COGNITIVE PERFORMANCE IN RELATION TO PERSISTENCE HUNTING AND MEAT CONSUMPTION

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By

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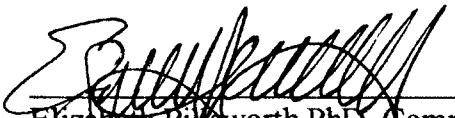

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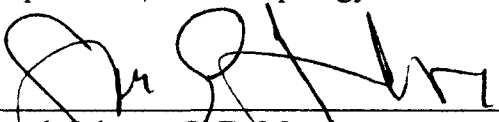

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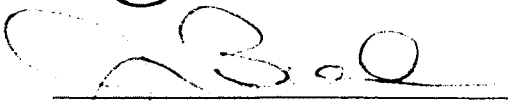

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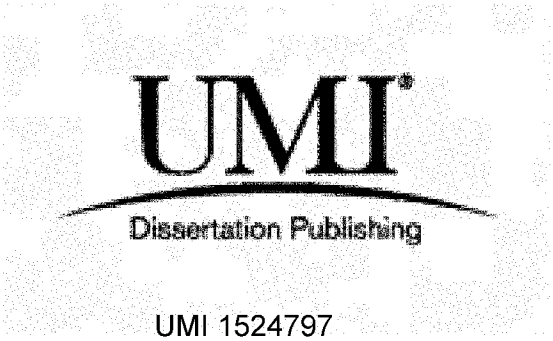

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ABSTRACT

The evolution of the human body and brain over the last two million years may have selected for traits for endurance running in addition to larger more expensive brains. The running hypothesis and the art of tracking hypothesis were used as a theoretical framework for hypothesizing particular cognitive abilities accompanied encephalization. Selection favored these cognitive abilities to improve access to high quality foods such as meat. Meat is thought to have been attained in part through persistence hunting which requires relentless pursuit of an animal over very long distances (17 km or more). During this pursuit hunters invest a great deal of effort in running and also in tracking animals. It is possible that chemicals in meat such as creatine help ameliorate the costs of mental fatigue in persistence hunts by improving or maintaining cognitive performance.

This study aimed to test whether creatine improved cognitive performance before and after long distance runs. Methods involved a survey assessing meat consumption levels in long distance runners accompanied by two tests of fluid intelligence where one test was given pre-race and a second test was given post-race. Results for this study found meat consumption was not significant for meat eating subjects that ran 4.5 km or longer ($n=38$ and $p=.324$) and a significant finding for female runners that ate meat ($n=15$ and $p=.025$). The lack of a similar significant finding in males is thought to be related to sample size, adherence of subjects to test protocols, and problems measuring meat consumption. Interpretation of these findings lead to the conclusion that more research is

needed to find out if meat consumption improves cognitive performance in fluid intelligence for long distance runners. The significant finding for female runners does appear to offer limited support for the running hypothesis and the art of tracking hypothesis.

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CHAPTER 1

INTRODUCTION

Why do humans have such large expensive brains? It would seem obvious that how we use our brains must have something to do with how encephalization occurred throughout human evolution. The ways in which we employ the cognitive abilities tied to encephalization must have links to the distant past.

One way that we employ these cognitive abilities today is through the practice of science. Scientific reasoning entails cognitive capabilities that enable complex forms of inductive and deductive reasoning. In deductive reasoning conclusions are the result of inferences based on premises which must be true (Ladyman 2002). Inductive reasoning relies on observations that can be grouped together to find commonalities (Bacon 2000). Observing that the sun rises every day and asserting that this pattern will continue based on past observations is an example of using induction. Combining these principles allows for more complex forms of reasoning such as hypothetico-deductive and abductive reasoning. A significant portion of these reasoning faculties fall under the term fluid intelligence. Fluid intelligence is the "deliberate and controlled mental operations to solve novel problems that cannot be performed automatically" and solving such problems involve the forms of reasoning mentioned above (McGrew 2009:5). These reasoning abilities when used in conjunction with other cognitive abilities such as memory and imagination allow people to engage in scientific thinking (Kuhn 1970; Popper 1959).

The benefits of science can be seen all around us today. Scientific thinking has increased our knowledge and understanding of the universe ranging from topics like physical laws of the universe to socio-political organization (Pinker 2007). Science has allowed our species to produce increasingly advanced technology that enable humans to live almost anywhere in the world (Pinker 2007). Our species advanced cultural institutions have reduced the likelihood of all sorts of maladies and undesirable events that afflict our species (Harris 2011; Pinker 2011). Death rates from disease, predation, accidents, and conflict have all been drastically reduced in the world when compared to rates among hunter gatherer populations (Harris 2011; Pinker 2011).

The cognitive abilities involved in scientific thinking must have had some adaptive significance in the evolutionary past, long before what many people may think of as the beginning of modern science during the Renaissance (Carruthers 2002; Ladyman 2002). The evolution of the human brain is a critical component of any attempt to connect cognitive capabilities in our species today with their origins in the evolutionary past (Geary 2005). One way of looking at the brain in relation to cognitive abilities is to understand the costs associated with a large brain. When humans are fatigued their vision becomes blurry, their ability to concentrate is reduced, they may become dizzy or even faint (Hitze et al. 2010). This connection between fatigue and cognitive abilities is related to the heavy cost of the brain (Hitze et al. 2010; Leonard et al. 2007b).

Our brains can be used to our advantage but there are also many disadvantages associated with having large brains. The cost of brain tissue is approximately 20-25% of resting metabolism in humans despite the fact that it makes up only about 2% of a

person's bodyweight (Leonard et al. 2007b). This cost cannot be down regulated, so it is important for the brain to have continuous access to large amounts of energy (Peters et al. 2004). If this energy flow were to stop then the brain would die (Peters et al. 2004). This contrasts with other tissues like muscle, which has the ability to atrophy and then be regrown at a later period (Peters et al. 2004). This is issue of cost is thought to be one reason that maintaining a large brain is associated with consumption high quality food sources that contain substantial amounts of energy (Kaplan et al. 2000).

Increased meat consumption by our ancestors over the last two million years or more has been argued to play a central role as the currency that allowed our species to evolve larger brains (Kaplan et al. 2000; Leonard et al. 2007b). Meat is a high quality, nutrient dense food, both in terms of its caloric value as well as in terms of the micro- and macro- nutrients it contains (Milton 1999). Unlike low quality foods than that other great apes depend on, such as leaves or grass, meat contains a great deal of calories (Kaplan et al. 2000). And unlike other high calorie foods like potatoes or roots, meat contains many vitamins along with many nutrients such as protein and creatine (Harris 1997; Milton 1999).

Aside from the nutrients and calories provided, meat also requires much less processing in the gut than do lower quality foods like plants (Aiello and Wheeler 1995; Milton 2003). The expensive tissue hypothesis argues that this allowed *Homo* make a tradeoff where larger guts could be reduced in size through a dietary change toward increased meat consumption (Aiello and Wheeler 1995). The hypothesis is that through this change in diet, Homo was able to make a larger investment in brain tissue (Aiello and Wheeler 1995). As Homo became more adept at acquiring meat this tradeoff could

continue (Aiello and Wheeler 1995). Eventually this continued tradeoff would result in gut and brain proportions of modern humans (Aiello and Wheeler 1995).

By offering a mechanism for the evolution of larger brains the expensive tissue hypothesis invites many additional questions about how such a dietary transition toward increased meat consumption could take place (Aiello and Wells 2002). The running hypothesis argues that early *Homo* was under selective pressure to be highly capable long distance runners in hot weather which allowed them to increase diet quality by hunting and scavenging (Carrier et al. 1984). Long distance scavenging while running allowed hominins to become competitive with other scavengers. Hominins that simply walked toward carcasses would be beaten by scavengers like hyenas (Carrier et al. These long distance running abilities would have then allowed for a transition to hunting by allowing *Homo* to chase animals to heat exhaustion and kill them with little more than simple tools (Carrier et al. 1984). This form of hunting may still be practiced by humans today and it is known as persistence hunting (Carrier et al. 1984; Liebenberg 2006). In evaluating such capabilities in humans Bramble and Lieberman (2004) have located at least 26 anatomical features of the human body form that they argue are specifically conducive to long distance running and heat dissipation. The ability to sweat is more highly developed in humans than any other species and it allows humans a significant advantage in maintaining body temperature over other mechanisms like panting (Bramble and Lieberman 2004). The large gluteus muscles are another example of a feature in the human body form that is specifically beneficial to bipedal running while benefiting walking relatively little (Bramble and Lieberman 2004).

While the adaptations found in the modern human body form allow humans to outrun other species over long distances another critical component to persistence hunting is the use of the human brain in tracking animals (Lee 1979; Liebenberg 2006). Humans are unlike other species of predator in how we go about finding and killing prey (Liebenberg 2006). Lions for example have a keen sense of smell as well as vastly superior hearing compared with humans (Guthrie 2007). Additionally, cats are able to see with only about a sixth the available light required by humans (Case 2003). Using these senses, lions can locate their prey and then employ short bursts of incredible speed along with their powerful jaws and large sharp claws to take down their victims (Guthrie 2007). Humans on the other hand are slow, have a poor sense of smell, and have poor hearing compared to other animals (Carrier et al. 1984). Human strength pales I comparison with other large predators and we lack built-in weapons such as sharp teeth and claws (Liebenberg 1990).

Human hunting styles utilize some unique traits and strategies that do not depend on superb hearing, eyesight, speed, or innate weaponry (Liebenberg 1990). Modern hunter-gatherers likely rely on many of the same methods that our earliest hunting ancestors did and exemplify the ways our ancestors may have used uniquely human physical and mental traits to achieve the same ends as other large predators (Liebenberg 1990). For instance, while we are slow we can relentlessly pursue animals (Carrier et al. 1984). A significant challenge to persistence hunting is the fact that prey animals will often use their superior short-distance speed to sprint out of the sight range of a hunter (Liebenberg 1990). Thus, in addition to being able to engage in endurance pursuits, human hunting also requires cognitive skills to interpret environmental information and

make predictions about the behavior of hunted animals (Liebenberg 1990). A lion cannot interpret footprints in the dirt to determine the direction, sex, age, and likely behavior of an animal but humans can (Liebenberg 1990). The cognitive abilities used in interpreting the environment and making predictions are argued to be essentially the same as those that allow humans to do science (Liebenberg 1990). In what may be termed the "art of tracking hypothesis" Liebenberg (1990; 2006) argues that cognitive abilities used in tracking animals may have been selected for during evolution to improve hunting success (Liebenberg 1990). The cognitive abilities used in both science and tracking as described by Liebenberg (1990) match up to a large degree with the definition of fluid intelligence. Therefore tests of fluid intelligence may be used as a limited type of proxy measure for aptitudes in science and tracking. Although more research linking the two has not been conducted at this time.

Evolving complex cognitive capabilities found in modern humans required increasing levels of encephalization (Kaplan et al. 2000). The art of tracking hypothesis connects the evolution of cognitive abilities that accompanied larger brains in relation to a specific type of high quality diet (Liebenberg 1990). If it was meat that acted as a currency to pay for larger brains then perhaps meat consumption may benefit cognitive functions in a variety of ways. Improvement to cognitive abilities from meat consumption can be illustrated by referring to the literature on the relationship between creatine and brain function (Laakso et al. 2003; Rae et al. 2003). Creatine is found in meat and is also endogenously produced in the liver (Brosnan and Brosnan 2007). Dietary consumption of creatine has been shown to elevate creatine levels in blood, muscle, and brain tissue (Dechent et al. 1999; Laakso et al. 2003; Pan 2007). There is growing evidence that

creatine serves many roles in the body, one of which may be to buffer sensitive brain tissue from energy fluctuations (Walliman et al. 2011).

In addition to the immense energy costs, the human brain brain is very sensitive to energy fluctuations (Hitze et al. 2010; Peters et al. 2004). Maintaining a consistent supply of energy is necessary to maintain a healthy brain (, Hitze et al. 2010; Peters et al. 2004). There are a number of adaptations that appear to allow human brains to withstand energy fluctuations without loss of function (Pfefferle et al. 2011). One such adaptation may involve the phosphocreatine circuit specific to human brain tissue (Pfefferle et al. 2011). This circuit uses the metabolite creatine as a quick response means of increasing ATP production for short periods (Pfefferle et al. 2011). When the brain is given a demanding task the amount of adenosine triphosphate (ATP) consumed increases suddenly and the phosphocreatine circuit is used as a mechanism that can buffer the brain from sudden energy drops (Pfefferle et al. 2011). The reason for this is that creatine is used in a process that can quickly replenish ATP (Pfefferle et al. 2011). Increasing creatine storage and use in the brain is therefore expected to improve this energy buffering system and benefit the cognitive functioning of the brain (Walliman et al. 2011).

A study from Pfefferle and colleagues (2011) measured gene expression of the phosphocreatine circuit in muscle and brain tissues across three primate species: rhesus macaques, chimpanzees and humans. The study reported findings that humans have around 50% higher gene expression rates specifically for brain tissue when compared to the other two primate species (Pfefferle et al. 2011). The authors reasoned that the phosphocreatine circuit may have been under selection pressure as means to allow the

function and growth of large brains (Pfefferle et al. 2011). Other evidence that the phosphocreatine circuit is important to brain function comes from a study that involved creatine supplementation to vegetarians who were required to take fluid intelligence tests (Rae et al. 2003). Increased dietary creatine intake improved fluid intelligence scores (Rae et al. 2003). Other tests have also found similar cognitive benefits supplied through dietary creatine intake (Benton and Donohoe 2011; McMorris et al. 2006).

Studies such as those cited above are relevant to the evolution of the brain by providing clues as to how the physiology of the brain relates to cognitive abilities like fluid reasoning. In the cases illustrated above there appears to be a possible physiological adaptation to maintain energy homeostasis in the brain involving creatine as well as a dietary means of increasing creatine stores in brain tissue (Pfefferle et al. 2011). This is one example of how diet may be related to brain function and specific cognitive abilities. Individuals with increased phosphocreatine circuit gene expression may have been able to maintain larger brains (Pfefferle et al. 2011). In addition to this, those individual who consumed foods containing dietary creatine would have seen a beneficial effect on the cognitive abilities in those brains (Walliman et al. 2011). Foods like meat are therefore argued to have played a role in brain evolution by providing a number of benefits pertaining to the cost of the brain and the cognitive abilities it allows for (Walliman et al. 2011). Improved cognitive abilities can be expected to improve persistence hunting success if the art of tracking hypothesis is correct (Liebenberg 2006).

One means of acquiring evidence favoring the art of tracking hypothesis is to find out if hunters who eat meat are more successful than vegetarian hunters. Such a test would be very difficult to achieve considering persistence hunters are exceptionally rare

in the world today and budget is always an important consideration. Alternatively a proxy measure for persistence hunting involving the mimicking of costs and measuring cognitive performance is perhaps a more viable strategy. Such a proxy measure has been used in this project where long distance running has been combined with tests of fluid intelligence to mimic the costs of chasing an animal over long distances while utilizing cognitive abilities needed for tracking. The cognitive performance scores were expected to be higher in individuals that consumed meat. It was predicted that increased meat consumption improves cognitive performance scores on fluid intelligence tests particularly after periods of intensely fatiguing activity like long distance running.

This study tested the relationship between meat consumption and cognitive performance. The aim of the study was to examine meat-eating in the regular diets of long distance runners in correlation to cognitive performance. Data was collected on the amount of meat consumed by subjects. This was followed by the administration of two cognitive performance tests measuring fluid intelligence. The first test was administered prior to a long distance run and the second test was administered after the long distance run was completed. There were two central predictions in this project. First, subjects that ate more meat were expected to score better on both cognitive performance tests than subjects who consumed less meat. Second subjects who ate more meat were expected to experience less deterioration in cognitive performance after a long distance run than subjects who consumed less meat.

CHAPTER 2

LITERATURE REVIEW

Subsistence and Hominins

Each animal has a niche (Chase and Liebold 2011). A number of adaptations to each niche are connected to diet. Ruminants that eat only low quality plants like grasses have specialized guts to process these foods to get adequate nutrition (Chase and Liebold 2011). The human species should likewise have adaptations that are specialized to allow for the most efficient use of a particular diet, whether this be in terms of physical or cognitive adaptations used to acquire certain foods or in terms of the ability to process and use certain foods (Kaplan et al. 2000; Milton 1999). This work focuses on the exploitation of animal source foods and possible adaptations human have in relation to acquiring these sources and maximizing their dietary value.

The extent to which humans have specialized in the use of the brain to succeed as a species is unrivaled by all other species. One question that arises from this observation is to ask how this happened? Part of the answer to this question may be found in looking into the evolution of hominins and how they made a living. The ability to grow and sustain large brains is dependent on the energy obtainable through diet. In the case of our lineage this diet includes high quality foods like meat. High quality foods are difficult to get and part of the story of our species' success is rooted in the long line of our ancestors who were able to improve diet quality and exploit the benefits of this diet. This section

will give a brief overview of some features of hominin evolution and subsistence leading up to humans. First there will be a review of the broad evolutionary context of the hominin line, including relevant information about climate and possible subsistence strategies

Bipedalism and Climate

Bipedalism in hominins was typical by approximately 4.4 million years ago (mya) in Africa with a species called *Ardipithecus* ramidus (Potts 2012; Klein 1999). This species shows some features of the upper pelvis that are associated with bipedalism while the lower pelvis remained more apelike (Klein 1999). The foot appears capable of grasping with a flexible big toe but with the general lever shape that is conducive to bipedalism (Klein 1999). *A.* ramidus is thought to have occupied an area in what is today Ethiopia which at the time was a wooded savanna environment with patches of trees and also patches of grassy areas (Klein 1999). Sometimes the wooded areas would expand and other times the grass areas would expand depending upon the aridity of the area during a particular time (Potts 2012). What this meant for ramidus was that it was important to be able to move across grassy areas to patches of trees where presumably food was more plentiful (Potts 2012). Although ramidus was a capable biped it is was also well adapted to climbing trees. It is argued that the variability in the climate made it so ramidus needed to be adaptable to different environmental conditions in order to succeed (Potts 2012). The ability to move between patches of trees and perhaps exploit grasslands to some degree could have been part of a strategy of versatility (Potts 2012). If ramidus had been strictly arboreal then a reduction of trees could spell extinction.

The trend toward bipedalism continued with the genus *Australopithecus* around 3.6 mya which included species that were better adapted to bipedalism than ramidus but were still capable tree climbers with apelike brain size (Klein 1999). Noticeably there is more of an arch to the foot and the toes are shorter and more in line with each other (Klein 1999). The Australopithecine environment would have been similar to that of ramidus (Potts 2012). The environmental variability along with morphological features indicative of improved bipedalism has led Potts (2012) to argue that the ability to both climb trees and walk bipedally may have been a response to the environmental characteristic of that epoch.

