimal foraging theories in an organism's natural environment. More recently, they have begun adoption of operant methodologies as a means by which to ensure a greater degree of control over extraneous sources of variability and thereby increasing the internal validity of the results (Fantino, 1991).

Within the operant laboratory a preparation that can be used to test the predictions of the marginal value theorem was introduced by Hodus and Trumbule (1967). In a variant of the concurrent chained procedure, chimpanzees made repeated choices between fixed (FR) and progressive ratio (PR) schedules of food presentation. In the initial link, subjects chose one of two concurrently available terminal link schedules by responding on one of two differently colored keys. Choice of either key deactivated both keys and activated a third key, designated as the response key. Depending upon the initial link choice, responding on the response key was reinforced according to either the FR or the PR schedule. The FR schedule requirement ranged from 100 to 1000 responses, depending upon condition. The progressive ratio schedule requirement began each session at 20 responses and increased by 20 responses after each reinforcer delivered by that schedule. For example, if the subject selected the PR schedule in the initial link, the two colored initial keys would darken and the response key would be illuminated and 20 responses on the response key would then be required for reinforcement. After reinforcement, the initial link choice condition would be reinstated. If the subject again chose the PR alternative, 40 responses on the response key would then be required for reinforcement. Under some conditions selecting and completing the FR schedule reset the PR schedule value to 20 responses.

This procedure is analogous to foraging in a patchy environment in which an animal encounters a situation of diminishing returns (Jacobs & Hackenberg, 1996). The consequences of persisting on the PR alternative are parallel to situations in which an animal continuously forages within a patch over an extended period of time. Resetting the PR value by choosing the FR alternative is akin to traveling to a fresh patch of resources and the FR requirement is functionally analogous to the time and effort required to travel from the old patch to the new patch.

The primary dependent measure in the choice in diminishing returns procedure is the pattern of switching from the PR schedule to the FR schedule. Schedule typical performance is characterized by a series of progressive schedule selections followed by a single fixed schedule selection, which is then followed by a return to the progressive schedule to repeat the pattern once the progressive schedule requirement has been reset to its minimal value. The marginal value theorem predicts that the subject should switch from PR schedule to the FR schedule at the point in the progression where overall reinforcement rate is maximized. To be consistent with the predictions of the marginal value theorem, subjects must switch from the progressive schedule to the fixed schedule well prior to the point in the progression where the schedule values are equal (the equality point). Thus, to maximize overall reinforcement rate or to minimize the overall ratio of responses to reinforcers, the subject must choose the fixed schedule when its schedule requirement exceeds the opposing progressive schedule requirement.

Figure 2 shows three theoretical efficiency functions for conditions where the FR schedule value is 20, 60, or120 responses, depending upon condition, and the PR step size is 5. Note that for each FR schedule condition, overall reinforcers per response are maximized at a point in the progression that is well prior to the equality point. Under FR 60, for example, switching at a PR 25 yields an overall average of .045 reinforcers per response, whereas switching at a PR 60 yields an overall average of .031 reinforcers per response. Note also that the switch point that maximizes reinforcers per response increases as the FI schedule requirement increases. Thus, as the overall resources density decreases (i.e., as patches are more widely distributed), the marginal value theorem predicts that organisms should forage longer in a given patch before giving up and traveling to a new resource site.

The response patterns of the chimpanzees in Hodos and Trumbule's (1967) study were in qualitative accord with the predictions of the marginal value theorem. The subjects consistently switched from the progressive schedule to the fixed schedule well prior to the equality point. Moreover, the switch points increased with increases in the FR schedule requirement. However, the chimpanzees tended to select the PR schedule beyond the point where the overall ratio of reinforcers to responses was maximized. Thus, although the response patterns indicate that the chimpanzees were sensitive to the distal consequences of the behavior, the response patterns were not in exact quantitative accord with predictions of the marginal value theorem.

