**Increasing Movement through an Adaptive**

**Reinforcement Learning Algorithm**

Principle Investigators:

Erik Summerside Dept. of Integrative Physiology,   
 University of Colorado at Boulder

Erich Riesen Dept. of Philosophy,   
 University of Colorado at Boulder

Megan Meyer Dept. of Linguistics,   
 University of Colorado at Boulder

Robert Crimi Dept. of Computer Science,   
 University of Colorado at Boulder

**A. Project Summary**

**A.1. Overview:**

**A.1.1. Integrative Value and Transformative Potential:** The following research best fits under the proposal class of ***integrative interventions*** since its primary goal is to develop a method of learning to categorize how exercise and movement based activities are perceived and second, to use these perceptions to develop an intervention technology that considers an individual’s movement preferences to increase activity in small doses throughout the day. We ask that the provided proposal be classified under the integrative themes of ***individuality and variation***, and ***cognitive processes in realistic complex environments*** as a heavy component of the project relies on individual perceptions of movement, and how to provide effective personalized incentivizes for a more movement-based lifestyle.

**A.1.2. General Overview:** Contemporary thinking foregrounds movement as relating entirely to exercise. Movement as conceptualized as exercise and is seen as time set apart from normal activities that one can perform in a day. This thought process can lead to people believing they do not have time to exercise, when in fact increased movement can be integrated into nearly anything. The purpose of our research is to identify aspects of an individual’s daily schedule, as well as features of one’s environment, that can be used to create increases, or ‘nudges,’ in movement activity.

We accomplish this by first running a variety of experiments designed to understand how individuals view different movement based activities and analyzing patterns in subjects responses to better understand the underlying conceptual and decision making factors involving movement across different demographics. Then, we input what we have learned and develop a reinforcement learning algorithm. We can update the weights and kinds of rewards for movement in the learning system by tracking the most salient perceived affordances in one’s surrounding environment, *for particular individuals.* We do this through a wearable mentor system that gains constant feedback from users. This demonstrates our intent to study cognitive processes in realistic complex environments.

**A.4. Intellectual Merit:**

The degree to which an individual moves or chooses not to move varies widely; spatially, temporally, and demographically. Understanding the motivations and the features of environments that motivate movement will allow research to more accurately describe the ways in which movement can be integrated into daily routines and increase positive health outcomes. Our wearable mentor product will utilize machine learning reinforcement algorithms as a method to nudge wearers into increasing their movement. This demonstrates the theme of individuality and variation.

**A.3. Broader Impact:**

Results from our project will allow us to help understand variation between those who move more and those who do not. Through this understanding of movement motivation, we can attempt to reform the way sedentary people think about movement. With this knowledge we hope to improve methods of identifying and promoting physical activity through understanding individual’s personal preferences, and thereby promote health and decrease the costs associated with unhealthy populations.

**B. Increasing Movement through an Adaptive Reinforcement Learning Algorithm**

**B.1. Background and Purpose of Research**

Our research program is motivated by predictions optimal foraging theory makes regarding the way in which animals act in the world based on their need for sustenance. At the most basic survival level organisms require an energy source to maintain life. Animals, including humans, rely on traversing environments, reaping the resources that are available in their current environment, and moving to new environments when the current one is no longer adequate to the organism’s needs (Stephens and Krebs, 1986). Many lines of evidence suggest that the role of the brain was initially to help optimize this task, giving us the ability to manipulate our current environment and coordinate the movements to take us to different environments (Ungar and Teaford 2002). These decisions of when to move and when to stay are very complicated optimization problems based on valuing the individual’s current energetic state, the energetic potential of the current environment, the energetic costs of moving to new environments, and the risks of obtaining necessary amounts of resources in the new environment (Charnov 1976). There are models spawning from a diversity of disciplines including ecologists, anthropologists, economists, and psychologists, that attempt to predict how, when, and why animals move to new environments (Ungar and Teaford 2002, Charnov 1976, Rowland et al. 2008).

One of the most popular models that has permeated disciplines is optimal foraging theory (Charnov 1976). Optimal foraging theory provides a biologically motivated prediction of what methods animals employ to seek out sustenance for survival. According to this theory, animals move because they are hungry; hunger initiates need-based movement. Animals will attempt to attain the highest amount of benefit for the minimum amount of cost while foraging (Pyke, 1984). An example of optimal foraging theory in practice is the behavior of starling birds when gathering leatherjacket insects for their young. Each starling will determine the optimal amount of leatherjackets that it will be able to carry back in its bill to feed their young, also keeping distance travelled back into consideration. This general description of why animals may be motivated to move, through optimal foraging, is the fundamental motivation for our research questions of human perception of movement and the conditions under which individuals chose to move rather than to remain still.