Around three mya to 1.8 mya the Australopithecines became extinct and genera *Paranthropus* and *Homo* show up in the fossil record (deMenocal 2004). At three mya the African climate saw a significant increase in monsoon variability and the relatively warm and moist Pliocene came to an end (Potts 2012). At 2.8 mya the glaciation of the northern hemisphere caused increased climate variability globally. In Africa the climate became more arid (deMenocal 1995; deMenocal and Bloemendal 1995) except for the African Rift System where evidence of large lakes and high levels of moisture have been found (Trauth et al. 2005).

The Turkana Basin on the border of Kenya, known to be area where many hominin fossils have been recovered, appears to have remained warm and arid from 4 mya to today (Passey et al. 2010; Hernández and Vrba 2006). This would mean that the Turkana Basin was not under consistently high levels of variability in temperature and moisture that were seen in other parts of Africa known to be occupied by hominins (Hernández and Vrba 2006; Passey et al. 20120). This has lead Passey and colleagues

(2010) to the conclusion that perhaps the evolution of hominins that took place around the Turkana basin was part of general trend in the area towards adaptations to a consistently arid climate. Plio-Pleistocene environments in the Turkana basin would have been similar to today or warmer. Passey et al. (2010) looked into whether it was possible that the area was also more heavily vegetated in terms of having a forest covering. A forest canopy would have effectively reduced radiative heating making it insignificant and leading to average air temperatures similar to soil temperatures. The average air temperature of the region would have been approximately 33 °C. Less than 1% of the tropical landmass on earth today has an average mean annual temperature of greater than 30 °C. Of this tropical land mass less than 1% of the tropical land mass of the specified temperature which gets enough rainfall to have forest has an average annual temperature of greather than 28 °C. Passey and colleagues (2010) note that no known contemporary forest site has a mean average temperature higher than 30 °C. This makes the possibility of forest covering seem very unlikely. Thus the Turkana Basin is most likely to have been a dry and hot place for the last 4 million years. Species that inhabited this area are likely have developed adaptations to hot, dry weather (Passey et al. 2010). Such adaptations can be found in our own species, and, based on fossil evidence, at least some of these adaptations were part of the evolution of *Homo* more generally (Carrier et al. 1984). These adaptations include the loss of body hair, increased number of eccrine sweat glands, bipedal posture, and longer legs and body (Carrier et al. 1984). All of these adaptations are implicated not only in withstanding hot, dry climates, but also in making hominins more efficient and effective bipedal hunters (Carrier et al. 1984; Liebenberg 1990).

The areas outside the Turkana basin experienced high climate variability fluctuating between arid and moist environments (Potts 2012). These periods of fluctuation lasted from periods of tens to hundreds of thousands of years. Periods of time most associated with these fluctuations are 3.2 to 2.9 mya and 2.8 to 2.5 mya and also 1.98 to 1.90 mya and 1.89 to 1.69 mya possibly coinciding with the origins of genus *Homo* (Potts 2012).

Between 800,000 and 300,000 years ago *Homo* erectus spread throughout Eurasia. One of the populations that stayed in Africa evolved into *Homo* sapiens while a different group living in Europe evolved into Neanderthals (Klein 1999; Potts 2012;). From 135,000 to around 75,000 there may have been dramatic periods of environmental fluctuations (Potts 2010). It is possible that there was a population reduction during this time that coincided with severe moist-arid oscillation which Potts (2012) referred to as megadroughts. Some genetic evidence suggest that the human population during this period may have been between 7,000 and 1,500 breeding age women (Rogers and Jorde 1995). This period of megadroughts was followed by human expansion into Eurasia around 60,000 years ago. These groups of humans carried with them more advanced tools, hunting techniques and other innovations not found in other hominin species (Potts 2012). The expansion of humans across the globe suggest that humans had become capable of using cultural adaptations to survive in a number of climatic conditions. One such example of a cultural innovation is that of sewing needles that could have been used to make snug fitting warm clothing (Klein 1999; Potts 2012).

Subsistence Strategies of Hominins

While a variety of foods were likely to be important to hominin diets the focus of this section is on meat consumption and the evidence regarding if it was acquired and in what way. The ability to acquire various types of foods depends upon the adaptations an animal has and the type of environment that animal lives in (Gilchrist and Mackie 1984). In regards to hominins there has been a long standing debate concerning hunting versus scavenging (Dominguez-Rodrigo 2002; Dominguez-Rodrigo and Pickering 2003). The questions center around how much scavenging or hunting occurred along with the possible methods available depending upon the species being discussed (Dominguez-Rodrigo 2002).

Chimpanzees, (among the other great apes) may provide clues about the diets of hominins such as the Australopithecines (Stanford 1996). Consider a pyramid where the base of the pyramid is made of the types of foods consumed in the largest quantities and the peak of the pyramid is made up of the foods least consumed. If a food pyramid were to be constructed for chimpanzees the base of the pyramid would be plant materials including various types of plant materials, which make up around 95% of the diet and the very peak of the pyramid would be animal foods which make up around 2-5% of the diet (Kaplan et al. 2000; Stanford 1996). Such a pyramid is the reverse of what we would see when constructing a pyramid for humans (Kaplan et al. 2000). A dietary consumption pyramid for humans would consist of the highest quality foods as the most consumed with the lowest quality foods consumed the least (Kaplan et al. 2000). If australopithecine diets were similar to chimpanzee diets then this illustration should be very helpful in visualizing a change from low quality foods to high quality foods (Kaplan et al. 2000). In

other words, an intermediate between chimp and human diets could be shaped more or less like a rectangle with high quality and low quality foods consumed in relatively similar amounts. Discussing the feeding niche of chimpanzees will make for a useful set up to a discussion about the transition from lower quality to higher quality foods.

Chimpanzees are known to hunt in groups and engage in tactics such as predicting potential escape routes of prey that has been surrounded (Stanford 1996; Stanford and Bunn 2001). Kaplan et al. (2007) reason that this level of cognitive processing is also required to engage in complex extractive foraging which makes up a more substantial portion of chimp diets. Although it is difficult to judge cognitive abilities in relation to brain size there does seem to be some connection between the two as evidenced by increasing brain size and increased tool complexity over the last several million years of hominin evolution (Klein 1999).

Diet quality and home range size have both been found to be correlated with brain in primates (Kaplan et al. 2007). Milton (1999) compared brain and gut size and found an inverse correlation where smaller gut size and higher quality diets are linked with larger brain size. Milton (2003) compared chimpanzee, gorilla, and human gut sizes; the size and composition of the guts of these species were different and this appears to be diet related. Human guts are approximately 56% small intestine (Milton 2003). The small intestine is useful in dealing with easily digestible foods like meat. In contrast the guts of chimpanzees are approximately 45% colon (Milton 2003). The colon can be used to a limited degree as a processing chamber for low quality foods (Milton 2003).

In contrast with contemporary chimpanzees, early hominins lived in an environment that was more variable in terms of moisture with the effect of periods where

savanna grasslands became widespread (Potts 2012). During the periods of increased savanna grasslands and little forest covering hominins such as the australopithecines would have had limited fruit trees available to feed on (Potts 2012). Savanna plants tend to have more emphasis on water storage with limited nutrient content (Guthrie 2007). These plants tend to reduce the amount of above ground presence, reduce emphasis on toxins for protection and increase the size of underground storage (Guthrie 2007). While these underground storage units would have been good sources of water and energy, other vital nutrients would not have occurred in substantial amounts within them (Guthrie 2007). A number of anthropologists believe that in a savanna grassland environment it would have been important for early hominins to supplement with animal source foods in order to take in nutrients that they would not have been able to get from the plant foods available to them (Aiello 2007; Guthrie 2007; Milton 2003). Acquiring these animal foods is generally broken into two main strategies: scavenging and hunting. Both scavenging and hunting may vary considerably in the investment of time and methods used. The means of obtaining animal foods is additionally complicated by the fact that other animals are in competition to acquire these foods as well.

In scavenging there are several options for obtaining animal foods such as passive scavenging, active scavenging, and aggressive scavenging/meat robbing. Binford (1985) and Blumenschine (1987) proposed passive scavenging as the method employed through much of hominin existence. This form of scavenging involves the consumption of animal foods only when they are encountered by chance while foraging (Blumenschine 1987). If the hominins happened to come across an animal carcass that had been killed and stripped by other predators and scavengers then the hominins would attempt to extract

what they could. Blumensschine's version of passive scavenging argues that hominins focused on bone marrow extraction since carcasses would have been mostly de-fleshed by the time hominins gained access to them (Blumenschine 1987). Passive scavenging would have made animal source foods a small portion of the total diet in terms of both energy and nutrient intake (Blumenschine 1987). The passive scavenging hypothesis has decreased significantly in popularity with mounting evidence that favors the notion of a shift to high quality foods and larger brain sizes along with fossil evidence that associates hominins with scavenging (Dominguez-Rodrigo and Pickering 2003).

Evidence suggesting that hominins engaged in more than merely passive scavenging was considered by Dominguez-Rodrigo and Pickering (2003). The sites in East Africa where fossil fauna associated with hominins dated to the Plio-Pleisotence share a number of commonalities. The sites are dominated by accumulation of limb bones which has been associated with the acquisition of fully fleshed limbs (Dominguez-Rodrigo and Pickering 2003). The evidence for the taking of fully fleshed limbs was found in the tool marks left by hominins who butchered carcasses (Blumenschine 1995; Dominguez-Rodrigo and Pickering 2003). Typically when carnivores consume an animal there will be a large number of tooth marks on the bones because these animals used their teeth to strip the carcass (Blumenschine 1988; Dominguez-Rodrigo and Pickering 2003;). In assemblages associated with hominins there were cut marks from tools often in addition to tooth marks (Dominguez-Rodrigo and Pickering 2003). These types of cut marks from tools used by hominins are explained by Dominguez- Rodrigo and Pickering (2003) to reflect butchering of more or less fully fleshed limb sections. This evidence had largely been ignored in passive scavenger models owing to a focus on marrow

extraction instead of butchering carcasses for meat (Dominguez-Rodrigo 2002; Dominguez-Rodrigo and Pickering 2003).

To reach to their conclusions regarding the amount of access to carcasses hominins had Dominguez-Rodrigo and Pickering (2003) looked at archeofaunal remains from the FLK Zinj site dated to around 1.7 to 1.9 mya. The assemblage is made up of over 60,000 animal bones, most of which belong to small mammals but approximately 3,500 belong to large mammals (Klein 1999:243). The site is associated with three types of consumers: large felids, hominins, and hyenas. The site is interpreted as the product of hominins transporting portions of felid kills to the FLK Zinj site for processing (Dominguez-Rodrigo and Pickering 2003). Most of the large mammal bones are upper limb bones which would have contained substantial amounts of meat before processing (Klein 1999). After the hominins had finished with the remains hyenas would scrounge what they could (Dominguez-Rodrigo and Pickering 2003). Blumenschine argued that the hominds were largely after the bone marrow as evidenced by hammer strikes on the bones at the sites (1986a). Cut mark evidence was considered to be ambiguous by Blumenschine (1986a; 1986b) although the marks appeared to be associated with the butchering of limbs that were still substantially covered in flesh. This would have been unlikely if carnivores like lions had been able to monopolize the carcass for significant periods of time after the kill (Dominguez-Rodrigo and Pickering 2003). Dominguez-Rodrigo conducted experiments to find out how much of the flesh on a carcass of a medium sized ungulate was regularly consumed by lions (2003). It turns out that very little flesh remains on a carcass including the limbs after lions are finished with it (Dominguez-Rodrigo and Pickering 2003). The upper limb bones in particular contain

very little flesh after lions had finished with it. This contrasted with cut marks found on the upper limb bones in the assemblages (Bunn and Kroll 1986). A conclusion that can be drawn from this is that hominins were gaining access to carcasses soon after the animal was killed and before the upper limb areas had been defleshed (Dominguez-Rodrigo and Pickering 2003). This evidence clashes with the idea that hominins were passive scavengers that waited until large predators had finished with the carcass before they could access it (Bunn and Kroll 1986; Dominguez-Rodrigo and Pickering 2003).

Aside from gaining early access to carcasses, evidence also implies that the hominins were transporting fully fleshed portions of the carcasses to processing cites like FLK Zinj (Bunn and Kroll 1986). The same conclusion was reached after examining archaeofaunal remains from a site near Koobi Fora dated to around 1.6 mya called F_xJ_j 50 (Dominguez-Rodrigo and Pickering 2003:278). Dominguez-Rodrigo and Pickering (2003) agree with Bunn and Kroll (1986) who believe that the evidence favors either hunting or power scavenging. Aggressive or power scavenging involves the use of intimidation or force to remove a predator or another scavenger from a carcass. At 1.6 million years ago it was likely a member of *Homo* that was engaged in such behavior (Dominguez-Rodrigo 2002). Australopithecines are likely to have engaged in less complex and aggressive forms of scavenging (Dominguez-Rodrigo 2002), although some have proposed that even Australopithecines could have engaged in power scavenging (Guthrie et al. 2007).

Power scavenging and even active scavenging are not without significant risks since predators and other scavengers can be very dangerous (Guthrie 2007). Large

carnivores such as those in Africa during the time of the Australopithecines and early early *Homo* posed a significant danger. Carnivores:

> bring exceptional capabilities to their niches: fantastic stealth, long endurance running, lightning acceleration, tremendous ability as scent followers, long sharp canines together with powerful neck muscles for killing, carnassials to scissor thick skin, and for the three main groups (lions, Panthera, spotted hyenas, Crocuta, and hunting dogs, Lycaon), elements of cooperation. [Guthrie 2007:137]

These carnivore capabilities should not be taken lightly since hominins would have needed to compete with these animals if they were to procure the animal source foods that would have been an important component in their diets. The ability to get to carcasses as well as the dangers posed by other animals are significant hurdles that should be addressed (Hill and Dunbar 1998).

Animals specializing in hunting and scavenging have adaptations that allow them to be successful in this niche (Gutherie 2007). Scavengers such as hyenas and wild dogs for example, have high levels of endurance, a powerful olfactory sense and are known to work in groups (Gutherie 2007). Hyenas also have jaws and teeth suitable to crush and consume bones (Gutherie 2007). Large felids have teeth and claws suitable to take down large ungulates and can even take down an elephant on rare occasions (Gutherie 2007). Animals being preyed upon are not helpless either and would need to be approached with caution. Large size accompanied by antlers, horns, tusks, fangs or powerful legs used to deliver damaging kicks are serious issues even for large predators like lions (Guthrie 2007:138).

If Pliocene hominins were scavenging they would need to have had methods of dealing with large dangerous predators. Guthrie 2007 has proposed that Australopithecines could have been more than just systematic scavengers. His argument is that Australopithecines would have been relatively efficient in bipedal travel and this would give then a decent day range. If these australopithecines were at least as intelligent as modern chimpanzees, then the most basic scavenging and hunting techniques would have been within their grasp mentally (Stanford 1996). Guthrie argues that australopithecines may have compensated for their lack of biologically grown defensive weaponry with cultural adaptations such as group size and the use of sticks and thorned acacia branches (2007). If this idea has merit then australopithecines may have had a means of defending themselves in open grasslands in addition to gaining access to carcasses where predators or other scavengers were likely to be.

Guthrie's argument cites the low levels of mortality from predation among apes as a critical point pertaining to bipedal apes surviving in a savanna grassland environment (2007). Apes have low reproductive rates and relatively long developmental periods (Bogin 2001). Guthrie estimates that a predation rate of higher than 2% among australopithecines would be too high to maintain a population (2007). While these early hominins would have been able to use trees to their advantage when available; periods of time when grasslands were widespread would have required them to have some other means of protection. Guthrie argues that acacia branches could have served this purpose for several reasons (2007). First, these branches would have been easy to come by and modify into a tool. An australopithecine would have needed to strip the thorns and small branches from one end of an acacia branch and the weapon would be complete (Guthrie

2007). The other critical component to Guthrie's argument hangs on how other animals would react to such a weapon. Guthrie cites an experiment (Kortlandt 1980) where a goat was tied up in an area with lions. The goat was caged and surrounded by boughs of acacia thorns and left overnight. Curiously, the goat was not eaten by the lions. Apparently, the tactic of using acacia thorns to ward off predators is/was commonly used by personal protection as well as defense of food and livestock (Augustine 2004; Mayhew et al. 2012).

Guthrie's justification as to why predators and large ungulates would be weary of acacia thorns can be found in the type of damage that they may cause (Guthrie 2007). Large predators like felids are particularly reliant on their vision (Guthrie 2007). Lions for instance have a natural aversion to acacia thorns and refrain from moving through the thorns lest they be poked in the eye and lose depth perception (. In contrast to apes large carnivores tend to have litters of offspring and the main reason for this higher level of offspring production is the fact that carnivore lives are dangerous. The weapons of large ungulates described earlier have evolved as effective defenses against large predators. A lion that is kicked in the face by a zebra may end up with a broken jaw (Schaller 1972). Such an injury for a lion would result in starvation (Schaller 1972). Blindness is a serious hazard for lions which has been seen with wounds caused by quills from porcupines which are similar in principle to acacia thorns (Smithers 1983). A moving swath of thorns each several inches long poses a significant enough hazard that it could be used as an effective defense according to Guthrie (2007).

If early hominins were able to use acacia boughs defensively then perhaps they could have also used them in an offensive manner as well (Guthrie 2007). When engaged

in scavenging these weapons may have been useful in driving large carnivores away from kills. If such a tactic worked then this would have improved the yield from scavenging significantly. Guthrie also advocates the idea that it may have been possible to use the boughs to separate young ungulates from herds as a method of hunting (2007). There is, however, little evidence to support Guthrie's idea at this time. Lee, (1979) has observed hunters in the Kalahari desert chase lions from a kill without much more than their digging sticks and a good deal of yelling. So perhaps meat robbing from loud hominins with primitive weapons is not out of the question as a viable strategy.

Scavenging to Hunting and the Running Hypothesis

In reviewing some of the evidence for scavenging among hominins it is also important to consider the possibility of hunting. Hunting could have perhaps evolved from or alongside scavenging or it may even be that hunting existed in early hominins and scavenging was merely opportunistic. This subject is still not well understood but some, such as Guthrie (2007) have provided perhaps an overzealous account of a possible means of hunting by animals like australopithecines. In considering the hunting capabilities of chimpanzees Stanford (1996) supplies some evidence for the notion of hominins as hunters instead of merely passive scavengers. While there is some agreement that Pliocene hominins were definitely engaged in scavenging, there is a great deal of disagreement as to whether and what hominins might have hunted (Dominguez-Rodrigo 2002).