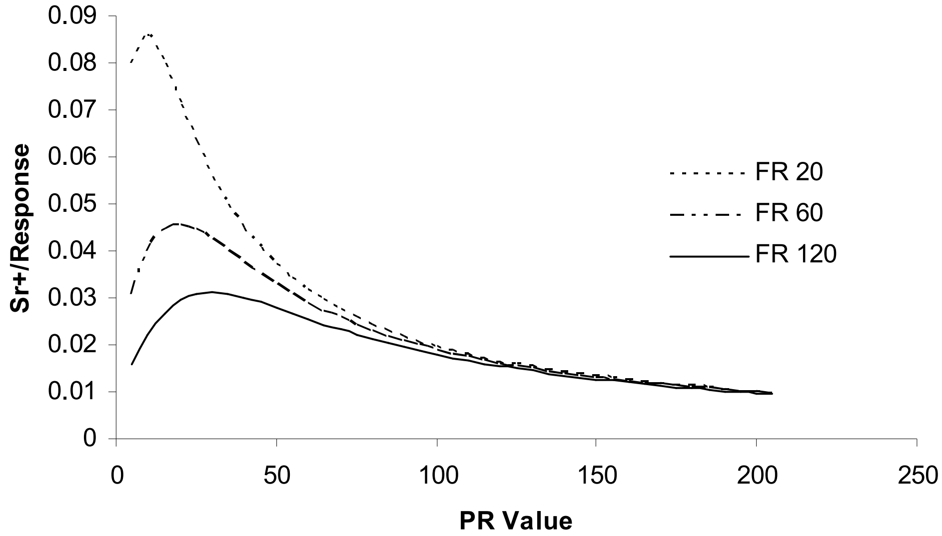

Figure 2. Theoretical efficiency functions displaying number of reinforcers per response as a function of PR requirement when FR is chosen. Efficiency functions are shown for three FR values, 20, 60 and 120.

This study has been systematically replicated across a variety of species including rhesus monkeys (Hineline & Sodetz, 1987), pigeons (Hackenberg & Hineline, 1992 Mazur & Vaughan, 1987; Wanchisen, Tatham, & Hineline, 1988) and humans (Hackenberg & Axtell, 1993; Jacobs & Hackenberg, 1996). The procedure has also been extended to time based schedules of reinforcement (Hackenberg & Axtell, 1993; Hackenberg & Hineline, 1992; Jacobs & Hackenberg, 1996). Using time based schedules allowed for a more direct comparison between the resulting data and predictions of the marginal value theorem because overall reinforcement rate is can be more easily controlled.

In general, the findings of these replications were again in at least qualitative agreement with the predictions made by the marginal value theorem. Switching from the progressive to the fixed schedule occurred prior to the point where the schedule values were equal. Thus, the subjects reliably selected the larger fixed schedule over a progressive schedule with a lower schedule requirement. As with the data from the original chimpanzee study (Hodus & Trumbule, 1967), data from studies using pigeons (Hackenberg & Hineline, 1992 Mazur & Vaughan, 1987; Wanchisen, Tatham, & Hineline, 1988) were better described by a models based upon the delays to a limited number of forthcoming reinforcers (Mazur & Vaughan, 1987; McDiarmid & Rilling, 1965; Shull & Spear, 1987). Subjects in these studies consistently overshot the optimal switch point predicted by the marginal value theorem. On the other hand, data from studies with humans (Hackenberg & Axtell, 1993; Jacobs & Hackenberg, 1996) and rhesus monkeys (Hineline & Sodetz, 1987) were in quantitative agreement with the predictions generated by marginal value theorem.

Jacobs and Hackenberg (1996) examined human choice in a situation of diminishing returns by presenting participants with two schedules of points exchangeable for money, a progressive interval schedule and a fixed interval schedule. In a 3 X 3 factorial design, FI schedule value and PI step size were varied over three levels across conditions. Under some conditions, completion of the FI schedule reset the PI to its minimum value in addition to delivery of a point. In 51 of 78 reset conditions the median switch points were in quantitative agreement with the predictions of the marginal value theorem. In all but 2 of the 27 remaining conditions the median switch point was within one PI step of the predictions of the MVT (Hackenberg, 1998; Jacobs & Hackenberg, 1996).

The Laboratory and Ecological Validity

The operant laboratory is well suited to test predictions made by optimal foraging theory. The simplifying assumptions made by theories of optimality are well met within operant preparations (Dallery & Baum, 1991). As the case in most laboratory settings, however, the above studies being no exception, there is an inherent artificiality in the designed procedures that results in the experimental conditions bearing little resemblance to the organisms' natural ecology. For example, with humans, pressing a left or a right arrow key to select a colored square on a computer screen bears little resemblance to the real world examples (e.g. apple picking). Starlings collecting prey dropped at a dish resembles the natural predatory environment of the bird in a minimal way. Yet, they are both situations of diminishing returns that are functionally equivalent to foraging within a patch of resources.

Researchers have noted the disparity between the laboratory procedures used to test predictions of optimality and the organisms natural ecology (Dallery & Baum, 1991; Baum, 1983; Shettleworth, 1989). Although, there is evidence pointing to the functional equivalence between responses on a key and actual foraging behavior (Dallery & Baum, 1991) and the data collected in more natural environments is similar to those collected with operant methodology (Baum, 1983), some have suggested that there would be benefits in making the experimental environment more analogous to the organism's natural ecology (Dall, Cuthill, Cook, & Morphet, 1987; Mellgren, 1982). This would serve to increase the ecological validity of such experiments and the quantitative findings could possibly more accurately represent the organism's performance in such situations.

