INVESTIGATION INTO THE LÉVY-LIKE NATURE OF COLLEGE STUDENT WALKING PATTERNS

By

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Abstract

The "Lévy-Walk" is a movement pattern commonly used by foraging animals in order to maximize resource acquisition in patchy environments. The walk consists of long linear movements between resource patches followed by concentrated disorganized movements within these patches. This pattern is notable in that there is no characteristic scale, it has been seen in species of all sizes ranging from microorganisms to large animals. My thesis adviser has previously done research that indicated that a human group, the hunter-gatherer Hadza tribe of Tanzania, also displays Lévy-like movement when obtaining food.

My thesis intended to investigate whether or not this walking strategy is exhibited in a non-foraging human population, college students at The University of Arizona. I asked several students to use an iPhone application which would record their movement. They were then asked to send me the data through an anonymous email account created specifically for this project. I received the data from several participants and sent it off to my adviser's colleague for analysis but unfortunately he was unable to get me any results. Thus I cannot come to a conclusion as to student walking patterns but I have learned a lot about conducting research.

"Lévy Walks" are supper diffusive and scale-free random walks which have been used to model animal search paths (Benhamou 1962). It is a movement strategy which has been determined to be highly efficient for animals foraging for resources in a patchy environment (Benhamou 1962). Lévy walks contrast with "Classical" random walks, in which length and orientation of steps is uniformly distributed in that they have some forward persistence (Benhamou 1962). Organisms performing Lévy Walks move in straight lines until they reach an area containing resources in which their movements become much more concentrated and disorganized. Once the area has been explored satisfactorily, the organism leaves the area and continues to search the environment in a linear path (Benhamou 1963).

Much research has been conducted on the movement strategies of a variety of species from microorganism to larger mammals. Currently, research at the University of Arizona is being done to see if this movement strategy can be extended to humans. If it can be extended, then it must be determined if it is a universal human strategy or only used in certain populations. The work of my honors mentor David Raichlen has focused on understanding whether or not a Lévy Walk strategy is used for a human hunter-gatherer tribe in Tanzania. So far it appears that it is. The goal of my honors thesis here presented is to determine whether or not this strategy is also used by a non-foraging population, in this case undergraduate students at the University of Arizona. The determination will be made based on an app using GPS tracking software used by individuals with Apple iPhones. For a year before beginning my official thesis project I collected several articles related to the Lévy Walk pattern and discussed them with Dr. Raichlen. For the literature review section of my thesis I will present the current thinking related to the Lévy Walk that provides the foundation for my project.

It has been noted that predator micro zooplankton alter their searching strategy based on the availability of prey species. Originally the plankton were assumed to exhibit Brownian (Gaussian) motion in which they move random distances and directions in order to acquire prey that were randomly distributed (Bartumeus 12772). However, it is believed that Lévy walks may be utilized under conditions of certain prey densities (Bartumeus 12772). It is proposed that natural selection favors flexible searching strategies under different conditions (Bartumeus 12772).

In an experiment conducted by the University of Barcelona, the feeding behavior of the heterotrophic dinoflagellate *Oxyrrhis marina* on the autotrophic *Rhodomonas* was observed (Bartumeus 12771). Three main resource scenarios were mimicked from nature: blooming conditions, productive ocean areas, and Open Ocean (Bartumeus 12771). Velocity and angle of movement were recorded over a week period (Bartumeus 12771).

The results suggested that the control of flagellar movements by *O. marina* allowed primarily for two distinct searching behaviors in natural environments (Bartumeus 12774). In times of high resource availability the dinoflagellate expends most energy in the longitudinal flagella which creates movement in a near linear axis (Bartumeus 12774). In times of low resource availability, the predator invests energy into the transverse flagellum which creates three-dimensional helicoid trajectories with constantly changing movements of the longitudinal flagellum (Bartumeus 12774). This resulted in a combination of "walk clusters" separated by larger straight traveling paths (Bartumeus 12774). The large helical Lévy-like pattern allows the organism to better re-sample previously explored areas in case of movement by prey species. The differences in energy investment indicate that the predator is willing to invest more energy into Lévy-like movements because it increases efficiency of prey gathering when prey is scarce.