If it is possible for chimpanzees to hunt then perhaps early hominins, such as australopithecines, also engaged in hunting to some limited degree (Stanford 1996, Stanford and Bunn 2001). Chimpanzees are not big game hunters, instead focusing on

animals smaller than themselves (Stanford 1996). In becoming bipedal, hominins would have extended their sight range as well as their day range, which would have been advantageous for locating and reaching foods of all types in open grasslands (Stanford 1996). However, early hominins would not have been very fast and the technologies available to them would likely have made hunting large game difficult or impossible at the very least it may have yielded very low success rates.

Hominins and Endurance Running

In 1984 Carrier et al. proposed the running hypothesis to explain a number of features of the modern human body form. More recent work by Bramble and Lieberman (2004) has lead them to agree with Carrier et al.(1984) that endurance running capabilities first appeared around 2 million years ago in the genus *Homo* and these capabilities are linked to the morphology of the modern human body type. Among primates, endurance running is unique to humans and may be an adaptation to a shift in diet toward high quality foods and cognitive capabilities.

The running hypothesis begins with an understanding of australopithecines as falling into the niche of competent foragers, collectors, and scavengers (Carrier et al. 1984). The central idea is that the transition to *Homo* involved improved bipedal efficiency accompanied the ability to run long distances (Carrier et al. 1984). These long distance travel capabilities are thought to have evolved under hot weather conditions that additionally selected for improved thermoregulatory adaptations (Carrier et al. 1984). The combination of these types of adaptations could have allowed early *Homo* to become a very effective scavenger (Carrier et al. 1984). The long distance scavenging may have been accompanied by limited hunting capacity where some animals could be chased to

exhaustion and then killed (Carrier et al. 1984). This long distance or persistence hunting capacity may have then become more developed allowing for the use of persistence hunting as a regular means of acquiring foods (Carrier et al. 1984). The art of tracking hypothesis (explained in a later section) accompanies this line of thought by explaining the relevance of increased persistence hunting success that greater cognitive capabilities would allow for specifically by improving the ability to track prey. The following section will explain the running hypothesis in more detail.

> Long before the development of complex culture and hunting weapons, early hominids may have been endurance predators equipped with biological weapons for hunting very different from those of other mammalian predators. [Carrier et al. 1984:487]

Humans are capable endurance runners, so much so that trained endurance athletes are often able to outperform horses and other ungulates, particularly in hot weather (Carrier et al. 1984). Endurance running (ER) is the ability to continuously run over distances of many kilometers for long periods of time (Bramble and Liebernman 2004). Endurance running appears to be a particularly odd capability for a species of ape because in general apes are not well suited for long distance travel (Carrier et al. 1984). The evolutionary forces that selected for these capabilities seem related to bipedalism (Carrier et al. 1984). For hominids over the last several million years selection favored improvements to bipedal efficiency (Bramble and Lieberman 2004). Walking long distances would have been a regular occurrence for hominids particularly the members of genus *Homo* (Carrier et al. 1984). The difference in body type seen with the evolution of

Homo may be connected to the ability to run in addition to walking efficiently (Carrier et al. 1984).

Bramble and Lieberman (2004) have found evidence of at least 26 features in the modern human body form that improve endurance running capabilities but do not improve walking efficiency. Running requires a different pattern of movement than walking (Bramble and Lieberman 2004). In walking the heel of the foot strikes the ground first. When running (without shoes) the forefoot strikes the ground first and tendons in the arch of the foot act as springs which store energy that is released with each stride (Bramble and Lieberman 2004). Attempting to run barefoot with heal strikes is painful and damaging. Foot arches are absent in the feet of australopithecines and this is one indicator that they may have been efficient walkers but not particularly adept runners (Bramble and Lieberman 2004). The longer legs found in *Homo* also give an efficiency advantage by allowing stride length to increase (Bramble and Lieberman 2004). The long legs of humans also display decreased distal limb mass with compact feet and shortened toes (Bramble and Lieberman 2004). Reduced distal limb mass decreases the amount of energy needed to move that portion of the body while running. These features do not have much effect when walking but they significantly improve running performance (Bramble and Lieberman 2004). The joint surfaces in the legs are larger than those found in australopithecines and this allows for improved mitigation of impact stress while running (Bramble and Lieberman 2004). The large gluteus maximums found in humans is used heavily while running but not walking.

An example of a group of people that engage in extreme long distance running on a regular may prove useful. The Tarahumara are a group of indigenous people living in a

system of canyons in Mexico in the Sierra Madre Occidental (McDougall 2011). They tend to use running as an all-purpose means of travel because the canyons are not amenable to the use of cars or horses (McDougall 2011). Endurance running has become engrained in their culture and they are known to travel distances of 200 miles as part of one endurance run (McDougall 2011). This is an amazingly long distance to say the least. The Tarahumara are not different than other humans in this ability but they do seem to have a culture that emphasizes using running and as a result their people tend to be very good at it (McDougall 2011). These long distance running capabilities have also been recorded in other groups as well, such as the Ju/'hoansi located in and near the Kalahari desert in Africa, the Paiute and Navajo Native American tribes, and also aboriginal groups from Australia have all been recorded to engage in long distance running similar to the Tarahumara (Carrier et al. 1984).

A recent book by Christopher McDougall has ignited increased interest in the Tarahumara (2011). McDougall (2011), by his own admission was not a particularly good runner but he became proficient during the time he spent with the Tarahumara . He learned that these people do not think of running as a painful chore or a type of punishment to burn off extra calories from eating too much cake. Instead, running is simply part of the daily routine and it is considered enjoyable (McDougall 2011). The point is that any group of humans, with the right training, may become capable long distance runners. The Tarahumara are capable of using this long distance running capability for the same purposes that any other form of travel is useful for. One of the activities that is of particular relevance to the running hypothesis is the use of long distance running in hunting. Members of the Tarahumara have been known to chase deer

through the canyons the live around until the deer becomes physically exhausted or succumbs to heat exhaustion (Carrier et al. 1984; McDougall 2011). The deer can then be strangled to death or killed with a number of simple tools.

Cost of Travel

When walking humans are approximately as energetically efficient as other quadrupeds like hyenas (Carrier et al. 1984). When running humans burn up around twice the amount of energy compared to a running ungulate, such as a horse (Carrier et al. 1984). How then, is it possible for a human to chase a large quadruped to exhaustion? It turns out a variety of human features coalesce to make this possible (Bramble and Lieberman 2004). The human cost of travel is relatively constant when running slowly or quickly and this fact contrasts with large quadrupeds which prefer specific speeds where costs of travel are lowest (Carrier et al. 1984). Heat dissipation and the ability to force quadrupeds to run at inefficient speeds are argued to make up for this seeming disadvantage in costs of travel (Carrier et al. 1984).

While training horses Hoyt and Taylor (1981) found that there are specific speed ranges that allow for oxygen consumed per-unit distance to be minimized. Horses would consistently choose these speeds over others (Hoyt and Taylor 1981). This also means that horses resist using inefficient gaits (Hoyt and Taylor 1981). This same principle has also been observed in wildebeest and gazelle (Carrier et al. 1984). Humans on the other hand do not have the efficiency ranges similar to horses (Bramble and Lieberman 2004). While running at speeds between eight and 20 km/hr the energetic cost per unit of distance does not change much (Blanco 2006; Carrier et al. 1984; Cavagna and Kaneko 1977; Diedrich and Warren 1995; di Prampero et al. 1989). The reason that energetic

costs of running for humans are so different from animals like horses has to do with the human body form.

While moving at any speed a quadruped cannot take more than "one breath per locomotor cycle"(Carrier et al. 1984:486) due to pressure on the animal's thoracic space caused by each step from the front limbs. Humans do not have this issue since their front limbs do not touch the ground during locomotion. This allows humans to vary breathing frequency relative to gait. In other words, humans can breathe faster or slower at any speed they choose to move at (Carrier et al. 1984). This becomes important when the depth of breath is also taken into account since it results in ventilatory efficiency ranges for oxygen intake that pair with specific gaits. Running outside of these specific gaits make it so the quadruped's breathing is interfered with by its gait (Carrier et al. 1984). Because humans lack specific efficient gaits they are less efficient than quadrupeds traveling within their comfort ranges, however, they are more efficient than quadrupeds when running at any speed outside of the small range of efficient speeds of quadrupeds (Bramble and Lieberman 2004; Carrier et al. 1984). Running outside optimal speeds for quadrupeds not only negatively impacts their ability to take in oxygen efficiently but also limiting the animal's ability to dissipate heat through panting (Carrier et al. 1984).

Heat Dissipation

Heat dissipation is highly developed in humans, and presumably earlier *Homo* as well (Bramble and Lieberman 2004; Carrier et al. 1984). Most large quadrupeds rely on panting as the primary means of heat dissipation (Carrier et al. 1984). Ungulates as well as humans (to a degree) lose heat while breathing; however:

> The amount of heat that can be lost through evaporation from the respiratory surfaces severely limits the maximum rate of heat dissipation during running in animals that rely solely on panting. [Carrier et al 1984:484]

In contrast, old world anthropoidea including humans along with horses and camels are not reliant on panting for heat dissipation instead they rely on sweating (Carrier et al. 1984). Humans also have an advantage in their lack of body hair since animals with fur coats do not have as effective convection when moving through the air (Carrier et al. 1984). Per unit of skin surface area humans produce more sweat than any other species (Bramble and Lieberman 2004; Wheeler 1991). In particularly hot environment an animal will begin to lose functionality and can die if core body temperature is too high (Adolph 1947). Body temperature in placental mammals ranges on average between 36-38 °C (Morrison and Ryser 1952) The average lethal temperature ranges from 42-44 °C (Adolph. 1947). For humans the temperature at which harm begins to occur is approximately 42 °C (Kosaka et al. 2004).

A quadruped chased by a human/hominid at a non-optimal speed could either try to run away at a non-optimal speed or increase its speed to an efficient gait and then stop for a rest (Carrier et al. 1984). Upon stopping to rest the animal would find itself in the same situation all over again with the human/hominin still in pursuit. Running in bursts has been shown to be less efficient by up to26% than running at a constant rate for a given distance (Edwards et al. 1973). Either strategy adopted by the quadruped (inefficient gait or running in bursts) would cause it to be less efficient than the human/hominid in covering the same distance. The human/hominin would also be superior at dissipating heat (Lieberman and Bramble 2007). The result is that humans can

chase quadrupeds to physical exhaustion or until they overheat and are forced stop running at which point the human/hominid can move in for the kill.

Endurance Running and Hunting?

Endurance running is argued to be part of a strategy that improved scavenging and persistence hunting success starting with the genus *Homo* (Carrier et al. 1984). This strategy could also be implicated in a shift to an increasing dependency in *Homo* on high quality animal source foods. High quality foods could have helped to pay the costs of endurance running and the growth and use of a large expensive brain as well (Liebenberg 2008). Relevant to this point is a study conducted by Louis Liebenberg (2006) on persistence hunting among the Ju/'hoansi. This study was to test the various forms of hunting available to hunter gatherers in environments similar to those that genus *Homo* is thought to have evolved in (Liebenberg 2006).

The Kalahari desert where the Ju/'hoansi live is an arid region where temperatures during the hottest times of the day may range between 39-42 °C (Hitchcock et al. 1996). The methods of hunting Liebenberg (2006) compared were: hunting with dogs, bow and arrow, club and spear, spring hare probes, persistence hunting with dogs, and persistence hunting without dogs. Persistence hunting with dogs was found to be the most effective strategy; however, persistence hunting without dogs was the second most successful form of hunting (Liebenberg 2006). Dogs have an incredible sense of smell that aids in locating animals. Dogs can also be trained to provoke some animals to stand their ground which allows hunters time to catch up or strategize on how to bring down the animal (Liebenberg 2006). Success in hunting was measured using meat yield in kg. Hunting with dogs took in an average of 14.8 kg/day. Bow and arrow hunting took in an

average of 2.9 kg/day. Club and spear hunting took in an average of 1.6 kg/day. Spring hare probes brought in 0.1 kg/day. Persistence hunting without dogs brought in an average of 4-5 kg/day. The average for persistence hunts was somewhat uncertain due to issues with collecting data. Several persistence hunts on foot were engaged in for the purposes of filming a documentary which was on a strict time schedule and this resulted in a number of persistence hunts that took place under conditions in which hunters would normally not engage in this form of hunting (Attenborough 2002; Liebenberg 2006). Liebenberg (2006) believes that meat yield would have possibly been higher if more hunts were observed under conditions where persistence hunting would normally occur. The conclusion arrived at by Liebenberg (2008) was that persistence hunting is indeed a viable hunting strategy.

Hunting

Hunting is considered to be among the most difficult skills to learn by hunter gatherers (Kaplan et al. 2000). One definition of *hunting* is the finding and killing of animals with the aid of weapons, traps, or vehicles (Liebenberg 1990). This is a type of predation that requires cultural innovation to accomplish. The adaptations humans use to hunt are unique among predators. The human body form with its adaptations to bipedal endurance running and heat dissipation paired with use of tools held in the forelimbs is dissimilar to the means other animals typically engage prey (Carrier et al. 1984; Liebenberg 2006). Hunting the way hunter gatherers do should be differentiated from predation in that Hunting utilizes the intellect, communication, and cultural adaptations to succeed (Liebenberg 1990; Blurton-Jones and Konner 1976).

Our species is partly the product of selective pressures that favored adaptations that improved capabilities relevant in acquiring high quality foods (Kaplan et al. 2000). In studying hunting methods among hunter gatherers it may be possible to project backward in time to illuminate some of the story behind the evolution of the human brain and body. A plausible explanation for the beginnings of hunting as related to the evolution of the body form seen in *Homo* was offered by Carrier et al. (1984). This section will focus on the use and development of the intellect in hunting. The groundwork for the connection between hunting and the evolution of brain has been laid by Liebenberg (2006). Liebenberg's works can be integrated with the running hypothesis to provide a clearer picture of one piece of the puzzle that is human evolution. These two hypotheses can be connected in that the body (running hypothesis) and the brain (art of tracking hypothesis) are both used together to obtain a diet made up of the highest quality foods. To investigate the development of hunting it may be useful to start where the original version running hypothesis leaves off with the origin of hunting related to the ability of *Homo* to engage in endurance running. This type of hunting is known as persistence hunting.

Persistence Hunting

This section will describe persistence hunting and will then transition into the development of tracking. Persistence hunting in its simplest form may be among the oldest methods of hunting for species in the genus *Homo* (Liebenberg 2008; Bramble and Lieberman 2004). The ability to engage in persistence hunting requires specialized adaptations that are only found in humans and other species of *Homo* (Bramble and Lieberman 2004). This form of hunting in its most primitive form may have been

discovered by hominids that were able to use their adaptations for long distance bipedal travel and heat dissipation to exploit a variety of resources in hot savanna environments (Carrier et al. 1984; Liebenberg 2006). As the ability to run long distances in hot weather improved in *Homo* there may have been a point where persistence pursuit of animals became a viable hunting method (Carrier et al. 1984).

A persistence hunt is a specific form of hunting that requires extreme endurance capabilities used for chasing an animal until it reaches a state of exhaustion and can then easily be killed with simple tools like clubs or spears (Liebenberg et al. 2006). Persistence hunts usually take place during the hottest time of day which can range from 39-42° C with hunters drinking as much water as possible before starting because dehydration may become a serious issue is such hot weather (Liebenberg et al. 2006).

While the technique of persistence hunting appears simple on the surface, it is in fact a very difficult skill to accomplish. At the very least, such hunts require incredible physical stamina under difficult conditions (Attenborough 2002; Carrier et al. 1984; Liebenberg 1990; Salisbury et al. 2003). Observations of the shortest recorded persistence hunts by Liebenberg (2006) lasted two hours with a hunter running the entire time and only occasionally slowing down. Some hunts may last longer than a day (Liebenberg 2008; Attenborough 2002). Hunting in groups makes the task easier by combining skills and physical capabilities of multiple people (Lee 1979). This means that three to four hunters will often cooperate on a hunt (Lee 1979; Silberbauer 1980). The process of the hunt has been described in some detail by Liebenberg (1990). Initially the hunters run at an easy pace so that less fit hunters (old for instance) can keep up. After some time the fastest best runner goes off on his own to finish the hunt. This point is

typically close to the end of the hunt when hunters believe the animal is beginning to succumb to poison or heat exhaustion. Poisons can be made from a variety of sources but certain types of beetle are used by the Ju/'hoansi (Liebenberg 1990). The length of these hunts does not always require running nonstop and hunters will occasionally walk part of the time (Liebenberg 2006). This time can also be used to reassess the strategy being used to find or pursue an animal or rehydrate.

There are many considerations mentioned by Liebenberg (1990) that are important for persistence hunters. It is preferable to hunt the day after a full moon because animals stay awake during a full moon and tend to be tired in the morning making them easier to hunt (Liebenberg 1990). Animals are also easier to hunt around the end of the dry season since they are not well fed during this period (Liebenberg 1990). In addition to this the dry leaves available for food during this period tends to give some animals like kudu diarrhea. Hunters say it is possible to do persistence hunting during any time of the year but cooler temperatures and other factors may make it more difficult (Liebenberg 1990).

Aside from the physical endurance necessary, persistence hunting also requires advanced cognitive skills used in tracking over long distances and time spans. Hominids like *Homo* ergaster, for instance, may have been able to engage in a limited form of persistence hunting similar to what has been described above (Carrier et al. 1984). If *H.* ergaster could see the animal throughout the pursuit in terrain that is mostly open, then advanced tracking abilities would not be a necessity (Liebenberg 1990). However, in less open terrain, tracking would be more difficult and those with higher cognitive skills (i.e. better trackers) would be more likely to succeed in their continuous pursuit of the target

animal (Liebenberg 1990). Once early species of genus *Homo* attained a more or less modern human body form the emphasis of selection pressure for success in hunting could be shifted to the brain and its use in interpreting environmental information to keep the hunter on the right track (Liebenberg 1990).

The majority of animals killed by hunter gatherers engaged in persistence hunting are wounded, stunned, poisoned, or otherwise immobilized making long distance flight unlikely (Lee 1979). Early *Homo* would not have had the technology to do this and would therefore need to rely more heavily on other methods which may have included running an animal to heat exhaustion (Carrier et al. 1984; Liebenberg 1990). This presents another facet where the evolution of increased intelligence could have been selected for since weapons and other technologies like poisons can reduce the physical effort needed for a successful hunt (Lee 1979; Marlowe 2010). Reduction of effort or energy expenditure in food gathering is desirable because a reduction in costs of energy and time used (Speth 2010) and this time and energy can then be devoted to further energy acquisition or other efforts that improve reproductive success (Bogin 2001).