Madden, Peden, and Yamaguchi, (2002) studied human choice in an experiment designed to test the predictions of the Ideal Free Distribution (IDF) theory of optimal foraging (Fretwell & Lucas, 1970). The IDF predicts that the distribution of foragers will match the relative distribution of resources across patches. For example, for two patches each containing 5 and 10 units of a resource, respectively, the number of foragers at the second patch will be double the number at the first. In the first experiment, patch choice was determined by colored cards.

Participants had the option of holding up either a red or blue card to indicate what “patch” they were foraging in. Once all the cards were up, they had an opportunity to switch cards, functionally switching to another patch. Once all the participants stopped switching, reinforcement (points) were distributed based upon the amount of resources available at each site and the number of participants at each site. The second experiment was similar to the first except that participants were not allowed to switch colored cards after the initial choice. The results of the first two experiments were in accord with the IDF. That is, the proportion of foragers at each site generally matched the proportion of resources available at each site.

The third experiment replaced the cards with two areas, red and blue, and reinforcement was arranged according to concurrent variable-interval (VI) VI schedules of reinforcement. By allowing participants to freely move about the room from patch to patch and by programming a schedule of resource delivery more closely resembling those faced by foragers in natural settings, Madden and colleagues (2002) approximated a laboratory preparation more closely aligned with actual foraging conditions. This programmed schedule increased the difficulty of calculating the relative rates of reinforcement for each patch and thus, according to the authors, made for a more stringent test of the ideal free distribution. Also, the first two experiments were defined by discrete choice points, whereas the third was a free operant procedure, meaning that participants could move freely from one patch to the other and no final choice had to be made before reinforcement was delivered. The results of all three experiments were similar to other studies testing the ideal free distribution. The relative distribution of foragers was biased towards the patch with a lower rate of return. This pattern of forager distribution, known as undermatching, results in an overexploitation of the poorer resource and a lower rate of return than optimal for the given environment. However, the third experiment, which included contingencies of point delivery more closely related to actual foraging situations, yielded a higher degree of undermatching (deviation from strict predictions of IDF).

While Madden et al. (2002) allows for a more realistic environment, it has the potential of adding undesired extraneous sources of variability by introducing subject's extra-laboratory biases or by allowing participants to generate verbal rules of performance based on others behaviors. In other words, allowing human participants to interact could interfere with the results by introducing confounding sources of control. For example, the type of clothes, perfume, cologne or outward appearance of the other participants may affect the results.

Foraging in a Virtual World

Goldstone and Ashpole (2004) introduced a procedure by which humans interacted in a virtual environment to test the predictions of the IDF. The participants were seated in front of a screen which represented the foraging area. On the screen participants were represented by blue dots and food resources where represented by green dots. Two important manipulations were made in order to make the virtual environment more naturalistic, the resources were not distributed in discrete patches. Rather they were distributed in a continuous pattern across two pools. Also, the pools of resources were not identified to the participants, as in real foraging environments they had to discover them. Patches were replenished according to one of three relative rates (50-50, 65-35, and 80-20). Between conditions, the visual presence of the food resources (green dots) and other foragers was manipulated. The results of the study indicated that, as a group, the participants over exploited the patch with a lower density of resources (undermatching). This finding is in accordance with previous findings of human performance in situations designed to test the predictions of the IDF model in that there was consistent under exploitation of the more profitable resource pool.

The virtual world programmed by Goldstone and Ashpole (2004) is a good starting point towards a more ecologically valid design that allows for the level of control desired from the laboratory, while relieving the experiment of as many extraneous sources of variability that inherently influences human performance. It eliminates the potential confounding variables that having participants interact in a shared physical space can introduce to the study, while still allowing those participants to forage within the same ecological space.

In addition to the above mentioned advantages, the virtual world allows for a more accurate measure of time allocation that can reveal potentially important patterns of forager behavior. Madden et al. (2002) relied on human recording of data, while the data collection in Goldstone and Ashpole (2004) took place within the program responsible for the virtual world. Because of this, an analysis of the dynamics of forager behavior is more readily accomplished by the latter. In fact, cyclical patterns of group behavior were revealed when such an analysis was performed.