The place of optimal foraging in the modern age has greatly changed the scale of movement required. Physical activity is no longer a necessary precondition for the attainment of food because of modern resources like motor vehicles and the abundance of supermarkets. Individuals in industrialized societies are often able to gather food without any significant amount of movement. Specifically, online services now enable people to have food delivered directly to them, saving time and energy which in turn incentivizes the behavior of staying still. Many also expect a sharp increase in the use of delivery groceries as new technologies continue to reduce the cost and speed of shipping.

Instead of optimal foraging, movement today is frequently motivated by one’s desire to be ‘healthy’ or to achieve a healthy body-image. The current exercise culture, in only attending to individuals who are motivated by health and body-image reasons, is ignoring important consequences of foraging theory. Historically, humans have been motivated to move by external pressures such as the need to find food. If we could motivate individuals to move because it leads to self-craving rewards and not because that exercise itself is rewarding, then we could incentivize more individuals to lead an active life. The current research looks to explore this possibility and hopes to provide results that can be used to better motivate individuals to engage in physical activity.

**B.2. Approach, Context, and Anticipated Outcomes:**

Recent research has looked in detail at what influences children to engage in physical activity and what features of a child’s environment promote movement, such as jungle gym equipment and organized after school activities (Harmon, et al., 2014). The current project seeks to extend these efforts to adults. We hypothesize that certain populations will be better motivated by benefits of movement that are not connected to the health benefits of the activity itself. Moreover, we intend to look at the features of one’s environment that incentivize or require movement. Features refer to any aspect of one’s surroundings that can be interacted with and influence, or can be influenced by, agents. We anticipate that certain populations will respond to different motivational forces and will be prompted to move by different features of the environment. For example, teenagers may participate in physical activity when the activity itself provides enjoyment--such as surfing or playing sports. However, older individuals may be more inclined to move if the movement is necessary (or sufficient) for completing some aspect of their daily routine. For example, people often ride their bikes or walk to grocery stores if such stores are nearby. These actions greatly increase the average person’s daily movement. Knowing the pertinent environmental features and individual motivational structures is essential for constructing personalized programs that motivate movement.

One aim of this project is to understand how we can reinforce motion by identifying the most salient reasons for engaging in physical activity. From here, technological applications (such as fitbit and other wearables) can be better designed to take individual motivational structures into account. A further aspect of this project will be locating features of environments which tend to promote healthy living. There is already a body of research on the relationship between health and local planning. We will extend this body of evidence by paying particular attention to individuals and understanding why certain features of their neighborhood, city, or even their houses, cause them to move. These two questions (features and motivations) can be partially collapsed into one using the notion of affordances. An affordance is a perceived relation between an agent and its environment. The same feature of an environment may provide dissimilar affordances to different individuals due to different internal factors of the agents, such as motivational structures. Our research can capture the important relation between a person and her environment using the framework of affordances. This highlights our focus on individuality and variation.

**B.3. Research Questions**

**Question 1**: How do people perceive the costs and benefits of movement based activities? Are there shared universal connotations of these costs and benefits across demographics and if so, where do those connotations nest?

**Aim 1**: Using image discrimination tasks and similarity ratings, establish how individuals interpret and classify different daily movement based activities ranging from explicit exercise focus activities to activities where movement benefits are secondary to the primary utility of the activity (ex: walking around the block verse walking to a neighbor’s house).

**Question 2:** Using Reinforcement Learning (RL) structures like in optimal foraging theory, can we model the salient motivations and influences that cause the average person to move? If so, can that information be used to promote more movement behaviors throughout an individual’s whole day?

**Aim 2**:Create a tool that tracks daily activities, and based on a user’s motivational structures, provides personalized suggestions for alternative methods of transportation or different routes for a given method. The intent is to increase physical activity through several small ‘nudges’ integrated throughout the user’s regular schedule.

**Question 3**: What features of one’s environment afford motion? Why do some features afford motion only to certain individuals? What aspects of a person’s psychology (motivational structures) dictates whether or not a certain object will afford motion?

**Aim 3:** Study the relations between features and motivations in order to locate and group affordances via the image description and similarity rating tasks, as well as from data gleaned from the nudging application.

**B. 4. Importance**

*Intellectual Merit*

The current project advances science by looking at the consequences of optimal foraging theory and arguing that the theory predicts the necessity of creative new solutions to encourage movement. Moreover, we are testing a classic ecological model in a contemporary human environment. We need the benefits of moving to outweigh the costs. However, we are focused on the benefits of movement that are not directly related to health, because we want to motivate movement for everyone, not just those who know and care about their health. These benefits are things like the pleasure one feels while roller skating, the delight of knowing your actions help the environment, or the increase in social interaction gained from traveling by foot or on public transportation. The goal is for our research to result in a successful model of human motivation for movement, which when implemented, will cause sustained increases in physical activity, a behavior shown to have both short and long term health benefits, which is good for everyone whether they are motivated by such facts or not.