Persistence hunting can be used to hunt a variety of animals aside from just large game like eland, kudu, gemsbok, hartebeest, duiker, and steenbok (Liebenberg 1990). Smaller and slower animals such as antbears and porcupines are easier to run down when caught in the open compared to large ungulates like gemsbok (Lee 1979; Marshall et al. 1989). Animals that may not typically be thought of as prey such as cheetah, caracal and wild dogs are also hunted using persistence hunting as observed by Liebenberg among the Ju/hoansi hunters (2006).

According to experience persistence hunters, the most important factors in having a successful hunt are the level of a hunter's tracking skills and the difficulty of the terrain as it pertains to tracking (Liebenberg 1990). Aside from the terrain, the hunter must consider important factors such as seasonality, which affects the choice of species to hunt (Hitchcock et al. 1996). In the rainy season duiker and gemsbok are favored for hunting (Liebenberg 1990). These animals hooves are spread apart in wet sand and this causes their joints to become stiff (Liebenberg 1990). This minor handicap is an example of one factor that improves the chance that a hunt will succeed. Another example can be found in the dry season because some animals such as kudu, eland, and red hartebeest tire more easily when running through loose sand (Liebenberg 1990). Still another example among the Ju/'hoansi hunters occurs in spring when ruminants spend more time eating (because its after winter) and so hunters can chase these animals and prevent them from chewing their cud which gives them indigestion and slows them down (Liebenberg 1990).

Tracking

This section will summarize the possible evolution tracking in relation to how it is used by the Ju/'hoansi in hunting as described largely by Louis Liebenberg. *Tracking* is the use of information collected from the environment to pursue an animal (Liebenberg et al. 2012). In studying of tracking Liebenberg (1990) has found it helpful to break down tracking into three categories simple, systematic, and speculative. These categories may broadly be used to reflect increasing difficulty and cognitive demands. Liebenberg and colleagues (2012) central argument is that the evolution of tracking is connected to the evolution of same cognitive capacities used in doing science. To understand the possible connection between tracking and science in the evolution of the brain it useful to explain

what tracking is and then to give an account of what science is. Tracking will be summarized in this section while science will be the focus next section.

Simple tracking involves following footprints under the best conditions where the prints are easy to see and not obscured or partially erased (Liebenberg 1990). Plants, rocks, other animal prints, or other objects may obscure or prevent tracks from being clear and easy to follow (Lee 1979, Marshall et al. 1989). Under the very best conditions it may even be possible to keep the animal in plain sight or keep it in sight a large portion of the time (Attenborough 2002; Liebenberg 1990). This type of tracking may have been possible for early *Homo* since it does not involve much in the way of critical analysis and interpretation other than potentially associating clearly defined foot prints with an animal that is thought of as a potential meal (Liebenberg 1990). There are two types of environment that present the possibility of ideal tracking conditions: arid and cold environments where vegetation is sparse and tracks can be made in dirt or snow, which are easy to see and read (Liebenberg 1990). A good example of such conditions currently exists in the southern Kalahari dune lands which are an arid-savannah environment (Hitchcock et al. 1996; Lee 1979; Silberbauer 1980). The area can be described as sparsely patched with bushes, trees, and grasses that dot large dunes that run across the landscape. Depending on the time of year this area contains little or no surface water (Silberbauer 1980). Small pools from rain are present for a number of months but run dry during the hottest times of the year (Silberbauer 1980). The riverbeds in the area may be dry for years at a time. Water stored in certain plants such as the Tsamma melon are often the main source of water for a variety of animals (Lee 1979). Other areas in the Kalahari offer a range of tracking conditions from ideal to difficult.

Developing rudimentary tracking skills could be used in a variety of locating signs that may lead to carcasses or small game (Liebenberg 1990).

> The most likely environment for the development of tracking would have been an optimum combination of ideal tracking conditions, abundant wildlife, limited visibility which would have made tracking a necessity, and adequate water resources. If tracking evolved in southern Africa, then the semi-arid savanna of the southern Kalahari would have been the most likely place. [Liebenberg 1990:43]

This assessment by Liebenberg may be linked with the discussion of climatic conditions under which *Homo* may have evolved (Carrier et al.1984; Klein 1999; Potts 2012). The area around Lake Turkana over the last four million years, where numerous fossils from hominids have been found, may be a possibility for an area that would fit Liebenberg's (2006) description of ideal conditions for tracking to become a necessity. Such conditions may make it possible to link the evolution of *Homo* with tracking. This would also seem to fit with the need for long distance travel capabilities as described in the running hypothesis. These conditions also fit with the notion of a transition to higher quality foods since plant foods would have been sparser in such an area while animal foods may have been more abundant (Guthrie 2007).

These environments are important in linking the scavenging to persistence hunting. If dietary quality had been increasing even with our Pre-*Homo* ancestors then adaptations that improved scavenging or and foraging over long distances could be likely choices for selection to favor. The low levels of plant foods that could be eaten by pre and early *Homo* in these areas would have made animal source foods a more attractive

prospect (Guthrie 2007). Selection favoring simple tracking along with long distance scavenging and endurance running could have been some of the main factors in the origins of *Homo* (Carrier et al. 1984; Liebenberg 1990). The capacity for endurance running paired with the cognitive capacity for some level of simple tracking would have enabled the simplest form of persistence hunting. *Homo* could have found itself in a position where it had the adaptations for endurance and heat dissipation that allowed it to use its limited tracking abilities to follow an animal until the animal succumbed to heat exhaustion (Carrier et al. 1984). The simple tools available to early *Homo* would have been enough to finish off an animal in such a condition just as persistence hunters today do not need more than simple tools to finish off their prey (Carrier et al. 1984). The success of this strategy could encourage its further use and the benefits of such high quality animal source foods may have paid the significant energetic and nutritional costs involved. The further development of more advanced tracking could have been under selection pressure since improved cognitive capacities for tracking would have increased success in hunting (Liebenberg 1990). This concept links the physiological and mental capabilities found in the human lineage with means to pay for them.

In his assessment of the evolution of subsistence strategies Liebenberg (1990) believes that simple tracking would not have been probable before *H.* erectus and that it may not have been until archaic *H.* sapiens that simple tracking possibly developed into systematic or systematic/speculative tracking. This may underestimate the cognitive capabilities of *Homo* prior to archaic *Homo* sapiens and possibly prior to *Homo* erectus. In referring back to the hunting and foraging capabilities of chimpanzees it should be considered that all species in genus *Homo* had grew increasingly larger brains with much

of this increase in the neocortex which would be used more heavily in learning, problem solving, reasoning, and planning (Kaplan et al. 2007; Lieberman 2012). *H.* erectus had a brain of somewhere between 800 and 900 cm^3 which is around twice the size of a chimpanzee brain (Leonard et al. 2003). Even accounting for increased body size of *H.* erectus this is a very noticeable increase in brain size (Aiello and Wells 2002). It is difficult to estimate what *H.* erectus would have been capable of but it seems likely that the ability to think symbolically and solve problems was more exaggerated than it is in chimpanzees. The connection between thinking in terms of symbols will be examined further in later sections as it is critical in tracking. Suffice it to say here that simple tracking requires the use of symbolic thinking on some level (Liebenberg 1990).

Even if early *Homo* had the mental capacity to develop simple tracking or more complex tracking there are environmental conditions that would be necessary for this development to occur. Liebenberg (1990) describes these conditions as existing between the southern and northern regions of the Kalahari. As mentioned previously the southern Kalahari receives little rainfall and is covered by large areas of dirt and savanna grasslands (Hitchcock et al. 1996). When traveling to the northern Kalahari the amount of rainfall increases and with it the amount of vegetation also increases with areas occupied in large part by savanna woodland (Lee 1979) This sort of environment with more vegetation and less dirt makes tracking conditions more difficult (Liebenberg 1990). Depending upon the area tracking conditions can become gradually or quickly more difficult (Liebenberg 1990). Trees can block a hunter's view and vegetation on the ground can prevent, distort, or cover up tracks (Lee 1979; Liebenberg 1990). These type of conditions are of the same type that both Potts (2012) and Passey et al. (2010) refer to

as occurring in the areas occupied by hominids over the last several million years. The area around the Turkana basin may have been more consistent in terms of having a dry and hot climate but there may not be a good reason to suppose that early *Homo* limited itself to such an area for large periods of time (Passey et al. 2010). In the evolution of tracking capabilities fluctuations between savanna grasslands and relatively more moist savanna woodlands would allow for exactly the types of environments where tracking could have evolved according to Liebenberg's (1990) views. Passey et al. (2010) may be correct that adaptations to dry hot conditions occurred in areas that were consistently like this for long periods.

The pattern outlined above can be expanded upon further with a description of the cognitive capacities needed for more complex tracking skills. The second category of tracking described by Liebenberg (1990) is called *systematic* tracking and this type of tracking involves the same sort of abilities used in simple tracking but to a higher degree. A hunter using systematic tracking will look at signs in the environment that can be associated with an animal's behavior until the hunter has a good idea of an animal's recent behavior (Goldenhuys 2013; Liebenberg 1990). In simple tracking the complexity of signs associated with an animal are usually limited to footprints that are not difficult to see or follow (Liebenberg 1990). In systematic tracking a hunter will include a larger variety of signs related to animal behavior (Liebenberg 1990). The separation between systematic and simple tracking is centered around the amount and variety of information that is used to track (Liebenberg 1990). These first two types of tracking are quite different from the final and most complex form of tracking. *Speculative tracking* involves the ability to construct hypotheses from available data and past experience (Liebenberg

1990). Simple and systematic tracking use signs as indications of the direction an animal may be headed and the amount time that has gone by (Liebenberg 1990). These skills involve the use of induction where as speculative tracking uses induction as wells as hypothetico-deductive reasoning (Liebenberg 1990).

What Makes a Hunter?

Learning to hunt proficiently takes many years to learn (Lee 1979). The primary factors for hunting success haveto do with the intelligence and experience of a hunter along with cooperation with others according to Ju/'hoansi hunters (Goldenhuys 2013; Lee 1979). Strength, good eye sight, hand-eye coordination, and stamina are important to a hunter but these abilities are wasted if a hunter never encounters prey (Liebenberg 1990). The ability to find an animal is paramount in hunting and it is the intelligent and experienced who have the advantage in these areas based on observations by Liebenberg 1990, Silberbauer 1980, and Lee 1979, of hunting among Kalahari hunter gatherers. This is primarily true of speculative tracking as it is the most dependent upon the cognitive capacities of the hunter (Liebenberg 1990).

Among the Ju/'hoansi the better hunters make a larger percentage of the kills of animals like kudu (Lee 1979). Kudu prefer the savanna woodland (Silberbauer 1980) and this type of terrain increases the difficulty of tracking conditions and is much more likely to require the use of speculative tracking. Above average intelligence is something of a necessity in successfully hunting kudu according to interviews with Ju/'hoansi hunters recorded by Lee and colleagues (1979). Alertness and ingenuity are two of the most important mental qualities in a hunter according to Ju/'hoansi hunters that were interview

by Liebenberg (1990). Ingenuity is the ability to concoct creative and successful solutions to problems (Silberbauer 1980).

> The art of tracking involves a process of creative problem solving in which hypotheses are continually tested against spoor evidence, rejecting those which do not stand up and replacing them with better hypotheses. Intuition is important in dealing with complex variables, such as in estimating the age of spoor or interpreting spoor in loose sand. Concentration and memory play a vital role in tracking. [Liebenberg 1990:82]

Another important skill in the art of tracking is social cooperation (Goldenhuys 2013). Hunts are most often undertaken in groups and the hunters will converse or use other means of signaling information with each other (Blurton-Jones and Konner 1976; Lee 1979). It is useful for hunters to exchange thoughts on the who, what, where, why, when, and how questions that are relevant to tracking (Liebenberg 1990). Much of this discussion takes place before a hunt is undertaken and usually involves many more group members, male and female, than just the few individuals who go out on the hunt (Lee 1979; Blurton-Jones and Konner 1976). It is important for the success of the hunt to separate out useful information that is likely to be true from exaggerations and flawed ideas (Liebenberg 1990). In other words skepticism of the information presented in discussing a hunt is key to creating and implementing a successful hunting strategy (Liebenberg 1990).

While it seems that men do hunt more often than women, particularly in terms of large-game hunting, this likely has more to do with the circumstances of childbearing and care than any differences in the cognitive abilities or physical endurance required for

hunting and tracking. In modern foraging societies, both women and men are capable of becoming expert trackers and hunters (Biesele and Barclay 2001). In addition the success of a hunt can, and often does, benefit greatly from information provided by women who have been out gathering (Biesele and Barclay 2001; Hitchcock et al. 1996). Biesele and Barclay (2001) argue that both men and women make hunting-relevant observations while engaging in gathering tasks and share these observations with others in the group. Hunting is a skill that is often developed by both sexes among the Ju/'hoansi (Biesele and Barclay 2001). If this group is any indication of the behavior of other human groups then hunting among women would have been. Among the Ju/'hoansi, women will often go hunting, particularly in pairs with their husbands, if they are not inhibited by pregnancy or breastfeeding an infant (Biesele and Barclay 2001; Liebenberg 1990). Even if women were going along with men during hunts to help carry meat back to camp then persistence hunting would still be relevant. Cognitive abilities relevant to tracking would have proven just as useful from women as men in considering options for continued pursuit of an animal.

Age is another factor in hunting that can often be correlated with success (Lee 1979). More experienced trackers are often more successful with the exception that particularly bright individuals may be able to overcome the handicap of little experience with creativity (Liebenberg 1990). This is not to say that young hunters are not taught a great deal before they are old enough to begin attempts at hunting (Lee 1979). A good deal of learning about subjects related to hunting comes informally in the form of storytelling (Heinz 1978; Lee 1979; Siblerbauer 1980). Children begin learning about tracking while they are very young (Lee 1979; MacDonald 2007). Many of the games

and play activities of children involve the development of mental and physical skills that are used in tracking (MacDonald 2007). Small bows and arrows are constructed for and by children and used in the hunting of small animals and insects (Lee 1979). Storytelling and direct instruction from adults is another way tracking skills are communicated and passed on (Lee 1979). Much of the learning process in tracking involves more than just memorizing an enormous quantity of facts (Liebenberg 1990). Critical thinking skills are important and their development will allow a hunter to use what is known and potentially discover new methods or concepts that improve hunting success (Liebenberg 1990).

With boys among the Ju/'hoansi, hunting may start at around age 12 ostensibly, typically a boy will accompany his father on portions of hunting expeditions (Hitchcock et al. 1996; Lee 1979). Around age 15-18 boys might make their first kill of a large animal and be promoted to hunter (Liebenberg 1990) although full adult status may come many years later when an adult big game animal such as a kudu is taken down (Lee 1979). Success in hunting typically peaks from ages 30 to 45 (Lee 1979). During this time the skills, experience and physical prowess are all usually sufficient so that hunting success can be maximized (Lee 1979). Older men may be less physically capable but they are still useful on hunts as well as in their capacity for teaching (Lee 1979; Marshall et al. 1989). The older and most experienced men who go on hunts may not be able to keep up the entire time but their knowledge and wisdom are often key in increasing the encounter rates of younger hunters who may then go on to fulfill the more physically demanding requirements of a hunt (Silberbauer 1980).

Spoor

Spoor refers to any sign indicating information useful while tracking an animal or some object that is being sought, such as footprints, scent, dropping, or other sources of information (Liebenberg 1990). The information learned from spoor can allow for a detailed picture of what an animal was recently doing, what it may currently be doing, and what it is likely to do later (Blurton-Jones and Konner 1976; Heinz 1978; Liebenberg 1990; Liebenberg et al. 2012).

Learning to identify and use spoor effectively is fundamental to learning how to track and this knowledge is built up over a lifetime (Lee 1979). The purpose of learning about spoor is ultimately to improve hunting success and there are seemingly endless varieties of spoor, some of which are much more common and likely to be useful (Liebenberg 1990). Spoor can be thought of in the same way that people think of any other types of signs that are useful in everyday activities (Liebenberg 1990). A street sign may be easier to locate than footprints in many cases but both give an indication as to the position of the object that is being searched for whether it is a home, a type of animal, or any other sort of object. The ability of humans to use and interpret signs may be rooted to some degree in interpreting spoor (Liebenberg et al. 2012). Humans use signs, whether artificial or natural, in quantities that vastly exceed the known capabilities of other animals. Koko the gorilla for instance was able to learn several hundred signs used in sign language whereas humans may learn tens of thousands (Patterson 1981). The evolution of tracking may be just such an example of how the brain evolved under such selection pressures (Liebenberg 1990).

When it comes to all the types of signs that can be discussed in relation to tracking it may be best to use some of the most common. Footprints, for example, are among the most common and useful type of spoor (Liebenberg 1990). A footprint is not necessarily limited to a perfect cast of a hoof or paw that is easy to see and clearly defined. Footprints can include disturbed vegetation or any partial sign found on the ground of tracks an animal has made (Lee 1979). Animal sex, size, and age, for example, can often be determined by looking at footprints (Marshall et al. 1989). It is not uncommon for trackers to be capable of using footprints to identify members of their group (Lee 1979). Aside from identifying species and age, distance from the spoor under review, and direction are also useful bits of data usually be determined from footprints (Lee 1979; Marshall et al. 1989). The size of a print may often be used as an indicator of the sex of an animal since adult males tend to be larger than females (Lee 1979). The type of terrain will have a significant impact on locating and interpreting footprints. Footprints that are less clear may include things that only a well trained eye can spot such as rocks that have had some dirt wiped off of them when an animal stepped on them making them slightly shinier in appearance than other rocks (Liebenberg 1990; Blurton-Jones and Konner 1976). Conversely animals walking in mud may wipe mud onto a rock which would then serve as a partial print (Liebenberg 1990). Bent grass or grass that has had morning dew wiped off of it as it was walked on by an animal are also good examples of partial footprints (Liebenberg 1990).

Liebenberg (1990) asked hunters among the Ju/'hoansi about the relationship between footprints and animal behavior and discovered some of the insights that trackers have gleaned from observing and tracking animals over their lifetimes. The Ju/'hoansi

know, for example, that steenbok, live in open plains and must sprint fast to outrun predators, their sharp pointed hooves help them grip the loose sand allowing them to run faster (Liebenberg 1990). Kudu are heavy animals for their size and the walk flat footed with rounded hooves (Liebenberg 1990). These hooves allow them to support their weight and give them agility (Liebenberg 1990). They need agility because they live in thick brush and need to run in zigzag patterns to get way from danger (Lee 1979). These examples of knowledge of animal behavior are the result of observations made by hunters on their own in combination with cultural transmission of the knowledge passed down through generations.