Researchers at Boston University have studied the flight patterns of the wandering albatross in order to determine if they appear Lévy-like (Viswanathan et. al 413). Data was collected over a three month period in the region of the South Atlantic Ocean (Viswanathan et. al 413). Electronic GPS recording devices were placed on the legs of adult albatrosses from Bird Island, South Georgia and monitored the course of 19 different foraging trips (Viswanathan et. al 413). The monitor took measurements every 3 seconds and was able to mark times in which the animal was under water (Viswanathan et. al 413). Wet periods indicate times in which the bird stopped over water to eat or rest. It is assumed that that the distance travelled is proportional to the time spent dry and that the direction of travel changes randomly after being in water (Viswanathan et. al 414).

This paper brings up the idea that Lévy-like patterns may be particularly advantageous for foragers working in swarms or flocks (Viswanathan et. al 414). There is little difference in the number of sites that an individual is able to visit with Brownian as opposed to Lévy-like movement patterns (Viswanathan et. al 414). When the individual is placed in a group setting however, a Lévy-like pattern allows the individual to visit a larger number of sites that the group has not visited (Viswanathan et. al 414). As prey leaves sites in response to the predator swarm, it appears that the increased efficiency of the Lévy-like pattern as opposed to the Brownian allows the swarm to more easily find new resource-rich locations (Viswanathan et. al 414). The results of this study are mostly qualitative in that the GPS data was visualized in the form of a flight path. The researchers suggest that for future studies more quantitative results can be recorded (Viswanathan et. al 415). My project in particular is fairly similar to this one presented however I intend to take the suggested next step and quantify the flight path of my subjects by sending that data to be analyzed by a colleague of my research mentor.

Lévy walks first became known when they were observed in the movement of foraging ants (Reynolds 117). Lévy Walks consist of clusters of short step lengths separated by longer movements (Reynolds 117). This movement pattern is most notable in that it is fractal which means that the patterns have no characteristic scale (Reynolds 117). It has been found that Lévy Walks outperform Brownian walks and straight-line movements when an organism is searching for resources that are randomly and sparsely distributed in a non-destructive manner (Reynolds 117). Non-destructive refers to the fact that search areas are not deleted after they have been explored. Instead, they can be researched at a later time either because the resources are not completely consumed with each visit or because they replenish over time (Reynolds 117).

Composite Correlated Random Walks (CCRW) have been proposed as an alternative to pure Lévy Walks. CCRW assumes that animals switch between two or more kinds of walk such as Lévy, Brownian, and straight line movements (Reynolds 118). The CCRWs can resemble Lévy Walks when frequent short steps alternate with rarer longer steps (Reynolds 118). British scientists at the Rothamsted Research center used computer simulation to model the movement of a hypothetical predator in a resource gathering situation (Reynolds 118). They operated under the assumption that if a target is within its perceptual range, it moves in a straight line pattern, otherwise it chooses its direction at random (Reynolds 118). The goal of this research was to determine why such a variety of species all exhibit a similar movement strategy (Reynolds 118).

It was found that CCRWs are most effective when they resemble optimal Lévy-Walks rather than sub-optimal Lévy Walks (Reynolds 120). While animals are capable of executing a variety of movement patterns under pressure of resource scarcity they will shift towards a Lévy-like pattern (Reynolds 121).

Various animals including the wandering albatross and the dinoflagellates previously discussed, as well as jackals, reindeer, and spider monkeys have been claimed to display activity that has been designated Lévy-like (Benhamou 1962). Numerous previous ecology studies have relied on the null hypothesis that animals distribute themselves diffusively in the environment and therefore the realization that they in fact use Lévy-walks could have consequences for previous research (Benhamou 1962).

It is possible however that some animals classified as using Lévy walks may in fact be using Composite Brownian Walks (CBWs) (Benhamou 1966). CBWs occur when an organism is searching for patchily distributed resources in a complex environment as was the case with Lévy Walks (Benhamou 1966). CBWs, rather than following a power law the way that Lévy Walks do, consist of two types of random walks (Benhamou 1963). The first occurs in resource patches where the steps are short and frequent but in random directions and the second occurs between patches where steps are less frequent and traverse greater distances (Benhamou 1963). The similarity between the walking patterns brings up the possibility that some CBWs may be mislabeled by scientists as Levy-Walks. CBWs, like other random walks are particularly inefficient because they lead the predator to search the same area too many times (Benhamou 1967). The directionality of Levy-Walks avoids this problem.

Lévy-walks may not always be the most efficient, for example when resources take long periods to renew. Lévy-walks rely on feeding patterns that are non-destructive, which may not be the best strategy for animals such as nectar feeding insects which nearly exhaust resource patches (Benhamou 1967). Therefore, a Lévy-like pattern may not be as universalistic as was originally thought among various animal species (Benhamou 1967). If my data appears Lévy-like but does not follow the expected mathematical models, perhaps it is because CBWs are observed.