This research will also extend the theory of affordances by locating the salient features of environments that afford movement and looking into why such features afford movement to certain individuals and not to others. An affordance is a perceivable dyadic relation between an organism’s abilities and the properties of the environment (Anderson, 2014). The same object will provide different affordances to different agents depending on what the agent can do with it. Rocks afford throwing for humans, but not for ants or dogs. Moreover, the same object can afford different things on different occasions. Usually, wooden chairs afford sitting. However, in a desperate situation they could afford heat through a fire.

The behavior of animals can be explained by referencing the affordances that objects in their environment provide. Thus, affordances have become a useful notion in cognitive science, especially embodied cognitive science which emphasizes the relationship between an organism and its environment. Decision making can also be understood through the lens of affordances. Cisek theorizes that decision making is choosing which perceived affordances to follow (Cisek, 2007). On this view, our environment restricts the range of possible actions available to an agent. The agent can choose only among those affordances presented to them. An important part of our project will be looking at those features of the environment that afford motion and why people choose them. Remember, an affordance is a *perceived relation* between an agent and an object. Different agents, even in the same situation, may perceive different affordances given the same feature in their environment. Our research will look at why certain features (certain aspects of houses, neighborhoods, etc.) afford movement in general, and also why they afford movement more for certain types of individuals.

A body of research has grown up around the idea that aspects of one’s neighborhood can have drastic impacts on one’s health. For example, it is well known that the physical characteristics of buildings, roads, and other constructed features can have an affect on levels of obesity and exercise (Sallis, 2006). Individuals are also more likely to be active in safe, close-knit communities that have less graffiti and crime. Having more health supermarkets, sidewalks, biking/jogging trails, and parks increases the average health and exercise level of the population (Cubbin, 2008). The availability of these resources spur movement. People are not likely to travel far from their house to visit a healthier supermarket, and they are unlikely to bike to work, or allow their children to bike to school, if they feel it is not safe because of crime or lack of designating biking paths.

However, this body of research leaves open two explanations for why individuals in certain types of neighborhoods are healthier. It could be that the features of these neighborhoods make people more healthy by offering movement affordances that many neighborhoods lack. Conversely, it could be that healthy people choose to live in those types of neighborhoods. People who like a healthy life may be more inclined to move to a neighborhood that affords movement. We presume that both explanations are causally relevant. Our hypothesis is that the reason people move more in certain neighborhoods has to do with both their individual psychologies and the features of the environment. An affordance is a relation between an individual and her environment. Therefore, by looking for and categorizing affordances we can take both the individual psychological factors and the external environmental features into account at the same time. This provides a means for disentangling the two potential contributions to movement (individuals’ psychologies, and features of the environment), and a way of evaluating the relative importance of each.

*Broader Impacts:*

Populations around the world have very high percentages of individuals living with health problems related to obesity and cardiovascular disease. There are two primary causes of this problem. First, in modern western societies the access to food is now easier than ever with a high caloric snack available with a telephone call or click of the mouse, especially unhealthy food. Initially, the problem of having large amounts of food at one’s disposal was constrained to affluent regions, and was viewed as a sign of wealth. However, the cost of having easy access to food has dropped dramatically. Even impoverished regions are able to partake in excessive eating with minimal immediate financial consequences. Moreover, the type of food that is becoming available to impoverished countries and poor neighborhoods is often unhealthy food that is cheap to process and easy to ship.

Secondly, physical activity is becoming less necessary to complete daily routines. Commuter heavy city planning with minimal infrastructure for alternative forms of transportation outside of automobiles (at least, and especially, in America) results in long periods of time sitting before and after the workday. Many are required to drive in order to go to school, to work, to the grocery store, etc. For these reasons, it is extremely important to understand the motivational structures behind movement and how these are changing in modern life. Moreover, we need to find new and creative ways to motivate people to move in a culture with a sedentary life style where movement is no longer necessary for survival.

Our research, in looking at individuality and variation, will provide new and personalized ways of increasing motion. We hypothesize that many people have negative associations with the term ‘exercise’ and think that the only reason to engage in movement (which they equate with exercise) is to be healthy.[[1]](#footnote-1) Such people may think that exercise is something to be disliked, they view it more as a chore; something that one needs to do but does not want to do. Our goal is to motivate movement generally by distancing it from the negative connotations associated with exercise and by highlighting the non-health benefits. If people want to move, instead of just realizing that they ought to in order to be healthy, they will be much more likely to do so. Moreover, we hope to increase movement especially in those individuals who are not motivated by the distant and somewhat intangible health benefits that it brings.