Aside from footprints there are many other types of spoor. Some of the more common examples mentioned by Liebenberg (1990) are scat, urine, saliva, objects that have been chewed on, tufts of hair, feathers, quills, sounds, blood, pieces of a carcass, etc. Animals of various types often use the same paths repeatedly and knowledge of these paths may be a good place to search for other signs of spoor (Liebenberg 1990). Many types of spoor may not have be the direct product of an animal that is being tracked. Birds in some cases form symbiotic relationships with animals that are being hunted (Blurton-Jones and Konner 1976). When hunters see such birds it can be an indication that their quarry is not far off. Nocturnal behavior of animals can often be read by trackers the following morning to reconstruct the events the night before (Heinz 1978). Caracals and many other animals engage in mating at night time and this information may be useful in predicting what the animals will doing the next day (Heinz 1978).

Knowledge of a variety of animal behaviors that may not at first seem relevant to tracking can become very useful in creating a picture of what the animal will do in the

future (Heinz 1978). !Ko hunters appear to have extensive knowledge of the mating cycle of some animals they hunt such as springbok (Heinz 1978). !Ko hunters are able to use this information to their advantage in knowning the time frame for when pregnant springbok are likely to give birth (Heinz 1978). At this point the mother animals may be susceptible to calls from newborns for help (Heinz 1978). The !Ko are able to imitate these calls as a means of luring the animals closer (Heinz 1978) so as to shoot them with poison arrows (Liebenberg 1990).

Different species have different patterns of behavior and so mistaking the spoor of one species for another can reduce the likelihood that an animal will be encountered while tracking it. Animals tend to prefer different types of terrain according to species (Blurton-Jones and Konner 1976).

Wind, moisture, heat, and humidity and other weather conditions all have an impact on locating and interpreting spoor. For example, in hot and windy conditions foot prints tend to erode faster (Lee 1979). Thus one might infer that footprints found on a hot and windy day are likely to be very recent, whereas footprints found when it is cold and windless might be relatively old (Liebenberg 1990). Age of the spoor is critical and one of the most difficult aspects of tracking owing to the number of variables that can affect the appearance of spoor (Lee 1979; Liebenberg 1990).

One of the most important uses of spoor interpretation is to arrive at a reliable cost benefit analysis related to the pursuit of a given animal. It is important to pursue animals that will yield a high enough benefit to offset the costs hunting such as time and energy expenditure (Lee 1979). Thus hunters use information in spoor that tell them about the size of the animal, the speed at which its traveling, its current state, and other

variables to come to a decision about whether to stay on a track that has been located or to abandon it and search for another (Lee 1979).

Liebenberg (1990) describes knowledge of animal behavior among the /gwi, !Xò, and Ju/'hoansi as stemming from identifying themselves with the animals in terms of motivations, values, desires and so on. The Ju/'hoansi often consider animal behavior through the use of anthropomorphism (Blurton-Jones and Konner 1976; Heinz 1978). While an animal is being tracked the hunter will often be put into situations where anthropomorphizing helps in working out the possibilities of what the animal's motivations are making it possible to hypothesize what the animal may have chosen to do (Blurton-Jones and Konner 1976; Liebenberg et al. 2012). Physicists have been known to anthropomorphize particles and biologists write about motives and goals of micro-organisms knowing full well that particles and bacteria do not have brains with which to think let alone feelings and complex thoughts about issues (Davies 2010). Liebenberg (1990) points out that it makes some sense why a tracker would anthropomorphize an animal in an attempt to understand it's behavior. However, it would seem to be odd why a scientist would do this in the case of particles or microbes which are far removed from the behavior of animals (Davies 2010; Liebenberg et al. 2012). One question that might be brought up from this observation is whether anthropomorphism is the result of selection for a social adaptation or rooted in solving ecological problems such as with the example from tracking. The next section addresses some of the questions concerning the evolution cognitive capabilities used in tracking.

Science in Relation to Tracking

> The art of tracking, as practiced by the contemporary trackers of the Kalahari, is a science that requires fundamentally the same intellectual abilities as modern physics and mathematics. . . . Natural selection for an ability to interpret tracks and signs may have played a significant role in the evolution of the scientific intellect. [Liebenberg 1990:15]

Louis Liebenberg et al. (2012) proposes that the human intellect was at least partially formed in response to selection pressures to improve tracking capabilities over approximately the last two million years. Additionally he argues that the capacity of the human intellect used in doing science involves the same cognitive capabilities used in scientific reasoning (Liebenberg et al. 2012). I will call this the art of tracking hypothesis which is taken from Liebenberg's (1990) book on the subject. Science and tracking are argued to be connected in that both require the interpretation of signs and the formation of hypotheses and experimental testing (Liebenberg 1990). A reader unfamiliar with tracking may find it easy to recognize that science involves the use of signs such as in mathematical equations, writing, and using instruments to take measurements. Tracking, however, also involves the use of signs as they are simply bits of information gathered from the environment. Animal foot prints for example can be thought of in the same way any other type of data, they can be assessed and measured and then used to formulate a hypothesis concerning that animals past, present, and/or future behavior. The relationship between the art of tracking as it connects to science will be explained in the following pages.

Liebenberg's Conception of Science

By Liebenberg's (1990) account, science involves several elements including: observations, inductive and deductive reasoning, hypothesis creation and testing, critical discussion and analysis, anthropomorphism, intuition, and complex interpretation of signs. Using these elements a scientist/tracker can make generalizations about the universe. Using these generalizations plays a large role in creating predictions and explanations of phenomena which is fundamental to science (Ladyman 2002). Activities such as hunting by the Ju/'hoansi have been observed and characterized as a continuous process of hypothesizing and testing those hypotheses in pursuit of game (Blurton-Jones and Konner 1976).

Classically, the use of inductive and deductive reasoning are fundamental to scientific thinking and can be explained as arriving at conclusions which are logically consistent with observations which are assumed to have some validity (Ladyman 2002). The concepts are often broken apart and defined separately to reveal the limitations of both.

In deductive reasoning conclusions are the result of inferences based on premises which must be true (Ladyman 2002). If the premises are not true then the conclusion cannot be guaranteed as true (Hume 1975; Hume 1978). An example of a deduction could be something like: all cats are animals, my pet is a cat, therefore my pet is an animal. While this is true it is limited in the sense that it does not give us any new information, it simply asserts the necessarily true connections among the premises.

Induction is any form of reasoning that is not deductive reasoning (Ladyman 2002). Inductive reasoning relies on observations that can be grouped together to find

commonalities (Bacon 2000). Observing that the sun rises every day and asserting that this pattern will continue based on past observations is an example of using induction. The problem with induction is that we cannot be certain that the observed events in the past will repeat in the future (Hume 1975). If the sun went supernova or was consumed by a black hole then it would not rise tomorrow. This is a serious problem in epistemology but perhaps not as much for considering the development of science from an evolutionary perspective. As long as conclusions drawn from induction have a degree of reliability, then natural selection could favor the use of induction. A hunter may identify that every year it rains and these rains consistently leave watering holes in particular places. Using inductive methods the hunter may predict that next year water may be found in the same places as it was last year after the rain comes.

To combine induction and deduction the example above can be continued and expanded. Similar to observations about when and where water may be found, a hunter might observe that a particular type of animal is commonly found around water sources. When multiple inductively arrived at premises are joined together then deduction can be used to link the two or more premises which are assumed to be true (Ladyman 2002). In this case the hunter believes the locations of water are known after the rain comes and that species of animal is usually if not always found around water sources. After the rain comes the hunter may deduce that water and particular animal will be found at places where water was found the previous year after the rains. This simple example illustrates inductive-deductive reasoning. This method of reasoning does not allow for explanations of general statements and it does not allow for novel predictions about what will be the

case in the future (Ladyman 2002). More is needed to make the jump toward something that can be considered an approximation of science.

Hypothetico-deductive reasoning takes induction and deduction further by allowing for creation of possible causes concerning the observations and principles that are known or at least assumed to be known (Lakatos 1978). Predictions generated from this process are then tested through experiments (Lakatos 1999). Liebenberg (1990:166) refers to this creative or imaginative thinking as being generated through processes that are "non-logical" or "outside logic." This non-logical process uses experience and various forms of imaginative capability such as intuition, anthropomorphism and perhaps others. It is possible that these are some of the aspects of cognition that can be considered points of difference in the type of intelligence humans use as compared to other species.

Liebenberg (1990) relates anthropomorphism to causality in asserting that humans are able to assign causes through the projection of their own experience onto the world. This is a subjective means of inferring a cause where the scientist may use something like the recognition of internal motivations to explain some phenomena based on sets of assumed rules (Davies 2010). Physicists have been known to use anthropomorphic projection in particle physics when they ask themselves questions about what they would do if they were a particular subatomic particle in some circumstance (Monod 1975). The motives of the particle in this case would use an understanding of the rules governing the behavior of those particles to form hypotheses that predict behavior under some circumstance (Monod 1975).

Intuition is another example of non-logical thinking and it can be used in conjunction with anthropomorphic projection or on its own (Liebenberg 1990). The use of intuition is where a person reaches "a conclusion on the basis of less explicit information than is ordinarily required to reach that conclusion . . . [and the] individual is unaware of the process involved in reaching the decision" (Liebenberg 1990:170). This type of thinking is typically employed when data cannot be properly assessed due to a variety of constraints. Data may be too abundant or too complex to sort through in a given amount of time. Conversely data may be too sparse to allow for normal analysis.

When hypotheses are in the process of being created and then also after their creation, critical discussion and analysis play a central role (Ladyman 2002). While it is possible for an individual to engage in critical analysis regarding hypotheses, science may also be thought of as social in that critical analysis though group discussion is common (Ladyman 2002). Discussion may take a variety of forms from talking face to face to using written language over long distances etc.

Written language or the use of mathematical symbols is commonly associated with the process of conducting science but the ability to use and interpret signs goes beyond these two methods of symbolic representation. Humans have the ability to break down data from the environment into abstract and meaningful signs. Consider the variability in what can be considered a sign. Some paint on the side of a wall may be a sign that a person committed a form of vandalism or that a spot on the wall had been damaged and needed a fresh coat of paint to repair it. A leaf with rounded semi-circular sections missing may be a sign that a caterpillar had been consuming that leaf. Other animals may have some limited capabilities with regard to the use and interpretation of

signs but their abilities are far beneath what humans are capable of. A case in point is Koko the gorilla mentioned earlier which had an impressive vocabulary of several hundred words (Patterson 1981). The vocabulary of Koko is dwarfed in comparison to the vocabulary of even a young human child which may include thousands of words.

The concepts outlined above fit-together in Liebenberg's (1990) account of what can be called a research program. This term was borrowed from Imre Lakatos (1978) who described it as a containing two types of hypotheses: a hard core and a protective belt. Additionally, a research program offers an experience based means of testing these hypotheses. The hard core of a research program are those hypotheses that are believed to be supported by strong evidence. The protective belt of hypotheses act to protect the hard core (Lakatos 1978). The protective belt may do this by explaining unique circumstances that would otherwise appear to violate general principles of the hard core. If a protective belt hypothesis is falsified, then a new hypothesis can be put in its place to protect the hard core (Lakatos 1978). The protective belt might be thought of as something that attempts to answer why an apparent anomaly is not in contradiction with established hard core beliefs. If the research program is making progress then its explanatory and predictive power will grow over time (Lakatos 1968). The posited reason that such modifications are not merely ad hoc addendums is because of this growth in predictive power (Popper 1959; Popper 1962). This view concerning the construction of new hypotheses to answer questions regarding anomalies is shared by Popper (1959). Popper (1959) viewed these adjunct hypotheses as containing merit if they could provide further predictions that could also be tested. If predictions made by hypotheses cannot be predicted then Popper (1959) would reject them as unscientific. Liebenberg (1990) seems

to adopt this conception of science in conjunction with Lakatos's outline of what a scientific research program is.

The use of anthropomorphism and intuition as part of hypothesis creation can also be considered within the bounds of science

Aside from the importance of testing hypotheses, Liebenberg's (1990) views about the creation of hypotheses also fall in line with some of the more widely accepted views concerning demarcation (Ladyman 2002). Popper (1959) for instance pointed out that the source of a hypothesis is a creative activity and because one of the main operations in science is to test hypotheses the source of this creative activity does not invalidate the hypothesis itself. Sources for hypotheses may come from variety of sources such as dreams, religious views, metaphysical beliefs, and so on. Liebenberg's (1990; Liebenberg et al. 2012) view that hypothesis generation is often the result of anthropomorphic or intuitive capabilities does not appear to be out of line with Popper's (1959) view.

Elements of a set of views by prominent philosopher of science Steven Kuhn (1970) pertaining to the nature of hypothesis creation are also similar to Liebenberg's (1990) version of Lakatos's research program concept (Kuhn 1970). Kuhn (1970) may often be considered as muddying the water in the problem of demarcation due to his rejection of commonly held beliefs that empiricists and logical positivists agree upon (Ladyman 2002). Kuhn (1970) uses a model consisting of revolutions in science which involve transitions between theories which are well entrenched and surrounded by something akin to auxiliary hypotheses that serve as a means of preservation and protection of the central principles of an entrenched general theory (Kuhn 1970). Therein

lies the similarity to Lakatos (1978) and Liebenberg's (1990) view of science in that a set of broad principles are held onto and modified by a secondary ring of hypotheses which may be rejected. Kuhn's (1970) concept of a scientific revolution occurs when the entrenched theory becomes untenable because the number of anomalies grows and scientists begin to look for alternative theoretical explanations (1970). In both Kuhn's and Lakatos's descriptions of scientific progress may be interpreted as increasing explanatory and predictive power whether it be the result of auxiliary hypotheses or the switch to a new foundational set of theoretical principles which Kuhn (1970) labels a paradigm. Although Kuhn may not agree that this is necessarily progress in the sense that epistemologists typically think of. That is, Kuhn might argue that the new paradigm may not get us any closer to the truth about the entities or forces it posits to be in existence. These concerns over progress in science may be further linked with the currently popular position in philosophy of science generally referred to as Inference to the best explanation (Ladyman 2002).

Inference to the best explanation (IBE) is a principle used for the selection of a hypothesis among several where the explanatory power of each hypothesis is a key consideration the selection (Ladyman 2002). This form of abductive reasoning may be problematic when considering several problems concerning the nature of possible hypotheses to choose from. The available hypotheses in a given situation may exclude what would be considered the best explanation and a scientist may simply be choosing the best explanation out of a list of bad explanations (Ladyman 2002). Alternatively the seemingly best explanation could be incorrect for a variety of reasons. If a key piece of data is missing an incorrect explanation may be the best explanation based on the

available data (Ladyman 2002). An example of this may be illustrated by imagining a person walking outside and finding that the ground was wet. An individual may infer that rain has caused the ground to be wet. Upon further examination however it may come to light that this person accidentally left the hose on after watering the flower bed and this eventually caused the entire front yard to be flooded. Even with such problems at this, philosophers such as Harman (1968) argue that this is what people do in everyday life and it tends to work well. Consider an optimistic example of IBE where you hear a scratching at your window, it might be a tree branch blowing in the wind or it could be evil aliens from another dimension who came to earth to slightly annoy you. The tree branch is the best explanation for the noise of the two given. The best explanation for some phenomena is partly inductive in that it takes into account instances observed in the past.

Liebenberg's conception of science could be considered to rely on IBE when it comes to sorting through hypotheses. The use of IBE sounds similar to how Liebenberg (1990) describes creating and choosing hypotheses created by using hypothetico-deductive reasoning. Experience and Liebenberg's (1990) non-logical thinking play a significant role in making these choices and so mere induction and deduction cannot be what Liebenberg is referring to when considering how to distinguish which is better among hypotheses. Additionally, Liebenberg (1990) is concerned with connecting the cognitive abilities used in science with those of tracking such that tracking is itself argued to be a science. Liebenberg's view of science falls within what appear to be a generally acceptable view of science based on the review above. The next question however is

whether tracking actually is science and how the evolution of tracking coincides with the cognitive abilities used in scientific thinking.

Is Tracking Science?

What are the similarities between the cognitive abilities used in science and those used in tracking? Should tracking be considered a science? This section will review the three types of tracking explained earlier in relation to the cognitive abilities required to do science.

Simple tracking involves following footprints and under the best circumstances the animal these tracks belong to will be in visible range a portion of the time. This concept can be broken down a bit farther. Simple tracking requires a limited capacity to interpret and remember signs (Liebenberg 1990). The signs in this case are the footprints that belong to an animal. The interpretation of these prints requires a determination of whether markings on the ground are tracks and if so to which animal they belong. Simple tracking only utilizes tracks that are recent and relatively clear (Liebenberg 1990). This means that the animal(s) that the tracks belong to is likely to be fairly close by. To do this kind of tracking requires an intellect that can associate a specific type of shape with a target animal. In relation to scientific thinking this would fall under a very crude form of induction where experience can lead to an association. Simple tracking also requires that a direction is chosen. The direction chosen also illustrates a form of interpretation because the shape of a track indicates which direction an animal is headed only if a tracker can determine which portion of the track is the front end and which is the back end. An inability to do this would result in tracking in the opposite direction of where the animal actually is. Determining the direction of tracks could be learned by trial and error

or it could be learned from observing the tracks left behind as an animal walks. In either case a primitive type of induction is necessary. Liebenberg (1990) writes that much of the time direction of travel is difficult to determine and requires more sophisticated tracking capabilities that simple tracking (1990). This may be the case if another animal has run across terrain that makes spotting tracks very difficult. Alternately, if many of this species of animal have recently traveled through the area the footprints of the animal being tracked may be difficult to distinguish from other similar tracks. It should be kept in mind that simple tracking is only possible when environmental conditions for tracking are good (Liebenberg 1990). Many of the elements needed to do science are not present in simple tracking and so simple tracking cannot be considered a science. However, it can be thought of as perhaps a factor in the origin of where scientific thinking evolved from.

Systematic tracking is a more complex form of simple tracking (Liebenberg 1990). The difference between simple and systematic tracking is a matter of skill where more skill is required as conditions become more difficult for the tracking to see and interpret (Liebenberg 1990). This form of tracking broadens the types of data from the environment that are meaningful to the tracker. In addition to broadening the type of signs that are meaningful to the tracker this type of tracking incorporates signs that are less obvious or obscured in some way (Liebenberg 1990). A track that might be missed when only using simple tracking may be possible to see if systematic tracking is used. This improvement in the number, type, and quality of signs that are useful involves a more complex ability to interpret signs compared to simple tracking but the difference seems to be more a matter of memory than creative problem solving (Liebenberg 1990).