Fishery scientists know the importance of understanding how fishermen allocate their effort in space in relation to the concentrations of fish (Bertrand et. al 331). Understanding fishermen's effort and prey distribution can help avoid the collapse of fish populations such as the Atlantic cod in the 1990s (Bertrand et. al 331). Satellite vessel monitoring systems (VMS) are now commonly used in many fisheries and allow cheap, high quality information regarding the vessels' trajectories (Bertrand et. al 331). Movement patterns are so important because they drive population redistributions and are the primary determinant of organism interaction. It is a functional response of organisms to their environment (Bertrand et. al 332).

Each fishing vessel equipped with VMS has a receiver and transmitter (Bertrand et. al 332). The receiver collects positioning data on an hourly basis from a GPS satellite. Transmitters then send the data to VMS services for quality control, which then forward the information to fishery administrators in the form of angular coordinates (Bertrand et. al 332). The positional data of fishing trips were collected under specific criteria. First, a trip was defined as a series of positions at a distance greater than 2 nautical miles from port. Trips of speeds more than 3 knots were discarded because this is the maximum speed for purse seine fishing. Displacements observed during fixed time intervals were classified as "steps" (Bertrand et. al 332).

The monitor data indicates that fishermen perform Lévy walks during fishing excursions (Bertrand 334). The experiment looked at 14 million vessels therefore the researchers are confident in this conclusion (Bertrand 335). There are several reasons why fishermen may retain the foraging techniques of other predators. In fishing, humans do not shape nature but rather face the same uncertainty of prey location as other predators. Also, a fisherman's incentive to maximize profit is comparable to that of an animal's incentive to maximize energy acquisition. Like fishermen in port, many animals forage from a central location (Bertrand et. al 335).

The movement patterns of urban dwelling humans have been attributed to lifestyle in a human designed environment as opposed to an evolved search strategy comparable to animals (Raichlen et. al 728). A study of Ju/'hoansi hunter-gatherers in Botswana and Namibia suggested that Lévy-walks may be present in humans who live more traditionally (Raichlen et. al 728).

Raichlen's team looked to "the most cognitively complex foragers on Earth," the Hadza hunter-gatherers of northern Tanzania to determine if they too perform Lévy-Walks (Raichlen et. al 728). A selection of 44 Hadza subjects was recruited from two camps. Each was given a GPS unit to wear during foraging bouts over multiple days (Raichlen et. al 728). A foraging bout is a round trip taken by the subject from and back to his residential camp (Raichlen et. al 728).

The results indicate that Hadza travel patterns consisting of searching, acquiring, processing, and transporting food to camp follows Lévy-like patterns similar to those of less complex foraging organisms (Raichlen et. al 731). This study is the most comprehensive demonstrating Lévy-walk strategies in humans (Raichlen et. al 732). Only a very small percentage of foraging bouts (0.62%) indicated movements that had Brownian properties (Raichlen et. al 732). When the Hadza did not use Lévy-walks, their patterns could best be approximated with the Composite Browninan Walk pattern suggested by Benhamou (Raichlen et. al 732). External cues like depletion of search targets may cause changes in walking patterns and thus exponential distributions (Raichlen et. al 732). This study is important because it demonstrates that despite the fact that humans are more complex than other animals displaying Lévy-walk patterns, their foraging strategy is no different (Raichlen et. al 732). My thesis will attempt to explore whether this is also true for humans on a modern college campus.

The adaptive strategies of biological creatures are now being mimicked in the development of mobile robots which search and locate targets that affect gradient information (Nurzaman et. al 2019). Such robots can be important for such tasks as finding chemical leaks, oil spills, and other changes in the local environment (Nurzaman et. al 2019). The aim of a research project by Osaka University scientists is to find a searching pattern for their robots that is simple and effective at discovering environmental information (Nurzaman et. al 2020).