**B. 5. Theory and Prior Evidence**

Evidence suggests that the necessity of balancing diet and physical activity is not just applicable to a diseased minority, but is something that even seemingly healthy individuals must recognize. A possible explanation for the lack of internal motivation to move is that it goes against basic evolutionary ecological principles (Harris and Mattes, 2008). According to foraging theory, the primary reason for animal movement is to satiate hunger and thirst. However, as the result of modern life, the frequency of physical activity, even of the lightest exertion, is rare and normally done for the health and body-image benefits of the movement itself. While these activities often come with tertiary benefits such as fresh air or a time to unwind, the main motivation for movement is not internal, but promoted by external pressures like medical providers and cultural norms. Foraging theory predicts that if individuals are able to receive the benefits that motion was evolutionarily designed to achieve, but without moving at all, then individuals will save energy and stand still. This is the situation that many humans currently find themselves in. Therefore, we need to identify new reasons to get people to move, reasons that will be salient to those who are not motivated by health itself.

There are several new tools that have made novel attempts at identifying and reframing the motivational drive for movement. Using simple electronic devices such as a mobile phone as a platform, software designers, with the help of health care providers, have been able to write programs that deliver information to do primarily two tasks: promote physical activity and to provide personalized feedback on previously completed activity. Currently, the majority of these tools are used in a clinical setting to promote compliance in treatments for diabetic individuals (Rabbi et al. 2015; Sazlina et al. 2015). The strongest aspects of these programs, and likely the reason for their success, is through the inclusion of reinforcement learning algorithms. The implementation of these algorithms allows for an identification of optimal strategies to deliver feedback necessary for improvement. These programs are able to detect when a certain form of communication strategy is not adequate and move on to a new style (Littman 2015). For example, if a particularly motivated individual is making large performance gains, a traditional treatment schedule would be unable to identify that and may be providing suggestions that are too small for the extra-motivated user. This leads to frustration from the user who may abandon the tool. On the other extreme, an individual may be struggling to keep up with the speed of the traditional schedule which also leads to frustration and abandonment by the user. Through the use of a reinforcement based program, a user’s progress can be constantly monitored and tailored in a way that is best suited to the user, increasing the rate of compliance and in the end, getting a better health outcome.

The success of some of these programs have resulted in their implementation in a much larger, generally healthy population. For example, a very popular mobile device application known as ‘Zombies, Run!’ (Six to Start Development) is software that uses accelerometer and GPS information to augment an exercise experience, either running or biking. The software works by creating a virtual environment where the user is given instructions that require exercise to achieve, in this case, running away from imaginary zombies. Again, the major strength of these tools is that they are customizable to the users, allowing it to be accessible and beneficial across a range of physical capabilities, furthermore, the software considers these performance constraints and optimizes how further activities should be later introduced to get best workout while minimizing the risk of losing interest from the customer. This technology is to be distinguished from other exercise behavior such as listening to music or watching television, which simply distract the user from the activity they are doing. The biggest advantage of this environmental augmentation is that it directly ties the movement task to a greater goal where better and more movement results in better and more interaction with the virtual environment. Our idea is not much different than this framework. We propose a means to augment low intensity movement not just for short exercise bouts, but across the longer duration, regularly occurring tasks such as working at a desk, performing home chores, and while filling recreational time.

It has been repeatedly shown that health benefits from movement can be obtained independent of the duration of separate bouts of activity. Per week, the regular amount of movement for adults is 150 minutes of moderate activity. There is no difference in health benefits if this time is divided across one, two, five etc., different activities (Diabetes Prevention Group, 2002; Rose et al. 2008). These results provide evidence that integrating even the smallest increases in movement throughout a regular work day can result in sustained, long term health benefits. In the ideal situation, desirable and enjoyable everyday movement would completely erase the need to include undesired exercise into a user’s lifestyle.