Speculative tracking is different from other types of tracking in that it not only uses abilities to recognize a broad array of useful signs it also requires the ability to posit scenarios that may or may not be true (Liebenberg 1990). If a particular scenario is deemed superior to others then a speculative tracker can project a somewhat reliable prediction about the future behavior of an animal (Liebenberg 1990). In this way speculative tracking requires the ability to weigh the value of explanations and predictions as to whether they are more or less likely to be true. Liebenberg (1990) does not refer to this as inference to the best explanation but it sounds very similar. In other words, the predictions are subject to a type of critical skepticism where conclusions drawn are subject to doubt (Blurton-Jones and Konner 1976). The tracker cannot be sure in many cases whether the signs being interpreted parallel what actually happened. For this reason the inductively arrived at premises may be false and any deductions that are made from these false premises will result in incorrect conclusions and ultimately predictions that fail to allow the tracker to pursue an animal.

Beyond the use of inductively arrived at premises preceding deductively arrived at conclusions, the ability to come up with explanations and predictions also requires some form of imaginative intelligence (Carruthers 2002). As previously outlined above Liebenberg (1990; Liebenberg et al. 2012) uses his own conceptions of how this imaginative intelligence is used and where it may have come from. Intuition and anthropomorphism are two parts of this imaginative process although this area is left unclear in terms of how it functions (Liebenberg et al. 2012). This is a problem, it seems that the process and origins of creative or imaginative intelligence are not well understood in relation to science generally (Carruthers 2002; Ladyman 2002).

The explanations or predictions that are constructed using a combination of inductive, deductive, creative hypothesis generation are subjected to testing as the tracker pursues an animal based in these interpretations of available data (Liebenberg 1990). In this way it could be argued that the tracker, perhaps without knowing it, engages in a practice of attempting to falsify the hypothesis. Falsifiability is another key element of science as has been mentioned previously with reference to the work of Popper (1959). If a tracker fails to find the animal being pursued then the prediction as to the animal's behavior is subject to doubt (Liebenberg 1990). A failed prediction may cause a tracker to re-examine the evidence and line of reasoning that lead to it.

When a prediction fails the tracker may refer back to a general body of beliefs which have allowed for successful predictions in the past (Liebenberg 1990). Some beliefs about animal behavior may be highly reliable and less subject to doubt as part of a failed explanation (Liebenberg 1990). Such beliefs could be thought of as reminiscent of the hard-core or the central concepts of a paradigm as described by Lakatos (1978) or Kuhn (1970). A tracker may often look at interpretations which are not reinforced by a large body of evidence (Liebenberg 1990). The cursory factors or interpretations that lead to a failed hypothesis may lead to exposure of a fault (Lakatos 1978). Identifying such a fault would then act to protect the beliefs that are held to be reliable (Kuhn 1970). Auxiliary hypotheses to explain failed predictions or anomalies is essentially the same practice in tracking as what Lakatos (1978) and Kuhn (1970) identify as common practice in science.

The practice of tracking like the practice of science is usually not done in isolation (Blurton-Jones and Konner 1976; Ladyman 2002). In both cases discussion among peers

often improves the probability of success whether it be in understanding the behavior of a subatomic particle or a gemsbok. Hunts among the Ju/'hoansi with typically occur in groups (Blurton-Jones and Konner 1976; Lee 1979; Liebenberg 1990; Liebenberg 2006) which enables discussions to break out and aid in the development of or choice among competing hypothesis (Blurton-Jones and Konner 1976). There does appear to be a significant limitation in discussion and critical analysis that occurs among hunter-gatherers in comparison to scientists regarding the quantity and quality of information available (Blurton-Jones and Konner 1976). The quantity of information available to hunter-gatherers with no writing system is limited to that which can be stored in the minds of the trackers (Liebenberg et al. 2012). This means that each tracker acts as a repository of information. A group of only a few trackers cannot match he sheer volume of scientific literature available to a scientist using contemporary technology and resources (Liebenberg 1990). This should not disqualify tracking as a science because it is not a difference in type it is only a difference in the amount of information available and not in the principles that are used in dealing with the available information (Liebenberg 1990).

The amount of information stored in the brain of a small group is less than that of a worldwide network of libraries and scientists but the principles of how this information is used is a critical factor. Scientists who worked during the beginning of what may be thought of as the modern age of science (starting with scientists like Francis Bacon 1561-1626 AD) would have also been very limited in the amount of information available on any specific subject (Ladyman 2002). This lack of group size and quantity of information

does not disqualify individuals like Galileo or Newton from being considered scientists and it may be argued that it should not disqualify trackers either.

Another possible objection is that the quality of information provided by trackers may not be up to par with scientists (Carruthers 2002). The information used by scientists is usually published and peer reviewed (Ladyman 2002). This system has advantages and disadvantages. A published study can be reviewed by a large number of people over great distances and critically evaluated for accuracy. Other scientists can reconstruct an experiment to see if they come up with the same results as those of a published study. While it is true that scientists can conduct experiments in an attempt to check each other's work a good deal of the time results are trusted as accurate and simply cited (Ladyman 2002). It would be difficult to make progress in science if every assertion made in a study required scientists to test its accuracy (Ladyman 2002). In groups of hunter-gatherers the problems of accuracy in reports given by individuals is similar to that faced by scientists in some ways. Hunter's often tell stories that include the methods, hypotheses, and other information relevant to a hunt (Lee 1979; Liebenberg 1990). During hunts, when discussions occur, the same types of information are passed among hunters (Liebenberg 1990). This information must be evaluated carefully because accepting erroneous information will increase the likelihood that a hunt will fail. In this way the information traded among trackers operates under a level of skeptical inquiry in the same way that scientific studies are subject to skeptical scrutiny (Liebenberg 1990). What this means is that trackers must be concerned with the veracity of information relevant to hunting because the success of the hunt depends upon it.

Scientists do seem to have an advantage in terms of the number of individuals to compare notes with and the reliability of data in the form of writing. Trackers living in hunter-gatherer bands and tribes are at a disadvantage in this regard. Even so, the quality of information accepted by trackers must be maintained at a level that is sufficient to allow success in hunting (Liebenberg et al. 2012). Trackers may be operating in a system where erroneous information causes misinterpretation of data and creates problems with hypotheses but it is a system that works against misinterpretation of data (Liebenberg 1990). One goal in science as well as tracking must be the elimination of incorrect assertions through the use of critical analysis among peers (Ladyman 2002; Liebenberg 1990).

In a small group of hunter gatherers a relatively great deal of information is lost each time a group member dies (Liebenberg 1990). Passing on information by spoken word is a limitation and inhibits progress in developing a better system of tracking (Liebenberg et al. 2012). Liebenberg (1990) suggests that this may allow only the survival of core principles of tracking which have proven to be most reliable. In other words, there is a limited amount of space in the mind of an individual and without writing it is difficult or impossible to pass on many of the nuances of what has been learned in a lifetime. The effect of limiting what information can be passed on to future generations no doubt inhibits progress in progressively improving tracking research programs (Liebenberg 1990). The effect is such that many principles may be continuously discovered and then forgotten over generations (Liebenberg 1990). While it is not impossible that something like this would happen in science, the ability to store and transmit data substantially reduces this problem. Once again, this points to an issue where

the principles of tracking and science may be considered the same. The difference is in the way knowledge is stored and maintained and not in the way it is used.

Epistemic Goals. In examining Liebenberg's assertion that tracking is essentially a science Peter Carruther's (2002) argues this is not the case for at least two reasons. First, he argues that the goals of tracking are fundamentally different from those of science. Second, he argues that trackers do not use the same sorts of methods that scientists use in explaining phenomena (Carruthers 2002).

Carruthers (2002) cites two different views about what the goals of science are and then proceeds to explain how neither matches with what trackers engage in. The first view states that the goal of science is to find fundamental natural laws of the universe through a process of postulating and testing theories in relation to observed phenomena (Carruthers 2002:78; Hemple 1965; Nagel 1979). The second conception about the goals of science is that scientists make and use models in relation to observed phenomena and refine those models over time to improve their accuracy (Carruthers 2002:78; Cartwright 1983; Giere 1992). Carruthers synthesizes the two conceptions as the creation and use of "theories and/or models to explain events, processes and regularities observed in nature" (Carruthers 2002:78). Part of this process requires ranking competing theories according to: accuracy, simplicity, consistency, coherence, fruitfulness, and explanatory scope (Carruthers 2002). Carruthers (2002) then argues that hunter gatherers merely engage in enumerative induction to explain what they see around themselves and this does not involve the testing or construction of theories and/or models.

While Carruthers (2002) agrees that trackers are using the same principles as scientists he disagrees that they are engaged in what can be called a science because the

epistemic aims are different. A criticism of Carruthers's (2002)criterion for what counts as science can be illustrated through an example. Carruther's (2002) point is that tracking cannot be thought of as science because the goals of tracking are based on acquiring food (an immediate goal) and not on discovering general principles. Consider an example from medical science in comparison to the claim that tracking should not be thought of as a science. In medical science the goals encompass both general principles and immediate success in some area. In research on cancer the main goal appears to be finding a cure for cancer. This goal often serves the larger purpose of uncovering general principles relevant to biology but it is not strictly necessary to be considered science. If a paper was published which showed eating broccoli three times a day would cure lung cancer (and it was true) it is doubtful that the paper would be cast aside as outside science simply because a greater unifying principle was not posited. Tracking could be considered in a similar vein to this example, meaning that it should not be immediately rejected as a candidate for science.

In most cases tracking appears to be used more or less as Carruthers (2002) describes. However, in other cases research programs of trackers do illustrate comprehension and use of general principles. For example, Liebenberg (1990) describes incidents where trackers informed him as to why hooves were shaped differently by different animals. Some of the better trackers were able to arrive at general principles for determining that hoof shape is related to the type of terrain an animal is found in (see tracking section in the Hunting section for details). The shape of the foot has a lot to do with the type of terrain and mode of transportation of the animal. The principles here relate adaptations for locomotion to terrain type. A deep knowledge of the tracks of so

many different animals would be expected to allow trackers to make predictions about the behavior and environmental conditions preferred by animals they have never encountered before. If a tracker was transported to another continent it seems very likely that these principles learned from tracking would allow general predictions to be made whenever tracks of new species were found.

General principles relating foot shape and texture to preferences in terrain type could easily be translated into publishable scientific papers if a tracker were perhaps inclined to write down the data collected during tracking. The ability of hunter-gatherers to maintain large bodies of such principles would be limited where there is no system of writing and a great deal of knowledge is lost every time a tracker dies just as Liebenberg (1990) describes. With the invention of writing these principles can be kept for posterity. It may be more useful to consider the evolution of scientific thinking in terms of a continuum if the ability to think scientifically is essentially innate. It is similar to asking for the exact point where *Homo* sapiens became a species; the line remains somewhat blurry by necessity. The effect of a discrete cut off line for *Homo* sapiens would result in the offspring of a set of parents being classified as a separate species. Similarly, if humans are innately capable of and regularly engage in scientific thinking then perhaps the demarcation of science should be thought of more like species are thought of. This would mean that while the primary goal of tracking is not to discover general principles it should still fall within a definition of science.

So perhaps tracking can be considered a science after all. Further elaboration of the demarcation problem as well as improved understanding of human evolution and

capabilities will no doubt be useful in clarifying issues such as those contained in hypotheses such as the art of tracking hypothesis (Liebenberg 1990).

Cognitive Abilities Necessary for Science

> It would be surprising indeed if repeated activation of hypotheses, trying them out against new data, integrating them with previously known facts, and rejecting ones which do not stand up, were habits of mind peculiar to western scientists and detectives. !Kung [Ju/'hoansi] behavior indicates that, on the contrary, the very way of life for which the human brain evolved required them. [Blurton-Jones and Konner, on the subject of tracking in relation to science among the Ju/'hoansi 1976:224]

If the cognitive capabilities used in science are the same as those used in tracking perhaps Liebenberg et al. (2012) is partly correct that science is possible because of selection pressures that relate cognitive function to improved success in hunting. This line of thought may offer insight into the selective pressures that shaped human cognition. This section will attempt to offer a short discussion of some cognitive abilities that may have evolved which enable humans to conduct science.

Evolution would not have had the goal of shaping human cognition for conducting science. In fact, while studying our own species we continuously run across limitations and misconceptions of the way the universe works (Pinker 2007). We have an intuitive sense of physics which is incorrect according to our current best theories on the subject (Pinker 2007). The ability of humans to conduct science must be the result of selection for many cognitive abilities that were critical in enhancing survival and reproduction during our evolutionary past (Pinker 2007). This subject is large and

complex and so the point here is simply to outline a few thoughts on how selection might favor cognitive abilities that would later become useful in science.

Tool Construction and Science

Steven Mithen (2002) makes an argument concerning the transition toward larger more complex cognitive capabilities as evidenced by tools associated with australopithecines up to the beginning of the genus *Homo* (Mithen 2002). The brain size of animals range from 400 to 750 cc depending upon which species is being considered (McHenry and Coffing 2000). The cognitive capabilities of early australopithecines was probably similar to those of the great apes which have similar sized brains (Stanford 1996). Mithen cites chimpanzees and their tool making capacity as a likely similar to what early australopithecines would have been capable of (2002). The abilities of chimpanzees include activities like stripping twigs of leaves to form a termite fishing tool (Mithen 2002). While chimpanzees have been known to use objects in a hammer and anvil fashion experiments attempting to teach chimpanzees to make stone tools show that they are not capable of that level of sophistication in tool making (Mithen 2002).

The difference in the ability to make stone tools versus the level of tool construction that chimpanzees are capable of is argued by Mithen to be a significant change in the brain evolution in the lineage leading to humans (2002). The types of stone tools in question are oldowan, in other words they are essentially comprised of hand axes and flakes (Klein 1999). The main difference in making stone tools compared to stripping twigs of leaves is that making stone tools contains an element of unpredictability (Mithen 2002). The very first stone tools may have simply involved using sharp stones or hitting two rocks together with the goal of getting any sharp edge (Mithen 2002). The stage at

which Oldowan tools come into play involves a different level of understanding. When two stones are knocked together the goal is not random. While making oldowan tools the shape and process requires a predictive element. The maker of the tools must have a conception of the end product desired and make predictions as to how stones can be hit together to achieve this idea (Mithen 2002). Mithen believes this is a very rudimentary form of hypothesis testing in that these early tool makers were dealing with a number of variables that could be adjusted in the tool making process (2002).

> An individual wishing to shape an artifact they will prepare a striking platform, select a hammer stone of a specific weight and density, strike the artifact at a specific angle with a specific force, and then often inspect the flake and the remnant flake-scar. . . . The differences between the expected and realize flake will be noted and will serve to modify their future knapping actions. [Mithen 2002: 26]

Mithen then states that this is different from trial an error where stones are slammed together at random in the hope the desired result will be achieved (2002).

While Mithen argues that these abilities to engage in rudimentary hypothesis testing are more advanced than what chimpanzees are capable of, he also argues that they are not very far from what other animals do (2002). Mithen points out that Dunbar (1995) argues for an even lower threshold for the definition of hypothesis testing, stating that foraging animals must have at least very limited mental capabilities while foraging. In other words these animals must have some way of sorting environmental information that allows for decisions to be made. Accepting such a view would broaden the point about prediction and hypothesis testing and may be used to set up a loose definition of

intelligence. This definition would require that one aspect of defining intelligence could include the ability to predict the future. This point has been made in a different context by Daniel Dennett in his attempt to deal with the issue of consciousness and artificial intelligence (Dennett 1991).

The use of the brain to make predictions would be useful if an animal can figure out a way to manipulate the present so that the future result pays off. In the case of termite fishing the results are fairly immediate where the chimp in some way predicts that making a tool now will facilitate the acquisition of food later. Humans do this on a much more complex level when you consider what we go through in manipulating the environment for future payoffs. Intelligence defined in this way can be linked to the acquisition of food as outlined in hypotheses like those predicted by the embodied capital model (Kaplan et al. 2000) where increased dietary quality is associated with the growth of larger brains in humans.

Although Mithen is arguing for the construction of tools as the significant step for the deviation in cognitive abilities in australopithecines from other great apes, the source of these abilities does not limit their utility from crossing over to other areas. If australopithecines engaged in scavenging as has been previously argued (Dominguez-Rodrigo 2002), then tools may have helped in butchering carcasses acquired through scavenging or even limited hunting (Dominguez-Rodrigo 2002). The predictive capabilities that went along with tool construction could also have been useful in the acquisition of carcasses. Cognitive capabilities concerning hypothesis testing are argued by Liebenberg (1990) to have played a role in the evolution of tracking. Regardless of whether these cognitive abilities initially arose from the need to track, make tools, or both

the payoff appears to be an increase in dietary quality for the line of species leading up to our own such as through the consumption of animal source foods.

Another view about the development of cognitive abilities that allow humans to do science relates selection pressures for imaginative thinking to the evolution of tracking, which can then be understood in terms of increased dietary quality through the acquisition of animal foods (Carruthers 2002). Peter Carruthers has argued that the cognitive capacities that are important in creating and testing hypotheses require some sort of imaginative thinking (2002). As mentioned previously this view appears to be the case by a number of scholars concerned with demarcation (Ladyman 2002). Hypothesis testing is central to science and, as stated previously, the creation of hypotheses is by no means a simple task. The ability to think imaginatively is a necessary component of hypothesis creation as it is used by humans engaged in science (Popper 1969). This use of the concept of hypothesis creation should be differentiated from the views of Mithen (2002) because the sort of hypothesis testing Mithen is concerned with is a great deal less sophisticated than what Carruthers (2002) describes.

Carruthers has suggested that imagination conducive to hypothesis creation can be broken into two types experiential imagination and spatial imagination (2002). Spatial imagination is argued by Carruthers to have possibly evolved along with selection pressures related to tool making approximately 400,000 years ago. The idea is that the visual imagination part of the brain would be the area that was modified in relation to tool making. Carruthers argues that since tools are made with a particular type of desired shape some imaginative ability would be necessary to figure out how to manipulate an object so as to achieve the desired tool as an end product. Propositional imagination is

"the capacity to form and consider propositional representation without commitment to its truth or desirability." (Carruthers 2002:91). Carruthers relates these abilities to Liebenberg's (1990) art of tracking hypothesis, arguing that these two types of imagination along with language are both necessary for speculative tracking to take place. The implication of this for Carruthers is that much of the evolution of tracking related cognitive capabilities occurred more recently from 400,000 to 100,000 years ago in conjunction with the evolution of language (2002). The reasoning behind the connection to language involves the need to think abstractly about concepts in conjunction with the use of symbols to take on the meaning of those concepts (2002).