Virtual Ecology: Foraging with the Torque® Game Engine

The virtual world of Goldstone and Ashpole (2004) provides a foundation for a potentially rich source of future foraging literature. It extends the external validity of laboratory preparations while retaining the level of control necessary in experimental research. Still, the nature of the preparation does not allow for a view of the world that accurately represents the foragers view. The game played in the above study takes place within a two-dimensional world and the entire foraging area is visible to the participant at once, two features rarely found in actual foraging. A more naturalistic analogue would involve the modification of these features to more closely approximate a forager’s actual experience when searching and acquiring resources.

When foraging, an organism acquires knowledge of the foraging environment through repeated exposure and interaction with the relative features of that world. That exposure and interaction is limited by an organism's relative biological restrictions. For instance, humans foraging for berries have a much narrower visual sample of the foraging environment than a bird searching for that same resource. The human forager's experience is restricted by lower visual acuity, slower speed, and relative immobility compared to the bird. What they share, though, is a first-person perspective of the three-dimensional world in which they forage. That is, their experience of the world is limited to relative visual fields. This feature is lacking in the above example of a virtual foraging space. What is needed is an environment that features the ecological validity and control already demonstrated with the added feature of a more accurate visual perspective of the foraging context.

The Torque® game engine allows for such an experience. This engine allows for worlds to be programmed that have perceived length, width, and height. This three-dimensional experience allows for a more accurate foraging analogue and thus would extend the external validity of laboratory even further while still retaining the desired level of internal validity. Participants would move through this virtual world and interact with its features through an on-screen character, much like in most video games. In essence, it would be a combination of the first-person experience of Madden et al. (2002) and the control and precision of Goldstone and Ashpole (2004).

This three-dimensional virtual world would also allow for a greater range of programmed stimuli than conventional operant preparations. While disks or levers could be programmed within the world, response requirements could also be met by having the participant do a variety of tasks including shooting enemies, collecting tokens, solving three-dimensional puzzles, walking, swimming, flying, driving and a variety of other tasks limited only by programming competence. Also, schedule correlated stimuli can take on a more naturalistic role in the environment. For instance, when a particular schedule of reinforcement is in effect, features of a programmed sky, such as the speed of the clouds or the color of the sky can be manipulated. Another example, a signal detection task could take place within the context of a battle, with complex, but controlled sound or fog as introduced noise, with the dependent measure being the friend or foe the characters eliminated by the participant. All in all, the virtual world made possible by the Torque® game engine, would provide for a much richer and true to life experimental experience.

Three Dimensional Foraging: The Proposed Research

Considering the increased level of external validity possible with Torque®, it may be that results from studies testing models of optimal foraging may yield different results than more common preparations. Madden et al. (2002), after all, reported a higher degree of undermatching when participants were required to physically move from patch to patch and the scheduled contingencies more closely approximated those in a more naturalistic foraging environment. Given this result, it is necessary that predictions made by optimal foraging models be tested in a three-dimensional world so as to access any differences in performance and to take advantage of the rich, but controlled, complexity virtual reality offers.

The proposed experiment is designed to test the predictions of Charnov's marginal value theorem (MVT) in the context of a virtual world. As stated above, the MVT predicts that, given discrete patches, a forager's within patch foraging time will be a function of the between-patch travel time and the rate of resource depletion within the current patch. Participants will forage for points by collecting tokens available as their onscreen character walks within a three-dimensional world. They can choose to travel to a new patch of resources by pressing a key on a keyboard which will result in a period of time in which no points can be earned, the between patch travel time. Once this period of time is over they will again be placed within the virtual world with all the previously collected tokens replenished and available for collection on a progressive interval schedule of resource availability.

Thus, in the proposed research, to the aim is to systematically replicate previous research by embedding the contingencies of the choice in diminishing returns procedure within the context of the Torque® game engine. A between groups design will be used where the programmed FI travel cost will be 20, 60, or 120 s, depending upon group. According to the MVT, within patch dwell time should vary directly with travel costs.

CHAPTER 2

METHOD

Experimental Design

A between groups design will be employed to assess sensitivity to between patch travel times on human foraging in a virtual environment. The experiment will be a systematic replication of previous human operant research using the choice in diminishing returns procedure (Hackenberg & Axtell, 1993; Jacobs & Hackenberg, 1996). The contingencies in the present study, however, will be presented in the context of a virtual reality. The participant will have an onscreen character that will be dropped into a virtual world that includes a long corridor blocked of by mountains on both sides. At the beginning, immediately after being placed in the virtual world, the player will encounter a power pod. The player can collect this pod by moving the character one keystroke forward. There will then be two options, one option will be to walk forward and collect more points. The other option will be to hit the space bar on the keyboard and reset the mission. If the participant chooses to walk forward she/he will encounter more points on a progressive ratio schedule of 5 (PR 5). For example, if a participant chooses to walk forward after the initial drop the onscreen character will have to walk for 5 keystrokes before an additional point is available. If, at this point, the participant chooses to continue collecting points without resetting, a 10 step walk forward will be required to reach the next available point and the next point will be 15 steps away. If the participant decides to hit the reset key, a brief fixed interval (FI) will follow after which the character will be placed in a replenished patch of resources. The length of the fixed schedule will vary across three values 20s, 60s or 120s, by condition. The primary dependent measure will be the pattern of switching from the progressive to the fixed schedule of reinforcement. In order for a participant to maximize the number of reinforcers (points) they acquire, they must reset the progressive alternative before its value is equivalent to the fixed alternative. This is known as the optimal switch point and will be defined using the marginal value theorem.