**B.6. Research Methods:**

|  |  |  |
| --- | --- | --- |
| ***Research Question*** | ***Methods*** | ***Expected Outcomes*** |
| How do people perceive the costs and benefits of movement based activities? | Image-Description Task | Understand how individuals view different movement based activities. |
| Are there shared universal connotations of these costs and benefits across demographics and if so, where do those connotations nest? | Similarity Rating Task | Analyze patterns in subjects to better understand the underlying decision making processes across demographics. |
| Using reinforcement learning structures like in optimal foraging theory, can we model the salient motivations and influences that cause the average person to move? When do people perceive motion affordances? Which objects afford motion? | Map actions to costs and reward weightings | Learn initial reward weighting for an array of individuals in order to develop a reinforcement learning algorithm for a wearable mentor. |
| If so, can that information be used to promote more movement behaviors throughout an individual’s whole day? | Wearable Mentor | Analyze changes in participants’ lifestyles based on wearable mentor suggestions. These results will be used to update reward weightings. |

Research within the field of memory and cognition suggests that words, and their associated concepts, do not begin and end at the utterance level. The way humans conceptualize words and actions is a physiological process that affects one’s actions in the world. To better understand why people choose not to move, it is critical to have direct observational data on how people both define and literally picture movement, in contrast to exercise activities. Research from our carefully designed three-part study will highlight preconceptions and avenues that blindsight people to movement in order to program a wearable device that effectively integrates maximal movement into everyday life.

Boulder, Colorado was selected, from all other cities within the United States, to collect data related to movement, because the city of Boulder has been consistently ranked among the Top U.S. Cities with the lowest rate of obesity (McIntyre 2014), in addition to Denver and Ft. Collins also in Colorado. We believe that Boulder will provide participants with the motivational structure we aim for with the wearable mentor. By starting with a large population of people who may integrate maximal movement into their daily lives we will be able to assesses people’s conceptions about movement vis-à-vis these experiments. It will be equally as useful to study conceptions of movement in a less active city. Therefore, a second study will be done in Lexington, Kentucky, which is ranked among the least active in the United States (Roberson 2011). Data collected from Boulder and Lexington will be analyzed, in conjunction with other participant demographic and lifestyle data, to produce a model of movement, which will lead to the construction of our wearable mentor device.

**Participants - Set #1** will consist of 25 Boulder middle school students and 25 Boulder high school students, selected from a randomized pool of 100 middle school and 100 high school students. Waivers will be sent out randomly to 100 students from all class subjects; responses are believed to be few and 25 students from each middles school and high school will be selected to represent the available demographic range. Secondary data will come from the same number and school level of students as in Boulder for one selected Lexington, KY middle school and one high school.

**Participants - Set #2** will consist of 25 University of Colorado at Boulder undergraduate students and 25 University of Colorado at Boulder faculty, where 100 waivers will be sent out randomly to all departments. Secondary data will come from 25 university students and 25 faculty from the University of Kentucky.

Benjamin Bergen et al. provides evidence from a four-part study he carried out using semantic priming to examine low level-cognitive systems in order to see if there is a link between people's’ perception of action verbs in motor language with the modal experiences that the individual can evoke (Bergen et. al, 2010). The study consisted of image-verb matching, verb-verb matching, Verb-Image Matching in English and Cantonese, and image-verb matching in second language learning. The data collected indicate that verbs denoting actions performed with different effectors were processed in different regions of the motor cortex.

For this project, it is critical to find out why people are or are not integrating movement into their everyday routine. An understanding of what people consider movement to be and what movement can apply to is a necessary first step in goal of increasing their movement. Lexical decision tasks are perhaps the most applicable tool suited for the undertaking of studying the conceptualization of movement. We will use lexical discrimination in the first part of our study carried out with two participant sets, to include a wide range of age and education level. Our application of lexical discrimination will be to measure whether the target response is related to the idea of movement – a retrospective approach, rather than a traditional application of semantic priming to see if a response to a target is faster when preceded by a semantically related prime – a prospective method (American Psychological Association, 2014).

***Experiment 1: Image-Description Task***

Participants will be shown 25 images on a DELL computer screen with Keyboard attached – each image will appear individually for 15 seconds – where the participants are asked to type 3-5 words (while the image is shown) describing what they see. Free responses taken from the participants typed sentences will be hand coded using NVivo software to identify trends or ‘themes’ in associations. With this experiment we anticipate finding that the many participants will describe the images in terms of exercise activities over describing movement. The Similarity Rating Task in Experiment 2 will serves as a control to measure whether participants can be guided by the selected image triplets into selecting movement over exercise activities, substantially reducing the amount of diversity of answers and possibility of bias.

***Experiment 2: Similarity Rating Task***

Participants will be shown 3 images simultaneously on a DELL computer screen for 10 seconds; all pictures will depict a movement related scene with varying degrees of effort/exertion. Subjects will then be asked to click on the 2 images they feel are most similar out of the triplet set. Each participant will repeat this task for a total of 25 image sets (75 images in total). This test will provide information on how subjects categorize movement, removing the possibility for top down knowledge differences that may occur in *Experiment 1* by providing each participant with the same brief description and image set. Data will be analyzed by comparing which images are grouped to see if there are trends among particular sets.