By Carruthers's account, hypothesis creation and testing occurred relatively late in the evolution of *Homo*. On the other hand Mithen's (2002) account argues for a relaxed definition of hypothesis creation which places it much farther in the past with australopithecines. The issue in reconciling these views may be partly semantic in that the word hypothesis is treated differently. Though it is not part of this project to attempt to reconcile these views, it is useful to note that these two views share a number of things in common. Both Carruthers's and Mithen's views can be related to the use of cognitive capabilities relation to solving ecological problems. The implication is that both views can be used to argue in favor of the art of tracking hypothesis in that the evolution of the cognitive abilities useful in science today had their origins in selection pressures that enabled hominids to translate cognitive capabilities into improved dietary quality and food acquisition.

Measuring Cognitive Abilities

According to Liebenberg (1990), speculative tracking uses the same mental abilities used in sciences such as physics or mathematics. This would mean that the parts of the brain that are used in physics should correspond to those used in speculative tracking. If a test can be found which measures capabilities which are related to potential success in sciences such as physics then this test should also be relevant as a measurement of an individual's potential as a tracker.

In considering ways to measure aptitudes for problem solving the Raven's test appears to be appropriate since it is a measure of general fluid intelligence (referred to as simply fluid intelligence throughout this work and Gf in the quote below) (Chiesi et al. 2012; McGrew 2009; Raven 2000). *Fluid intelligence* is the

> deliberate and controlled mental operations to solve novel problems that cannot be performed automatically. Mental operations often include drawing inferences, concept formation, classification, generating and testing hypothesis, identifying relations, comprehending implications, problem solving, extrapolating, and transforming information. Inductive and deductive reasoning are generally considered the hallmark indicators of Gf. Gf has been linked to cognitive complexity which can be defined as a greater use of a wide and diverse array of elementary cognitive processes during performance. [McGrew 2009:5]

The definition of fluid intelligence entails many of the cognitive capabilities that are necessary for an individual to engage in scientific reasoning as it has been described previously.

The Raven's Progressive Matrices test involves the matching of patterns that are increasingly difficult to solve (Hamel and Schmittmann 2006; Raven 2000). The test does not rely on knowing a specific language or having a specific educational background (Hamel and Schmittmann 2006). This test is also one of the most used intelligence tests in the world and variations of it have been around for many decades (Hamel and Schmittmann 2006; Raven 2000). The original test called the Standard Progressive Matrices is a 60 item test which typically requires around 45 minutes to complete (Raven 2000). There have been several versions of this test developed including the Raven's Advanced Progressive Matrices (RAPM) (Chiesi 2012). Shortened versions of the RAPM have been administered in a with a ten minute time limit (Chiesi 2012). What this means is that an individual's fluid intelligence can be measured in a short amount of time.

Tools that assess fluid intelligence such as the RAPM may be useful in conjunction with theory concerning human evolution as a means to better understand the evolution of the mind. It would be possible to have subjects take multiple versions of the RAPM under various conditions to assess effects those conditions have on fluid intelligence. Much of this literature review has focused on hunting and tracking as part of human evolution. The study carried out in this work was an attempt to understand some of the effects of physical and mental activities on cognitive performance as these variables relate to hunting.

Measuring fluid intelligence by itself may be useful in allowing some prediction to be made about an individual's potential for speculative tracking. However, there are other factors that influence cognitive performance such as the mental and physical costs that occur during a hunt. To account for physical costs of hunting such as fatigue the

study presented in this work includes endurance running. One additional, but critical, piece of the study attempts to reconcile the effects of these costs on the mind and body in terms of the currency that is used to pay for them. In other words, hunting and persistence hunting in particular, have a number of significant of associated costs. When these costs are considered in conjunction with diet then the other side of the equation comes into view. The objective of hunting is to acquire a high quality nutrient dense food source, namely animal carcasses. This type of food source is critical in providing hunter-gatherers with the currency they need to make a living (Kaplan et al. 2000). The relationship between the costs on the human body for activities like hunting can be studied in relation to the payoff of a successful hunt. During the evolution of the human species diet is argued to have played a central role in allowing for the development of the modern human brain and body form (Kaplan et al. 2000). The next section attempts to describe elements of the relationship between the brain and the high quality diet that humans depend on.

Cognitive Function and Diet

If tracking is implicated in the evolution of cognitive faculties necessary for science are these faculties related to diet? The central purpose of tracking is the acquisition of meat. If cognitive abilities for tracking were selected for, then perhaps there is a link between brain evolution and dietary intake of animal foods. Diet quality appears to have increased over the last two million years or longer and this period coincides with the most dramatic changes to the size and composition of the brain (Kaplan et al. 2000; Leonard et al. 2007b). It might be expected that a sort of feedback cycle involving diet, brain size, and other factors took place over the past several million

years (Kaplan et al. 2000). This section aims to outline the connection relating brain to diet. First there will be a review of some of the evidence that favors the idea that humans are part of a long dietary shift towards increased consumption of animal foods. This evidence is important to establish that diet quality is linked with other aspects of human evolution such as brain evolution. This will be followed by a discussion of one nutrient found in meat called creatine and a possible relationship between it and human brain evolution. The connection between meat consumption and effects on the brain through chemicals like creatine will then be discussed in relation to meat acquisition through hunting (Babbitt et al. 2011; Pfefferle et al. 2011).

How Do We Know What Hominds Ate?

How do we know that humans and their ancestors were part of a dietary shift toward high quality foods? In previous sections some of the evidence for a dietary shift has been mentioned but there are other lines of evidence that may lead to this conclusion as well.

Cordain and others have looked at the diets of hunter gatherers in an effort to project possible diet scenarios concerning hominids in the distant past (Cordain 2006; Cordain et al. 2000; Kaplan et al. 2000). Aiello and colleagues have argued that meat eating was part of a tradeoff between gut size and brain size (Aiello and Wells 2002; Aiello and Wheeler 1995). Leonard and colleagues (Leonard and Robertson 1992; Leonard and Robertson 1997; McHenry and Coffing 2000) have related diet quality and brain size. Katherine Milton (1999) studied the composition and kinetics of the guts of humans and other great apes and believes the human gut has evolved to handle a high quality diet including significant quantities of meat. Finch and Stanford (2004) have

looked into possible genetic adaptations that humans may have that allow for a longer lifespan despite health problems related to diets high in animal source foods. It has also been argued that humans share some things in common with carnivores in terms of the limitations on synthesizing certain chemicals which are made up for through diet (Cordain et al. 2001; Milton 1999).The costs of brain growth in during childhood and infancy are more exaggerated than during adulthood .The same arguments for diet quality and energetic tradeoffs may be even more crucial when considering their role during the ages at which the brain is still rapidly growing and may use 60-80% of the body's RMR (Bogin 2001).

Hunter-Gatherer Diet Composition. Even though humans have the gut morphology for a higher quality diet that could include meat that does not necessarily mean increased meat eating occurred during human evolution. In pursuit of learning more about this issue anthropologists have examined the diets of hunter-gatherers. The idea is that hunter gatherer diets are relevant to projecting into the past. If hunter-gatherers have diets substantially composed of animal foods and this is common to many or all known about hunter gatherer groups then this may be used as evidence that such a diet is part of a trend in evolution of diets containing foods like meat.

In an effort to understand the diets of hunter gatherers Brand-Miller et al. (2009) used data on 229 hunter gatherer societies from Gray's (1999) corrected ethnographic atlas data to reconstruct the portion of diet composed of meat. It was found that on average the calories from animal foods made up 68% of all calories consumed and that plant foods on average made up 32% (Brand-Miller et al. 2009). This supports the notion that meat consumption is not simply the result of a modern western lifestyle choice or the

result of animal domestication (Brand-Miller et al. 2009). Kaplan et al. (2000) found similar results when investigating hunter gather diets with an average of over half of daily calories coming from animal foods with a range of 30% to 80%. These figures were compared to chimpanzee diets by Kaplan and colleagues (2000).

> Chimpanzee per capita meat intake is estimated at about ten to 40 g per day, while human meat intake ranges from about 270 to 1,400 g per person per day [Kaplan et al. 2000: 167]

The composition of hunter gatherer diets compared to diets of chimpanzees can be used to argue that the evolution of hominids from a chimp-like ancestor to a modern humans entailed increasing rates of meat consumption over a period of several million years.

Expensive Tissues

Brain tissue is very costly. Two problems that face animals with large brains have to do with the fact that the brain requires large quantities of energy to maintain in addition to the fact that brain tissue is sensitive and cannot survive without a constant supply of energy (Peters et al. 2004).

Aiello and Wheeler (1995) have argued that an energetic tradeoff occurred during human evolution where the allocation of energy and nutrients to the gut was reduced and this allowed for increased allocation to the brain. The costs of the human brain are high in terms of both energy and the nutrients it requires. Humans spend around 20-25% of their RMR on the brain (Leonard et al. 2007b). Other non-primate mammals spend around 3-5% of their RMR on their brains (Leonard and Robertson 1994). Non-human primates are in-between these two figures with approximately eight to ten percent of RMR spent on brain tissue (Leonard and Robertson 1994). In contrast to the amount of RMR that is

allocated to the brain humans have splanchnic organs (guts) that are only 60% of what would be predicted for a primate our size (Aiello and Wheeler 1995). These aspects of human body composition coincide with a total amount of daily energy consumption that is expected for a primate of our size (Aiello and Wheeler 1995). Extracting this amount of energy from food with a smaller than predicted gut size can be made possible with a sufficiently high quality diet. This is because high quality foods are easier to digest and contain higher concentrations of energy and nutrients than low quality foods (Kaplan et al. 2000).

The gut may not be the only tissue implicated in energetic tradeoffs that occurred during human evolution. Leonard et al. (2003) and Kuzawa (1998) have argued that another energetic tradeoff in humans involves fat and muscle. Humans have reduced levels of muscle and larger percentages of body fat than would be expected of a primate our size (Leonard et al. 2003; Kuzawa 1998). Muscle costs significantly more than fat and fat is a useful medium of energy storage (Kuzawa 1998). A reduction in the amount of muscle mass could be thought of as part of an energetic tradeoff for a large brain similar to a reduction in gut size (Leonard et al. 2003). The increased body fat proportions in humans compared to other primates could be an adaptation to provide a dependable supply of energy during times of resource scarcity at a low cost (Leonard et al. 2003).

Diet Quality and Complexity

A dietary quality (DQ) index developed by Sailer et al. (1985) was used by Leonard et al. (2007) to construct a table that rates the diet quality of numerous primates. A DQ index of 100 means a diet composed of materials equivalent to leaves while a diet

composed of all animal material rates a 350 (Leonard et al. 2007a). Humans Hunter-gatherers were rated at 263 on this scale which is a great deal higher than expected for a primate of our size. For comparison the DQ of orangutans (*Pongo* pygmaeus) which are similar in body size to humans is only 172.5. In general the comparison across all sizes of primates indicates a trend that increased body size is associated with decreased dietary quality, excepting humans of course (Leonard et al. 2007[a]). The energetic costs of the brain itself also appear linked to diet quality (Leonard et al. 2007[a]). A larger relative brain size is associated with a higher DQ index (Leonard et al. 2007a). Among all primates humans have the largest brains relative to body size in addition to the highest DQ index for all apes (Leonard et al. 2007a).

Aside from diet quality, another factor linked with brain size in primates is foraging complexity (Gurven et al. 2006). Complex foraging strategies may require larger brains for memory, skill learning, and other cognitive capacities that would improve success in acquiring a variety of foods (Kaplan et al. 2000). One of the most difficult skills among complex foraging strategies is acquiring animal source foods (Gurven et al. 2006). Hunting may be the most skill intensive of all foraging activities (Kaplan et al. 2000). The cognitive abilities associated with hunting may have been at least partially the result of selective pressures relating to solving ecological problems (Liebenberg 1990). Such cognitive abilities could have allowed for increased dietary complexity with improved dietary quality serving as the benefit to pay the costs associated with growing large expensive brains where these cognitive abilities reside.

Gut Kinetics and Morphology

What can we tell about the diet of humans based on gut morphology? How is this relevant to the evolution of our species from a chimp-like ape ancestor? Katherine Milton (1999) argues:

> That the pattern of gut anatomy and digestive kinetics characteristic of ancestral Hominoidea imposed certain constraints on their descendants in terms of diet. Meat-eating in the human lineage (Homo spp.) appears to be one way of circumventing these constraints [Milton 1999:11]

The argument involves comparing the diets and guts of various animals (Milton 1999). In herbivores increasing size is usually correlated with reduced quality in diet (Milton 1999). Gorillas and orangutans follow this pattern of increasing size and reduced diet quality (Milton 1999). One effect of this reduction in diet quality for these species is a reduction in sociality (Milton 1999). The reason behind this according to Milton (2003) is that evolution of increased size and lower quality diets does not allow the extra energy necessary to maintain additional cognitive complexity. Chimpanzees contrast with gorillas and orangutans in that they are smaller and have higher quality diets in that they consume a large amount of fruit and even a small amount of animals source foods (Milton 2003). Humans are then argued to be representative of a dietary strategy that went in the opposite direction of gorillas. In other words, the line that evolved into humans increased body size while simultaneously increasing diet quality. This allow these animals to not only pay for the additional cost of larger bodies but also to pay for the costs associated with more complex cognitive capabilities which appear to be linked to brain size to a degree.

Milton (1999) came to the conclusions above by studying the guts of various primate species as well as those of carnivores. While other apes tend to have the greatest amount (about 45% or more) of their guts composed of the colon humans do not (Milton 2003). The largest portion of the human gut exists as the small intestine (about 56%). In humans the colon makes up around 17-23% of the gut (Milton 2003). Small intestines are useful for digesting high quality foods while colons are useful for digesting lower quality foods (Milton 1999). Chimpanzees, for example, follow the general ape pattern for colon size (Milton 1999). The food that passes through a chimpanzees gut will spend a longer period of time in the colon than the same food would spend in a human colon (Milton 1999). Milton (1999) also points out that the rates at which food passes through primate guts is apparently highly conserved. This means food is not passed through some ape's guts dramatically faster than other species of apes (Milton 2003). There seems to have been selections pressures on our ancestors to increase the size of the small intestine and this is an indication of increased dietary quality in the past (Milton 2003).

Genes and Meat Eating

Finch and Stanford (2004) have gathered available information concerning genetic adaptations human may have that allows them to deal with negative effects associated with diets high in animal source foods.

A shift in diet of our evolutionary line toward increased meat consumption during the last several million years is expected to have increased the prevalence of diseases associated with meat consumption (Finch and Stanford 2004). This dietary shift occurred during the same period of time that life-spans increased and so it is expected that adaptations would have been selected for to compensate for the negative effects of a diet

with increasing quantities of animal source foods (Finch and Stanford 2004). The rates of diseases associated with meat can be compared with the rates found among chimpanzees with diets that contain a substantially higher proportion of plant foods (Finch and Stanford 2004). Finch and Stanford focus on mammalian meat for the reason that the evidence of other types of meat is very limited before approximately 200,000 years ago (Stiner et al. 2000). Evidence for the consumption of fish as a major dietary staple is not prevalent until approximately 20,000 years ago (Cordain et al. 2002).

One gene considered specifically is Apoe3 which has been linked to reduction in risk for Alzheimer's disease and vascular disease (Mahley and Rall 2000). The risk of these diseases increases with frequent consumption of meat. Approximately 65-85% of all humans have apoE3 and it is the most prevalent of the apoE alleles (Corbo and Scacchir 1999). The time range for when this gene spread was approximately 0.311-0.226 mya (Fullerton et al. 2000).

A number of diseases might also be considered in future work based on relating genes and diet. Such dieseases include prions, vibrio bacteria, ebola virus, HIV, and tapeworms (Finch and Stanford 2004). Tapeworms were the subject of a genomic analysis and were found to have infectious cycles specific to human hosts beginning around 0.8-1.7 mya (Hoberg 2002). This allows for at least two points to be made concerning diet. First the genomic analysis of tapeworms lends strong evidence that hominids were consuming significant quantities of meat at least as far back as approximately one mya (Hoberg 2002). Secondly, this genomic analysis offer evidence that while we may not currently know if the human genome was altered in our relationship with tapeworms it does seem to be the case that tapeworm genomes have

changed in their relationship with hominids. Given the evidence summarized by Finch and Stanford on the subject it may be fruitful to consider other possible genetic changes that are related to a diet of increased meat consumption during human evolution.

Humans and Carnivores

Humans actually have a number of dietary adaptations in common with carnivores (Cordain 2006). Though human guts are distinctly apelike the increased gut volume devoted to the small intestine is a pattern that is reminiscent of carnivore guts (Milton 1999). Carnivores eat only animal source foods to obtain all of their nutritional requirements and so their guts are adapted to digest these types of foods (Cordain et al. 2002). Pure carnivores (*Feloidea*, for example) of any size all have these same gut features (Cordain et al. 2002). This is an important point because it lends evidence to the notion that carnivores do not need to change their dietary habits in relation to their body size (Milton 1999). This is unlike what is seen in herbivores with increased size associated with deterioration in diet quality (Milton 1999). The amounts of energy and nutrients reaped from high quality animal source foods allow carnivores to maintain the same gut structure from lions down to housecats Cordain et al. 2002). When other non-carnivore animals are fed high protein diets a number of problems may result (Cordain et al. 2002). Processing a diet with a large amount of protein, especially without significant quantities of fat present may cause rabbit starvation with symptoms like diarrhea, hyperammonemia, nausea, and/or hyperaminoacidemia (Bilsborough 2006). This can result in a number of complications which can cause death (Cordain et al. 2002).

Humans are not carnivores but the incorporation of significant amounts of animal sources foods would have allowed for a solution to an energetic problem of diet quality,

body size, and brain power. Many of the nutrient requirements of hominids could have been met through increasing reliance on animal source foods (Milton 1999). This would also have allowed for a change in strategy regarding plant foods. Some foods, like potatoes, are energy rich but nutrient poor (Milton 1999). Consuming nutrient rich animal foods would allow for increased consumption of energy rich but nutrient poor plant foods (Milton 1999).

Another feature of carnivores is their inability to synthesize vitamin A and niacin along with a for need substantial amounts of taurine in their diets (Cordain et al. 2002; Knopf et al. 1978; MacDonald et al. 1984; Markwell and Earle 1995).Without taurine in their diets felines begin to lose their hair teeth and claws. Humans are also limited in their ability to produce taurine (Chesney et al. 1998; Cordain et al. 2002; Sturman et al. 1975). Cordain et al. (2002) argues that reductions in the human ability to produce taurine may be the result of a relaxation of selection pressure for its production as a result of increased animal source food consumption during human evolution. The limited ability to produce taurine may only be one example of a compound that humans produce which may be supplied through diet.