Participants

Thirty participants will be recruited from the population of undergraduate students enrolled in the Introduction to Psychology course at Southern Illinois University, Carbondale. All participants will receive course credit for their participation. They will be randomly assigned to one of the three experimental groups until each group has ten participants. At the conclusion of the study participants will be entered in a lottery drawing for a $50 Visa® Gift Card. Each point a participant earns will equal one entry into the lottery, thus the odds of winning the gift card are directly proportional to the number of individual points earned.

Apparatus

Subjects will be seated in a room in front of a 17" computer screen. In front of the subject will be a standard keyboard with only the "Enter", "→", "←", and "↑" keys operational. Next to the keyboard will be a standard two button computer mouse with only the left button operational. All data will be collected on the computer running the experiment, which will also be in the experimental room.

Procedure

The experiment will be divided into 2 – 90 min sessions. Participants will be told that they are going to be involved in an experiment on how people make choices within a in a virtual reality world in the context of a video game. Participants will then be informed that they will be dropped into a virtual world where they will find themselves facing a long corridor surrounded on both sides by mountains. They will be instructed to collect as many "power pods" as possible. They will be asked to play the role of an alien soldier looking for these power pods in order to build up the necessary resources for their anticipated battle with a rival alien race. The "power pods" (PP) are red Torque® game engine logos floating above the ground. The session will begin when the participant hits the "Launch Mission" key on the keyboard. When the session starts the participant will collect one logo when dropped into the world and will have to use the up arrow key on the keyboard, previously defined as the "walk forward" response, until they encounter other PP objects floating in mid air. Once they come in contact with a PP a counter on the screen will add 1 to the count in order to keep track of total number of PP's collected. At any point the participant may press the space bar to reset the mission. They will experience a brief pause, whose length will be determined by condition, after which the mission will be reset and the player will be dropped at the original drop point. When the participant's character is dropped it will collect the PP at the drop point and can then proceed to collect more PP as described above. Participants will be told that every token they receive will enter them into a pool that could result in them earning a $50 gift certificate to a store of their choice. Hence, the likelihood of winning the pool will vary directly with the number of points earned.

The participants will be divided into three groups of ten. These groups will be used to assess the effects of varying the fixed alternative schedule value (reset pause). The FI values for the reset groups will be FI 20, FI 60 and FI 120. A between groups design was chosen for this study because of the limited amount of time the participants will be exposed to the contingencies. This design allows for maximum exposure to the programmed contingencies within the allotted time and will increase the likelihood that steady state performance will be attained by the end of the last session.

CHAPTER 3

DATA ANALYSIS

Steady state performance on the choice in diminishing returns procedure consists of a sequence of progressive schedule selections followed by a single fixed schedule selection before returning to the progressive to repeat the pattern. The primary dependent measures of interest will be the point of switching from the progressive to the fixed schedule and the within patch dwell time (i.e., total time spent foraging before selecting the fixed schedule). Switch point will be arbitrarily defined as the current PR value when the FI is chosen. For each session, individual performances will be summarized by calculating the session-wide median switch points and within-patch dwell times for each participant. Group means of the medians will be used to assess the affects of travel time on foraging.

A 2 x 3 mixed factorial ANOVA will be conducted to assess any between group differences. Session number will be treated as a within subjects factor and FI value as a between subjects factor. If the ANOVA reveals significant main effects for either the FI value or session, Tukey's HSD post hoc tests will be conducted to identify any significant differences. This ANOVA will also reveal any possible interaction between the two variables if a significant interaction is present then simple main effects will be conducted to qualify the interaction.

In addition, the means of the median switch points and dwell times for each experimental group will be plotted against the predictions of the marginal value theorem for each FI value. This will allow for a visual inspection of the data and reveal any systematic deviations from the predictions of marginal value theorem.