The efficiency of Bacterial chemotaxis and Lévy Walks are compared for a mobile robot. In bacterial chemotaxis, a bacterium such as E. Coli performs "swimming" motions until it detects fluctuations in the environment at which point it begins to "tumble" (Nurzaman et. al 2020). This chemotaxis is a form of Brownian motion. Lévy walks are super diffusive, meaning that the displacement from the starting point increases faster than linearly with time while Brownian displacements increase linearly (Nurzaman et. al 2022). For the simulation, a robot with a microphone was placed in a room with a speaker. For the first experiment, the sound source is turned on so that gradient information exists everywhere in the environment and the robot performs a biased random walk towards the target (Nurzaman et. al 2027). For the second experiment, there is noise and no gradient. In this case the chemotaxis becomes a simple random walk and a Lévy model becomes more efficient for locating the target (Nurzaman et. al 2029).

It seems that rather than one pattern winning out over the other, the most efficient strategy is the ability to switch between stochastic and deterministic behavior. When there is gradient information in the environment, the robot will do a random walk towards the source according to the bacterial chemotaxis model (Nurzaman et. al 2034). When there is no clear gradient the robot will be better able to find sparse targets when it is following a Lévy-walk (Nurzaman et. al 2034). Lévy Walks appear to be better in complex environments.

Current research has thus far indicated that Lévy walks are the most efficient foraging pattern for locating patchily distributed resources in a complex environment where those resources are foraged non-destructively. Lévy Walks consist of patches of concentrated movement loci connected by long straight paths. This walk strategy has advantages over random walks because it allows predators to visit more novel areas for the same amount of distance traveled and time expended. This is partially because Lévy walks reduce the amount of times that an organism revisits previously explored locations.

Lévy Walks are a common pattern exploited by a multitude of animals however not always exclusively. The Mircrozooplankton *O. marina* uses a random walk in cases of resource abundance and switches to Lévy movements in situations of resource scarcity. Data from a study of the wandering albatross also exhibits Lévy-like movements; however the data was not quantitative enough to be conclusive. It is important to consider the possibility however that many animals which have been described as exhibiting Lévy-like character may actually be exhibiting the deceptively similar "Composite Brownian Walk."

More recently, scientists have extended the study of Lévy Walks to humans. Satellite positioning data demonstrates that industrial fishermen follow the same Lévy-like strategies as other predators due to the unique constraints of underwater resource gathering. My mentor, David Raichlen, and his team have found that the Hadza tribe of foragers gathers resources in a Lévy-like manner as well. As the field of robotics expands, scientists are looking at biological organisms for inspiration and using the Lévy strategy that appears so common as a means to increase movement efficiency. It seems likely given the research presented thus far that college students at the University of Arizona will exhibit Lévy-like movements despite the fact that they are operating in an artificially created environment.

Methods

In order to determine whether or not college students walk in a pattern similar to that of foraging people, data was collected using GPS recorded on an Apple iPhone application called "myTracks." The app, once activated, records the position of the participant over the course of several hours.

Participants were recruited by placing a request on my personal facebook page. The recruitment request read as follows:

> "Hello, my name is Jacob Davidson and I am looking for volunteers to help me with my Honors Thesis through the College of Anthropology.
>
> My project studys whether or not the movement patterns of college students at the University of Arizona are in any way similar to that of a contemporary hunter-gatherer tribe called the Hadza. The Hadza have been found to use a movement pattern known as a "Levy-walk" in order to efficiently gather resources from their environment. It is my intent to determine if this "Levy-walk" pattern is a movement strategy that can be generalized to all humans or only to those who must scavenge for food. *
>
> I need several volunteers with gps enabled smartphones who will agree to have their walking habits analyzed over the course of a week using the google maps application. No personal information will be recorded, we will not be able to see who you are or where you are at in any given moment. If you are interested in being a part of my project I would greatly appreciate it and am attaching further instructions below.
>
> *Inspiration for my project came from my thesis advisor David Raichlen's work with the Hadza in Tanzania. The paper can be found using the following citation:
>
> Raichlen, D. A., Wood, B. M., Gordon, A. D., Mabulla, A. Z. P., Marlowe, F. W., & Pontzer, H. (2014). Evidence of levy walk foraging patterns in human hunter-gatherers. Proceedings of the National Academy of Sciences of the United States of America, 111(2), 728-733. doi:10.1073/pnas.1318616111"

The conditions of our IRB required that data related to our participants needed to remain anonymous. My thesis advisor and I thought of using an anonymous email system in order to communicate with our participants. As part of the additional instructions for students interested in participating in my project, I wrote out step by step instructions for properly setting up an anonymous email address through Google mail service. These were the instructions they received:

"Instructions for Creating an Anonymous Google Account

1. Go to the following site to create an account: https://accounts.google.com/signup?service=mail
2. Make up whatever first and last name you want.
3. For username, use "anth#####" where the 5#s stand for a random five digit number of your choosing.
4. Create whatever password you wish
5. Fill in the birthday and gender selection dishonestly. *Do not include previous email or phone number.
6. Once you have created the account go to the inbox, this is the account you will be using to collect and send data.
7. When you have created your account, please send an email through it to jdavidson@email.arizona.edu. A simple "Hello" is sufficient, I just need to know how many people are signed up and I would like a way to contact back to remind you to send your data."