***Experiment 3: Nudging through a reinforcement learning based mobile application***

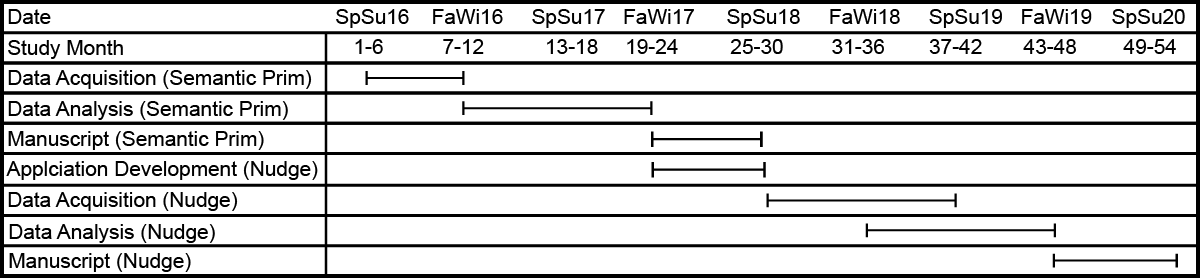
Experiment 3 focuses directly on individual answers to map individual movement outcomes. First participants will be asked to fill out an approximate daily schedule of their activities across a week’s time. This may include variables such as work, school work, family obligations, club membership or recreation, etc. Moreover, participants will be asked about features of their environments that we know are important for movement. Participants will then be tasked with analyzing different movement and non-movement related activities. Participants will be asked to categorize these activities by their views on the activities’ costs and benefits. To determine preferences between activities, participants’ will use a linear 1-10 point scale to rate these costs and benefits. This data in conjunction with an individual’s schedule will form individual Reinforcement Learning models for each participant. These models will act as a mentor in a Wearable or Mobile technology. This Wearable Mentor is constantly receiving feedback from the user. It would be able to ask its user about what caused them to move at some particular time. Perhaps the person was feeling frustrated, went on a bike ride, and felt much better afterwards. Wearable Mentor could extract this information, store it, and later prompt the user who is frustrated for some other reason (known by the wearable perhaps by an increase in heart rate or some other physiological response) that perhaps a bike ride would be nice.

**B.7. Significance**

By understanding the motivation behind strategies of movement conception, through research we will carry out, movement can be [metaphorically] reprogrammed towards increasing physical activity without the sole sentiment of exercise being the goal. Discourse surrounding topics of obesity and overweight in America have a strong tendency towards focusing on how to fix this problem and less on possible causation of overweight. Our research directly challenges institutionalized views on exercise as the only form of movement. Directly, the National Institute of Health’s website cites ‘being active’ as a healthy lifestyle choice featuring examples of “biking or rollerblading”, but does not indicate non-exercise alternative forms of movement (National Institute of Health, 2012).

Most current Reinforcement Learning techniques attempt to have an agent reach a desired goal in the shortest amount of moves. For example, an RL algorithm for playing chess will attempt to win in the shortest amount of moves. We plan on inverting this method and increasing the time a person is “playing the game.” In our case, the goal of “the game” would be increasing movement based activities. One possible solution would be to have movement be a side-effect of reaching a non-movement based goal. For example, if our RL learns that an individual takes the bus to work, one possible suggestion may be to walk instead.   
 We believe this methodology will improve RL methods in multiple ways. Most current RL techniques only focus on attaining a single goal. Primarily, our research will provide a framework for attaining a side-goal on the path to a major goal. This will not only have benefits in the study of movement. Side-goals could be built into game RL algorithms such that on an agent’s path to winning, it is also obtaining other beneficial rewards. For example, a RL agent for playing chess could learn about important aspects of the opponent while on its path to winning. Our research on movement will go beyond available shallow likert-scale survey data and provide a cognitive mapping for what movement is from a physiological standpoint, as well as a detailed plan for how movement can and should be included in lifestyle choices not motivated as exercise. Cognitive mapping is a type of mental representation a person can use to acquire, code, store, recall, and decode information about movement in their everyday spatial environment.

Phase I of our study will begin with a lexical discrimination experiment, akin to the study Bergen et. al of *Body part Representations in Verbal Semantics*, where participants will be shown a picture illustrating a motion verb and then will be asked to provide a brief 3-5 word description of the picture – these photos will range in intensity of physical activity in order to understand the varying degree of what people perceive movement as. Once a better cognitive understanding of the movement definition problem is achieved, Phase II will monitor a second set of participants daily schedule alongside their preference for movement to determine when and what types of movement can be integrated and . Phase III is the implementation stage where participants will be asked to increase their movement and then document their feelings towards this increased movement. After findings are recorded a report will be drafted provided detailed research on what people think movement is and how we can revise that conception and incentivize people to participate in more physical activity.