Testing Additional Optimality Models

The utility of the Torque® game engine in testing optimization models is limited only by experimenter's ability to design virtual worlds that functionally mimic the important features of more traditional lab designs. Towards this purpose two more models will be introduced along with their corresponding virtual worlds programmed with the Torque® game engine.

The Marginal Value Theorem introduced above corresponded to the behavior of organisms foraging in an environment wherein resources are distributed in discreet patches. However, when making predictions about behavior in an environment where resources are uniformly distributed the Optimal Diet Breadth Model can yield more precise predictions (MacArthur & Pianka, 1966). The optimal Diet Breadth Model also assumes that resources are found randomly or unpredictably and that foraging can be parsed out into two distinct and mutually exclusive activities, searching and handling. Also, like other models, it assumes that the organism has complete knowledge of a relatively stable environment with which it has extended experience (Hackengberg, 1998, p. 552).

This model's primary focus is on the acceptance or rejection of a food source. As an organisms travels along its ecological space various sorts of resources may be encountered. Along the way decisions must be made about whether the relative resource should be handled or whether it should be left alone in order to continue the search for other resources. Thus the choice of interest is whether the organism accepts or rejects a given resource. Although a given ecological context can contain a number of different qualitatively different resources, in order for a more practical laboratory test of the predictions the number of resources will be limited to 2 in this example

The currency for this given model is return rate per unit of handling time. For example, in a two item choice situation if item A is worth $10 and requires a handling time of 2 min, it’s return rate if $5 per min or $10/2 min of handling time. In contrast, if item B is worth $5 and also requires 2 min of handling time the return rate is $2.50 or $5/2 min of handling time.

In order to make predictions more ecologically accurate one more component is included in the above calculation of return rate, search time. For example, if item A has a value of $10, a search time of 1 min, and a handling time of 1 min, the return rate of the item is $10/ 1 min of search time + 1 min of handling time or $5. If we now include a second item in this scenario, item B worth $2 and also requiring 1 min of handling time, whether to accept the commitment to handle this less profitable item or reject it in order to search for the more profitable one, depends on the costs and benefits of doing so relative to the overall ecological context. For example, if an organism accepts both items A and B the rate of return would be $10 + $2/ 1 min of search time + 1 min of handling time for A + 1 min of handling time for B or $4. This lower rate of return means that it is in the best interest of a give organism to reject item B and focus exclusively on item A.

If however, item A is encountered less often or becomes scarcer (determined by an increase in search time) the model predicts that the organism would be more likely to accept the less profitable alternative. For example, if the search time for item A were to increase to 7 min the rate of return for item A would now be $10/ 7 min of search + 1 min of handling or $1.25. If item B were to be also accepted the return rate would now be $10 + $2 / 7 min of search + 1 min of handling for item A + 1 min of handling for item B or $1.33. In this scenario it would be optimal to select both items A and B.

Another prediction of this model is that the encounter rate of the less profitable item will not change the likelihood of the more profitable item being accepted. Stockhorst (1994) tested the above prediction on human participants in a successive choice procedure. Subjects were seated in front of an instrument panel with three translucent keys arranged in a pattern resembling an upside down triangle with the points of the triangle corresponding to the placement of the keys. The first component of the foraging episode (the search phase) was in effect when the bottom key was illuminated indicating the activation of a fixed interval response requirement (FI schedule). Completing the requirements of this schedule illuminated one of the two remaining keys. Each key was correlated with either red or green illumination and a variable interval 18 s (VI 18 s), the less profitable alternative, or a VI 3 s schedule of reinforcement. These two keys represented the two available resource items. Pressing the key once illuminated indicated "acceptance" of that item and the programmed response requirement correlated with that key was activated. If the participant did not press the key after a fixed amount of time it would signify a rejection of the item and the search phase was reinstated. In order to meet the model's assumption of random resource encounter, the less or more profitable schedules were both equally likely to be in effect.

The primary manipulation made in this experiment was the extension of the search time or FI requirement for the less profitable alternative. The results did confirm the model's prediction that changes in encounter rate with the less profitable item did not affect the likelihood of accepting the more profitable one.