Soon after posting my request, I received several emails with pseudonyms from people who had signed up to participate. In addition to the instructions on setting up the email, I created a set of instructions for the proper use of the app. These instructions were based on my experience using the app for a trial period before my official request went out.

Instructions for Using Map My Tracks

1. Download the free app "myTracks-The GPS-Logger." (https://itunes.apple.com/us/app/mytracks-the-gps-logger/id358697908?mt=8)
2. On the bottom of the screen there is a small circle that says "REC."
3. A pop up menu will appear, select "Change accuracy"
4. You will be taken to a new screen, scroll through the options and select "Best 30s." This setting will give the clearest data.
5. Click "Done" in the top right corner of the screen.
6. Press "REC" again but this time from the pop up menu select "Start recording."
7. The screen will give you a rough estimate of your position, you can pinch in on an iPhone in order to view your location more clearly.
8. Allow the app to run for a continuous week as it records your location.
9. When that time period has elapsed press the "REC" Button again and select "stop recording"
10. Your track recording will be saved in the "Tracks" folder.

Finally, in order to make sure that participants did not compromise their identities, I created this set of instructions for anonymously sending their data:

Sending the Data

1. From the Home screen of the app press the folder icon at the bottom of the screen.
2. This will open up your "Tracks" screen.
3. In the "Tracks" screen, select "Edit" in the top right corner.
4. Select the track representing your movements for the week, a blue checkmark within a circle should appear to the left of your selected track.
5. Press the export symbol (the square with an arrow pointing upward) at the bottom left of the screen, this will take you to the "Export" screen.
6. Do not select any of the options in the "Export" screen (i.e. Include Photos…), instead, press the export symbol (again the rectangle with the arrow) at the top right corner of the screen.
7. A pop up will appear which will allow you to email the data.
8. Select the email option and send your data to jdavidson@email.arizona.edu using your anonymous email account.

Though I did receive some initial interest for participating in my project, I had to do some in person recruiting as well. At first I recruited anyone with a smartphone to participate but I quickly realized that this particular app was only compatible with iPhone software. This limited my pool of potential participants. I would ask anyone I knew that had an iPhone to go on my facebook to find out more information about my project. I had to be fairly involved in finding people to participate because while the facebook post did recruit some people, it was not enough for me to have the sample size of around ten people that I wanted. While I knew that those who were participating were people that I am close to their identities were still preserved because I could not connect the person to the data once they sent it through the email service. Once I had a sample size of people that I was happy with, I would speak with them frequently to find out if they had been having any problems with the software and occasionally checking to make sure that the app was still recording. I myself had the app running on my phone so that I could have some reference in case there were any problems with the data collection.

Once about a week or so had passed, I contacted my participants through the email service and asked that they send in their data. The data came to me in .gpx format but using the converter website http://www.gpsvisualizer.com/convert_input I was able to get the data into .csv format. These files I then emailed to my professor and he sent the data off to his colleague for analysis.

Discussion

Though I submitted my collected data for analysis, unfortunately my professor's colleague never returned any results. The data was submitted anonymously so I have no idea what my subjects' walking patterns looked like. I cannot offer a conclusion as to the walking patterns of college students.

This project has taught me how difficult it can be to run a research project at the undergraduate level. First of all it took almost a month to get my IRB paperwork approved. Then it took some time to find willing participants because it turns out that the app we were using to collect data greatly drained the battery life of participants' phones. We intended for the app to run in the background for a continuous week however it turned out that the app would randomly stop recording after about six hours. The IRB specified that the information would be anonymous which meant that it was hard to me to stay in contact with my participants to make sure that they were checking their apps to see if it was still recording and to turn it back on when it stopped. Using the anonymous email was difficult because it was not one that the participants would check regularly and therefore when I asked them to submit their data to me I got very few responses. What responses I did receive I converted to the proper file format and sent off to my professor. Regardless of whether or not I found out anything about how similarly college students and foragers walk, I have gained a new found respect for researchers.

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