**B.8 Timeline**

**B. 9. Project Team and Project Management**

The research agenda outlined here builds on and is motivated by the prior work of the

investigative team:

**Summerside** (PI) specializes in the field of decision making, combining classic research ideas in ecology and behavioral economics and using them to predict human movement behaviors. His focus is on understanding the way humans consider costs and benefits in physical activity and how those valuations manifest into preferred naturalistic movement behavior. His interests have lead to designing several successful research paradigms that include quantifying how individuals subjectively value the metabolic costs involved in movement and how that valuation can explain seemingly small observable variability in movement speed within a population. He has also conducted projects investigating how different individuals respond to reward (reward sensitivity) and is curious in how reward can manipulate movement preferences. As the principal investigator, he will be responsible for directing the team’s efforts in successfully address all aims of the proposal, maintain communication across members, and in assuring experimental manipulations are conducted in a safe and productive manner.

**Crimi** (Co-PI) contributes expertise in the fields of Machine Learning, Algorithms, and Big Data. During his undergraduate career, he focused on Software Engineering with minor focuses on Artificial Intelligence, Numerical Methods, and Applied Mathematics. His graduate research is in the study of Reinforcement Learning and Big Data techniques. He is a software engineer at the National Center for Atmospheric Research, where he focuses on maintaining and curating large data sets. He has worked on a multitude of projects in the Machine Learning field, including developing RL techniques for Gerrymandering and Regression techniques for avalanche prediction. He is responsible for developing the adaptive RL algorithm for the wearable mentor as well as guiding the team in the fields of Machine Learning and Big Data.

**Meyer** (Co-PI) contributes expertise in the study of interaction and communication with technology, as well as linguistic semantics and pragmatics. She is a research assistant in the Arts and Sciences Support of Education Through Technology (ASSETT) department, at the University of Colorado at Boulder, responsible for assessing student and instructor response to teaching technologies. She is also a Learning Technology Consultant with the Office of Technology where she works directly with user support of campus technologies and a sales specialist at Apple. Her undergraduate thesis work at the University of California San Diego analyzed tablet device integration into primary education highlighting both technology barriers and affordances. She is responsible for the design of semantic experiments and will advise on user-based design of the wearable technology.

**Riesen** (Co-PI) specializes in the philosophical underpinnings and assumptions of cognitive science. He has an M.A. from Northern Illinois University in philosophy and undergraduate degrees in both philosophy and psychology. His past work has focused on clarifying the concepts and assumptions utilized in cognitive science. He works closely with Rob Rupert on the philosophical implications of new ideas in embodied and situated cognition. His role in this study is to critically assess the research methods utilized in order to make sure we are measuring what we think we are. Moreover, he will be useful in articulating and clarifying the distinction between exercise and movement, as well as other key concepts required by the current work.

The experimenters have the appropriate resources to successfully conduct the proposed project. Participant recruitment will take place over two locations and require cooperation with young members of the community. The researchers’ primary university has a strong tradition of working with these members both academically and in community improvement activities. Because of these relationships, the researchers will have the necessary resources to recruit the appropriate participants for this study. A second location, at Lexington Kentucky will be used to collect a comparison data set across all experiments. We will work with the necessary departments there to gather those data sets. To help strengthen the collaboration, we plan to fund a graduate student for one semester in order to spend time there as a guest researcher, while that enrollment process happens. All other tasks can thereafter be conducted remotely.

**B.10. Risk, Reward, and Risk Management**

There are both potential risks and rewards involved in the proposed research. Physical activity is strongly correlated with positive health outcomes including increased muscular strength and cardiovascular health, but also comes with the risk of musculoskeletal (strained muscles, broken bones) and cardiovascular (heart attack, stroke) injury. To minimize the risk of musculoskeletal injury, interventions will be limited to increased walking, running, and other low impact activities where the chances of these outcomes are minimal. To mitigate the chances cardiovascular injury, we plan to enroll young participants where the chance of a cardiovascular event is less than 1 in 400,000 hours of exercise. By agreeing to participate in this study, individuals must understand that the researchers are in no way responsible for any harm, injury, or financial loss experienced by the user during or after participation.

**B.11. Integrative Strategy**

There is huge variation in the amount of physical activity practiced across individuals, however, as a population, it is a general consensus that we need to move more. Traditionally, this problem has been addressed by suggesting individuals take time out of their day to dedicate to exercise. Due to the social and logistical complexities from person to person, time for exercise is often not feasible. Our proposal is attempting to catalogue the different ways individuals perceive physical activity then through the use of a reinforcement based software, use that information to create a novel way of nudging small personally tailored suggestions of ways to increase movement in a manner that is conducive to the users unique lifestyle. Early implementation of reinforcement based software has successfully increased movement behavior in individuals suffering from diabetes and has resulted in mitigation of their symptoms through benefits brought on by increased physical activity. We plan to build on this success by adding its application to the general population who operate in a much more variable and complex environment.