CHAPTER 4

DISCUSSION

Torque® and the Diet Breadth Model

In order to illustrate the utility of the Torque® game engine to test the Diet Breadth Model the same general successive choice procedure as described above will be used. Participants will first be shown a set of instructions informing them that they will be searching for coins to collect. These coins will be later exchangeable for money. They will be told that they must walk forward, using the arrow keys as described in the test of the Marginal Value Theorem, until further instructions are provided fore them on the screen. In order to allow as much interaction with the virtual world as possible, the response requirement will be ratio based. For example, while in Stockhorst (1994) a single response after a fixed amount of time activated the “accept” or “reject” choice, the current proposed design will require the participants to press the “forward” key a fixed number of time in order to make the on screen character walk towards a programmed opportunity to collect resources. Once a predetermined length of time the “forward” key is pressed, new instructions will be displayed. The participant will be told that “There is a coin in the distance on your (direction to be counter balanced across participants). You can either choose to walk towards it in order to collect it or you may choose to keep moving forward in order to find additional coins. If you choose to go after it please press the (directional key corresponding to the resource direction) on your keyboard in order to walk towards it or if you wish to keep searching press the forward “up” arrow key”. Each resource type (profitable, less profitable) will be correlated with a different background color on the choice instructions page, also counterbalanced between participants. A single response on the “Forward” key will signal a rejection of that resource and the participant finds their on screen character back on the path and the instructions to walk forward will come on the screen until a response is made. If however the participant chooses to consume the resource they will be required to press the key corresponding to the direction as per the instructions and the on screen character will turn in that direction and all keys except the forward key will be deactivated. A new instruction will pop onto the screen telling the participant to walk forward using the up "forward" arrow key in order to collect the coin. A counter on the upper left corner will track the total coins collected.

If the choice is made to collect the coin, the participant will find themselves either having to press forward a variable length of time that will average around 3s (VI 3 s) for the more profitable schedule and 18 s (VI18 s) for the less profitable one. As in Stockhorst (1994) the primary variable to be manipulated will be the encounter rate or search time for the less profitable alternative. In the case of the virtual world, it will be the amount of time the "forward" key is pressed in the search phase.

Risky Choice

A living organism has to meet relative nutritional needs in order to survive. Active foraging is a means by which to meet those needs. However, for various reasons, there are periods of time when an organism may not be able to forage for food or the amount of food necessary for survival may not be available. Thus nutritional reserves must be accumulated during times of active foraging. Often there are multiple food sources available for foraging animals to exploit and those sources may differ in the variability in net caloric gain provided from one foraging bout to the next. For example, one resource may consistently provide a moderate amount of calories, whereas another food source may sometimes provide more calories and at other times fewer calories than the consistent alternative. Choosing to engage in an activity in which the outcomes are varied is considered to be a risky choice.

In the laboratory, risky choice in non human animals is examined in reference to an animal's Energy Budget which refers to an organism's energy status in relation to its energy needs (Bateson & Kacelnik, 1998). When the nutritional availability exceeds the relative nutritional needs the energy budget is said to be positive. On the other hand, when there are not enough resources to meet nutritional needs the Energy Budget is said to be negative. In the studies with non-human animal subjects, level of food deprivation and rate of food delivery were varied in order to modify the organism's Energy Budget. For example, in Caraco, Martindale, and Whittam (1980), yellow-eyed juncos were given a choice between two feeding stations delivering a fixed versus a variable number of seeds. The Energy budget was manipulated by depriving the birds of food for either 1 or 4 hours prior to the experimental sessions and during the sessions food was available at a mean rate that either exceeded the bird's nutritional needs or at a rate that fell below its relative needs. The results demonstrated that the birds tended to be risk prone. That is they were more likely to choose the variable alternative versus the fixed, when faced with a negative energy budget.

Pietras and Hackenberg (2001) introduced a procedure for examining human decision making in the context of risky choice. While human performance in this context had been previously examined, they pointed a discrepancy in performance between human and non human animals. They attributed the difference in performance to methodical limitations when using human subjects. They introduced a laboratory method of choice in the face of risky situations that would more closely mimic the functional effects of non-human animal methods. For ethical and logistical reasons it is not possible to control the human participant's level of food deprivation. Pietras and Hackenberg (2001) point to this methodological constraint as a possible reason for the incompatible human and non-human animal performance. To more closely approximate the functional effect the manipulation of Energy Budget has on the risky choice behavior of non-human animals, they proposed a method that parallels an Energy Budget with an Earnings budget. Subjects were given choice between fixed vs. a probable delivery of points later exchangeable for money. If the certain option was chosen they would have 2 points added to their trial counter. If they selected the variable option 1 or 3 points (p=.05) were added to their trial counter. They were required to meet a certain earnings criteria in order to be able to keep the money they earned. If the criteria were not met, all the points earned in that block of trials would be lost. Sessions consisted of 12 blocks of five trials. In the positive earnings condition subjects were required to earn a total of 10 points in order to be able to keep the points earned in a given block of trials. This could be done by selecting the fixed option across all five trials of a block. In the negative earnings condition subjects were required to either earn 12 or 13 points in order to add those points earned to the session total. Exclusively selecting the fixed alternative in this condition would not meet the earnings criteria and all the points would be lost.