**C. References**

1. Stephens, David W., and John R. Krebs. *Foraging theory*. Princeton University Press, 1986.
2. Bergen, Benjamin, Ting-Ting Chan Lau, Shweta Narayan, Diana Stojanovic, and Kathryn

Wheeler. "Body Part Representations in Verbal Semantics." Memory & Cognition 38.7 (2010): 969-81.

1. Harmon, Brook E., Claudio R. Nigg, Camonia Long, Katie Amato, Anwar, Eve Kutchman, Peter Anthamatten, Raymond C. Browning, Lois Brink, and James O. Hill. "What Matters When Children Play: Influence of Social Cognitive Theory and Perceived Environment on Levels of Physical Activity among Elementary-aged Youth." Psychology of Sport and Exercise 15.3 (2014): 272-79.
2. McIntyre, Douglas A. "America's Thinnest (and Fattest) Cities." USA Today - 24/7 Wall St. Satellite Information Network, 07 Apr. 2014. Web. 11 Mar. 2016.
3. Pyke, G. "Optimal Foraging Theory: A Critical Review." Annual Review of Ecology and

Systematics 15.1 (1984): 523-75.

1. "Lexical Decision Tasks, Semantic Priming, and Reading." Particularly Exciting Experiments in Psychology. American Psychological Association, 6 Nov. 2014. Web. 12 Mar. 2016.
2. Rowland, Neil E., Cheryl H. Vaughan, Clare M. Mathes, and Anaya Mitra. "Feeding behavior, obesity, and neuroeconomics." *Physiology & behavior* 93, no. 1 (2008): 97-109.
3. Ungar, Peter S., and Mark Franklyn Teaford. *Human diet: its origin and evolution*. Greenwood Publishing Group, 2002.
4. Charnov, Eric L. "Optimal foraging, the marginal value theorem." *Theoretical population biology* 9, no. 2 (1976): 129-136.
5. Anderson, Michael. *After Phrenology: Neural Reuse and the Interactive Brain.* The MIT Press, 2014.
6. Cisek, P. “Cortical mechanisms of action selection: The affordance competition hypothesis. *Philosophical Transaction of the Royal Society of London. Series B, Biological Sciences,* 362, 1585-1599 (2007).
7. Cubbin, Catherine. “Where we live matters for our health: Neighborhoods and health”. September 2008.
8. Roberson, Laura. "Where Sit Happens: Summer Is the Season for Kicking Back and Doing Nothing, Which Means It's Always Summer in Lexington, Kentucky." *Men's Health Magazine*. Rodale Inc., 20 June 2011. Web. 16 Apr. 2016.
9. Sallis, J.F. “The role of built environments in physical activity, eating, and obesity in childhood” *Future Children*, (2006) 16(1); 89-108.
10. Diabetes Prevention Program Research Group. "Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin." *The New England journal of medicine* 346.6 (2002): 393.
11. Rose, Sally B., et al. "A single question reliably identifies physically inactive women in primary care." *The New Zealand Medical Journal (Online)*121.1268 (2008).
12. Harris, Ruth and Richard D. Mattes, eds. *Appetite and Food Intake: Behavioral and Physiological Considerations*. CRC Press, 2008.
13. Rabbi, Mashfiqui, et al. "Automated personalized feedback for physical activity and dietary behavior change with mobile phones: A randomized controlled trial on adults." *JMIR mHealth and uHealth* 3.2 (2015): e42.
14. Sazlina, Shariff-Ghazali, Colette Joy Browning, and Shajahan Yasin. "Effectiveness of Personalized Feedback Alone or Combined with Peer Support to Improve Physical Activity in Sedentary Older Malays with Type 2 Diabetes: A Randomized Controlled Trial." *Frontiers in public health* 3 (2015).
15. Littman, Michael L. "Reinforcement learning improves behaviour from evaluative feedback." *Nature* 521.7553 (2015): 445-451.

1. In this proposal we draw a distinction between movement and exercise which may not fit with everyone’s intuitions about these concepts. We assume that exercise is an activity that one does with the primary goal of becoming fit and healthy. On the other hand, movement is any sort of motion that a human engages in, regardless of motivation. We further assume that exercise, *but not movement,* has negative connotations for some people. Whether these assumptions are warranted will be born out in our experiments. [↑](#footnote-ref-1)