The authors draw an analogy between loosing all the points and survival of the organism. In real life, if relative nutritional requirements are not met, then the organism dies. In this preparation if a human participant does not meet the experimental earnings criteria then all the points are lost. Essentially, for both situations it is a game of all or nothing. The results of this experiment were more compatible with previous research involving non-human animals. It seems as though manipulating the Earnings budget functionally affected the behavior of the human participants in a way which would allow more accurate comparison with non-human animal performance. Human participants were more risk prone under the negative earnings budget in a manner that was functionally equivalent to nonhuman animals being more risk prone under negative energy budgets.

Risky Choice in a Virtual World

In the Torque® game environment a participant interacts with the virtual world through a surrogate character that is controlled by means of some intermediary device (i.e. mouse, keyboard, game pad). This allows for a more analogous comparison to real life foraging. It also allows for a simulation of the real life and death situation faced by foraging organisms. It may not be necessary to use the analogous earnings budget with human participants and instead use a virtual energy budget in which the virtual consequence is life or death for the on screen character.

The potential death of the on-screen character might be aversive enough to predict whether the participant will engage in risk prone vs. risk adverse behavior. In the game energy can be represented by a colored bar on the upper left hand corner of the screen. The player can be described a scenario in which they are on another planet and have just battled an alien race. They must now travel to a far away home, but in order to successfully return they must collect enough energy resources to meet their nutritional needs during the trip home. They have limited time though, as an overwhelming opposing force will soon overrun the area where the resources are located. They will have time to visit 5 locations, corresponding to the 5 trials in a block. Further, they can be instructed that at each location they will only have time to select one of the two available resource options. After the scenario is described the player will find themselves facing 5 discreet opportunities for collecting resources. The "left" and "right" arrow keys will be used to select whether the participant guides their on-screen counterpart to either the fixed or variable alternatives. Whether the situation can be described as one of positive Energy Budget or negative will be determined by the amount of energy left on the colored energy bar after the described battle. For example, when the energy bar is full this will represent a total of 15 energy units. In a positive Energy Budget 5 the participant will start the block of trials with 5 energy units and will need to earn 10 more across the block of trials in order to survive the trip home. In a negative energy budget, the player will start with either 2 or 3 energy units and will need to earn 12 or 13 units more across the block of trials in order to survive the trip home. If a participant fails to meet the criteria then a screen lamenting the demise of the "hero" will be displayed. On the other hand, if a participant meets the criteria then a screen celebrating the character's return home will be displayed. The number of times a player meets this criteria across the blocks of trials in a given session will be recorded and presented at the end of the session as the total number of space travelers "saved" as a result of the choices made.

The above scenario differs from the method introduced by Pietras and Hackenberg (2001) in that the Energy Budget is not replaced by an Earnings budget, but rather represented by a virtual Energy Budget. However, the flexibility of the Torque® game engine would allow for the programming of a scenario which would more closely resemble the original design. Instead of an elaborate scenario involving aliens and heroes, the player could be faced with choices that result in points exchangeable for money. Instead of an energy bar there could be a set of two counters, one for the within block total points earned and one with the session wide points earned analogous to the original experiment. The points earned can later be exchanged for money.

Summary

The Torque® game engine presents an opportunity to allow human participants to interact with a virtual world through a programmed surrogate. This virtual world can be programmed to provide access to a variety of choices and their programmed consequences. Thus, the Torque® game engine can be effectively used as a platform for researching human behavior and decision-making. The utility of this research platform has recently been demonstrated by Michael Young and colleagues (Young, Webb, & Jacobs, 2011; Young & Cole, 2012; Young, Webb, Southerland, & Jacobs, 2013; Young Webb, Rung, & Jacobs, 2013) in a series of papers assessing choice and self control in the context of a first-person shooter video game programmed in Torque® .

Although only three possible scenarios are presented in this paper, there are seemingly endless programmable possibilities, including scenarios in which multiple subjects interact within the same program. Another advantage is that while traditional laboratory preparations involve the use panel boards, levers, dials, mechanical counters and a number of other specialized equipment, one need only have access to basic computing hardware and software in order to program using the Torque® game engine. Perhaps the most important benefit of testing ecological models within the virtual game world lies in the similarities between the real and virtual worlds. Although not a perfect analogue to the real physical world, the game engine allows a more similar experience to the subject's own than traditional preparations. This is not to say, however, that using the proposed virtual environments will yield different results than traditional methods. After all, more important than looking like the real world is capturing the functional feature of the environment in question no matter the method.

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Research Paper Title:
Human Foraging in a Virtual World

Major Professor: Eric A. Jacobs