Cordain et al. (2001) argue that a shift towards a high quality diet would have allowed for the evolution of larger brains. The nutrients and chemicals in animal source foods are important to the growth and maintenance of a large brain. One example of this relationship is found in the polyunsaturated fatty acids (PUFAs) that are used in constructing brain tissues and may only be produced in limited quantities by organs such as the liver (Carlson and Kingston 2007). In all mammals the composition of brain tissue is similar with regard to concentrations of PUFAs, specifically arachidonic acid (AA) and

docosahexaenoic acid (DHA) (Cordain et al. 2001). In species with larger brains the percentage of AA and DHA is the same but the total pool of these acids must be larger (Cordain et al. 2001). Limitations on the quantities of these PUFAs that the body can produce would limit the size that a brain could grow (Cordain et al. 2001). The limited ability of the body to synthesize AA and DHA therefore poses a problem to a species under selection pressure to grow a larger brain. Cordain et al. (2001) argue that such a problem may be solved through a diet that contains substantial amounts of animal source foods which are known to contain these chemicals.

> Without the inclusion of energetically dense animal foods laden with AA and DHA, into the diets of our early hominid ancestors it is unlikely that increased encephalization would have occurred. [Cordain et al. 2001:149]

Children and Diet

The gut may not be the only tissue implicated in energetic tradeoffs concerning brain size that occurred during human evolution. Leonard et al. (2003) and Kuzawa (1998) have argued that another energetic tradeoff in humans involves fat and muscle. Humans have reduced levels of muscle and larger percentages of body fat than would be expected of a primate our size. Muscle costs significantly more than fat and fat is a useful medium of energy storage. A reduction in the amount of muscle mass could be thought of as part of an energetic tradeoff for a large brain similar to a reduction in gut size (Leonard et al. 2007[b]).The increased body fat proportions in humans compared to other primates could be an adaptation to provide a dependable supply of energy during times of resource scarcity at a low cost. This dependable energy supply may be more important for brain growth during infancy and childhood.

The dietary needs of children are also an important consideration in the evolution of humans. Infants require very high quality diets. Infants and children have even larger brains in relation to body size than adults. This presents a significant nutritional problem for offspring in our species. Nutritionally and energetically dense weaning foods such as animal source foods are argued to be something of a necessity for early humans according to Milton (1999). The protein content containing essential amino acids of an infant's diet needs to be more than twice as high as that of an adults (Milton 1999). The amount of growth of the brain during infancy and childhood would also require increased use of PUFAs like DA and AA as explained by Cordain et al. (2001) as critical building material in brain tissue.

Creatine

Multiple lines of evidence argue in favor of the idea that meat was consumed as a substantial portion of the diet during human evolution. In previous sections it has been argued that hunting and diet have played a role in human evolution. One nutrient in meat that has been little considered by anthropologists thus far (Babbit et al. 2010; Pfefferle et al. 2011) is creatine. This section will offer an examination of creatine and how it may be one more piece of the puzzle relating to brain function, human cognition and diet.

Creatine Overview -Creatine is a compound that plays a primary role in cellular energy homeostasis (Persky et al. 2003). It can be produced inside the body or consumed through dietary sources such as meat (Persky et al. 2003). Endogenous production of creatine occurs mainly in the liver and the majority of the body's stores of creatine can be found in skeletal muscle (95%) but a significant amount is also used in brain tissue and to a lesser degree the eyes, kidneys, and testes (Persky et al. 2003). While creatine serves a

number of functions (Wallimann et al. 2011) one of its primary roles is in energy maintenance during rapid shifts in consumption of adenosine triphosphate (ATP). ATP acts as the primary means by which chemical energy is transferred within cells. In other words ATP acts as the currency for energetic transactions that occur in a cell (Brosnan and Brosnan 2007; Peters et al. 2004). ATP gets used up in cells when a phosphate is broken off of it (becoming adenosine diphosphate or ADP) and the energy from the bond is used to catalyze other reactions (Brosnan and Brosnan 2007; Persky et al. 2003). One way to re-attach a phosphate to ADP to form ATP is through the phosphagen known as phosphocreatine. The phosphocreatine circuit allows cells to maintain energy homeostasis during times of sudden increased energy demand by quickly replenishing ATP (Brosnan and Brosnan 2007). Phosphocreatine used in this process can then undergo a reaction with the enzyme creatine kinase inside the mitochondria to attach a phosphate. In addition to its role in replenishing ATP there are a variety of pleiotropic effects which are also relevant to the topic of evolution which will be described later on.

Dietary consumption of creatine has offer substantial evidence in elevating the body's levels of creatine (Syrotuik and Bell 2004). About 5g of creatine can be found in about 1kg of meat, alternatively creatine can be purchased and consumed as a supplement in form of a tasteless powder (Persky et al. 2003). A few grams of dietary creatine intake per day will allow a person to maintain elevated muscle creatine levels (Owen and Sunram-Lea 2011). Excess creatine is excreted through urine (Brosnan and Brosnan 2007). It is possible to maintain elevated creatine levels by consuming a diet high in meat (Owen and Sunram-Lea 2011). This information is also useful in understanding why vegetarians are the preferred subjects in creatine supplement studies (Syrotuik and Bell

2004). Vegetarians have very little dietary intake of creatine and so supplementation in vegetarians is more likely to be a reliable indicator of the effects of creatine (Owen and Sunram-Lea 2011; Syrotuik and Bell 2004; Brosnan and Brosnan 2007).

As a supplement creatine has been given good evidence in affecting muscle tissue so as to improve athletic performance and hundreds of studies have been conducted on it in this regard (Becque et al. 2000; Bemben and Lamont 2005; Candow and Chilibeck 2008; Glaister et al. 2006; Kreider 2003). More recent research has been conducted on creatine indicating that it is surprisingly critical in brain function (Du et al. 2008).

There are a variety of creatine deficiency diseases pertaining to dysfunctional genes in the phosphocreatine circuit (Braissant et al. 2011; Schulze 2003, Salomons et al. 2010). Symptoms include mental retardation, delayed speech development, autism, and others (Braissant et al. 2011; Nasrallah et al. 2010). Possible reasons for this may have to do with the fact that brain tissue is especially sensitive to energy fluctuations since it is poor at storing energy (Hitze et al. 2010; Peters et al. 2004). Creatine allows the brain a buffering mechanism where immediate increases in energy needs can be met while other slower chemical processes can be brought online to supply larger amounts of chemical energy (ATP) (Brosnan and Brosnan 2007).

There are a small but growing number of studies that have tested for improvements in cognitive performance and healing of brain tissue (Rae et al. 2003, McMorris et al. 2006, McMorriss et al. 2007a, McMorriss et al. 2007b). These studies are important since they provide evidence for the possible use of creatine in relation to brain health and treating diseases specific to creatine deficiency syndrome as well as other diseases like Parkinson's and Huntington's disease (Schulze 2003, Braissant et al. 2011, Lin et al.

2011). Anyone concerned with brain health and performance in general may want to take note of the effects of creatine and its use as a dietary supplement. Although a significant amount of research is still needed to find out the circumstances under which creatine is particularly beneficial.

This information becomes important when considering the possibility that humans may have been under selective pressure to take advantage of extra creatine in their diet (Pfefferle et al. 2011).There are specific genes that exist as part of what is called the phosphocreatine circuit (Brosnan and Brosnan 2007). Some of these genes are active in muscle tissue and others are active in brain tissue (Pfefferle 2011).

Limited Summary of Creatine's Effects on Brain Tissue and Function -Though few in number, some examples of research can be used to illustrate the potential importance of studying the effects of creatine on brain function. Sullivan et al. found creatine had a 36% ameliorating effect in mice and 50% ameliorating effect in rats who had severe brain damage inflicted on them with hammers (2000). McMorris and colleagues (2006) found that creatine prevented cognitive performance loss after 24 and 36 hours of sleep deprivation (McMorris et al. 2006, McMorris et al. 2007a). Rae et al. (2003) found creatine supplementation significantly improved the intelligence test scores on Raven's progressive matrices. Benton and Donohoe (2011) have found evidence that creatine supplementation improves memory during word recall tests. Watanabe et al. conducted a study where subjects continuously conducted simple mathematical calculations and creatine supplementation offered evidence that it significantly improved scores (2002). Creatine supplementation on the elderly also yielded results that indicated improved memory function (McMorriss et al. 2007b) Protects newborn rat brains against Hypoxia

and traumatic brain injury (Adcock et al. 2002) protects against traumatic brain injury in mice and rats (Sullivan et al. 2000) and in children and adolescents (Sakellaris et al. 2006)

There are also a number of other positive effects of creatine on other systems of the body that may be mentioned although the focus of this work is limited to the brain and cognitive performance. Creatine has been implicated in increasing the lifespan when supplemented for long periods of time in mice (Bender et al. 2008a). Creatine may also be implicated in a variety of other functions such as increasing water storage and improving thermoregulation in the brain and body, and reducing muscle soreness (Hadjicharalambous et al. 2010). Such effects would relevant to organisms that are put under the strain of a hunting style involving endurance running and the use of intellect to track prey (Liebenberg 2006, Lieberman and Bramble 2007). Creatine studies have offered evidence to lessen noise induced hearing loss (Minami et al. 2007). Other studies offer evidence that creatine stimulates collagen type I bone synthesis (Gerber et al. 2008) and is important in bone metabolism (Choi et al. 2008). Cr "may prevent or delay onset of health problems such as type-2 diabetes, obesity and metabolic syndrome" (Gualano et al. 2008) also may prevent osteoporosis in postmenopausal women (Gerber et al. 2008; Gerber et al. 2005). Wallimann et al. (2011) has also recommended that creatine should be considered in increasing supplementing premature infants and children above levels found in dietary substances like infant formula, milk, and meat due to its plethora of positive effects and long history of safe use.

As creatine is important to cell function genetic disorders related to problems with producing or using creatine are linked to a host of negative effects such as mental and

physical retardation such as language impairment, microcephaly and seizures (Anselm et al. 2006; Pfefferle et al. 2011; Schiaffino et al. 2005). Three creatine deficiency disorders linked to specific genes are caused by problems with creatine synthesis (AGAT and GMAT) or creatine transport (SLC6A8) (Beal et al. 2011; Schulze 2003). Of these disorders creatine synthesis problems may be treated to a degree with creatine supplementation (Beal et al. 2011). Creatine supplementation may also be important in treating other neurodegenerative dieseases like Huntington's disease or Parkinson's disease (Beal et al. 2011; Lin et al. 2011).

Studies such as those mentioned above raise questions about why creatine has these effects and what role creatine should play in the human diet today and what role it may have played in the diets of our ancestors.

Brain energy Homeostasis. The brain itself is very sensitive to energy deprivation in addition to being energetically expensive (Hitze et al. 2010). Brain energy homeostasis would have been a continuous problem during the evolution of larger brains (Leonard et al. 2007[b]). According to Babbit et al. (2011:965) "the human brain may be operating at the edge of its metabolic capabilities". Creatine may be an important part of what allows human brains to be maintained at this edge (Babbit et al. 2011; Pfefferle et al. 2011; Walliman et al. 2011).

The Phosphocreatine Circuit . The idea that creatine is implicated in selection for larger brains has been lent evidence by comparison of phosphocreatine circuit gene expression in humans, chimpanzees, and rhesus macaques (Pfefferle et al. 2011). This study examined five genes in the phosphocreatine circuit two of which are found only in brain tissue while the other three are expressed only in muscle tissue in humans,

chimpanzees, and rhesus macaques. The two genes expressed in brain tissue are SLC68A and CKB. SLC68A is known to code for a protein that facilitates creatine to be transportation into a cell. CKB has the function of encoding a kinase that is involved in the use of phosphocreatine to produce ATP from ADP which is important for maintaining brain energy homeostasis. Both SLC68A and CKB were found to be expressed at roughly twice the levels in humans compared to chimpanzees and also rhesus macaques.

The greatly higher levels of phosphocreatine circuit gene expression in genes specifically expressed in brain tissue in humans may be a requirement of our larger brains. The phosphocreatine circuit is able to quickly buffer against energy fluctuations in the brain. The inability of brain tissue to store energy (Peters et al. 2004) makes the phosphocreatine circuit critical for brain function. Pfefferle et al. (2011) argue that increased creatine availability from dietary sources like meat would allow the brain to transport and use additional creatine. It has been found in other studies that creatine supplementation increases brain creatine concentrations (Dechent et al. 1999; Pan 2007). These findings are interpreted by Pfefferle et al. (2011) to mean that there may have been selection pressure to increase phosphocreaetine circuit gene expression coinciding with encephalization during human evolution. It is also possible that dietary creatine intake through meat consumption is relevant to encephalization during human evolution since additional creatine could be taken advantage of by the brain through transportation and production of ATP (Pfefferle et al. 2011). This may the effect of paying some of the energetic costs of maintaining a large brain (Pfefferle et al. 2011) in addition to the numerous other benefits to the brain and body discussed in this section.

Apoe4 and Alzheimer's Disease. In discussing genes that may be related to selection related to increased longevity alongside increased meat consumption Finch and Stanford (2004) use the apolipoprotein E (ApoE) alleles as examples. In particular they describe ApoE3 as an allele that may have been selected for because of its associated with decreasing the chances of neurodegenerative diseases like Alzheimer's disease (AD) (Finch and Stanford 2004). ApoE4 is a gene which is primarily associated with increased risk of AD and it is thought that it is also linked to a diet containing large amounts of meat (Finch and Stanford 2004). A study using magnetic resonance spectroscopy on elderly patients examined subjects who carried the ApoE4 alelle and others who did not (Laakso et al. 2003). It was discovered that the ApoE4 carriers showed significantly reduced brain creatine concentrations (Laakso et al. 2003). The link between the two also showed up when the carriers of ApoE4 were given cognitive performance tests on which scores were significantly correlated to age and brain creatine concentrations (Laakso et al. 2003). Measuring brain creatine concentrations may be one method of diagnosis for early AD (Laasko et al. 2003).

Early AD seems to be implicated in increased widespread activation of brain tissue when compared with control subjects (Laakso et al. 2003). The increased activation is connected to elevated metabolic demands (Laakso et al. 2003). Such demands would seem to be using up creatine at a faster rate which results in reduced brain creatine levels (Laakso et al. 2003). This may then be indicative of degeneration for individuals with the apoe4 allele and seems relevant to arguments concerning longevity made by Finch and Stanford (2004). It seems possible that the ApoE4 alelle may have been selected against and ApoE3 selected for, over approximately the last 0.3 mya (Finch and Stanford 2004).

The implication is that creatine's role in brain function may be linked to genetic adaptations for meat consumption and longevity and possibly other effects as well.

Creatine from Dietary Sources

If dietary creatine played a role in human brain evolution then it may be useful to know how much could have been ingested and how this amount could affect humans and their ancestors. Although there is variation in the amount of creatine in meat depending upon the species the number is roughly five grams per kilogram of vertebrate meat (Harris 1997). Using this figure it is possible to roughly estimate how much dietary creatine is ingested by hunter gatherer groups based on dietary figures from Cordain et al. (2001) and Kaplan et al. (2000).

Cordain et al. (2000) used data from the Ethnographic atlas originally compiled by Murdock (1967) and revised by Gray (1999) to investigate meat intake of the majority hunter gatherer groups that are known to history. Of the known 229 hunter gatherer groups 73% of had greater than 50% of their diets composed of animal foods (Cordain et al. 2000). Only 14% of these hunter gatherer groups had less than 50% of their diets composed of animal foods (Cordain et al. 2000). The median level consumption of animal source foods for subsistence was 65% with the remaining 35% comprised of plant foods (Cordain et al. 2000). Cordain et al. (2000) does not list an average for the caloric intake or mass amounts for animal foods in hunter-gatherer diets however Kaplan et al. (2000) lists both albeit from a much smaller selection of hunter-gatherer groups around ten depending upon how the groups of !Kung San are broken up. The groups examined by Kaplan based on data from a variety of sources also lead to the conclusion that hunter gatherers consume more than 50% of their daily energy intake as animal source foods.

Depending upon the group under review, the average daily meat consumption was figured at 270 to 1400 grams per individual per day. These figures from both Kaplan et al. (2000) and Cordain et al. (2000) lend evidence to substantial consumption of meat on a daily basis by hunter gatherers.

If vertebrate meat is estimated to contain approximately five grams of creatine per kilogram of meat (Harris 1997) then creatine composes 0.5% of the total mass of a quantity of meat. Figuring this into range of meat consumed daily at 270-1400 grams by hunter gatherers (Kaplan et al. 2000) this would mean that between 1.35-7 grams of creatine are consumed in a day by hunter gatherers. The average of these two figures puts the daily creatine intake at 4.175 grams per person per day. These figures do not seem to be abnormal when compared to current European or American meat consumption habits. The average daily intake of an individual in Switzerland 150 g meat per day which translates as 0.75 grams of creatine per day (Anton et al. 2004). The average meat consumption levels of a United States citizen ranges from 250-300 grams of meat per day which translates as approximately 1.5 grams of dietary creatine per day (Anton et al. 2004). In fact these figures are explained by Wallimann et al. 2011 to be at the lower end of the 2-4 grams per day that may be recommended in the near future by the European Food Safety Authority. The average figure of approximately four grams per day is strikingly similar to the amount recommended by kinesiologists to achieve maximal serum creatine levels (Bemben and Lamont 2005; Harris 2002; Hultman et al. 1996).

It has been calculated by Hultman et al. (1996) that creatine intake of 2-3 grams per day is sufficient to elevate creatine muscle concentrations. Even the lowest figure for creatine intake by hunter gatherers at 1.35 grams per day would be expected to elevate

serum creatine levels significantly although perhaps not to the point of complete saturation. Even so it would appear that with as little as 2-3 grams of dietary creatine taken in each day a person can maximize serum levels (Febbraio et al. 1995; Hultman et al. 1996; Persky et al. 2003; Snow and Murphy 2003). These figures can be interpreted in light of the literature concerning the effects of dietary/supplementary intake of creatine reviewed in this section. Supplementing with creatine has repeatedly been found to increase muscle creatine concentrations by 30% (Harris et al. 2002; Harris et al. 1992; Hultman et al. 1996) and brain creatine concentrations by 8-9% using quantitative localized proton magnetic resonance spectroscopy (Dechent et al. 1999). The body's ability to store creatine appears to be limited and creatine taken into the body in excess of this storage capacity is urinated out (Hultman et al. 1996; Snow and Murphy 2003). Percentage intake in diet is important but only meaningful when there is some way to measure the amount of daily energy intake.

It would appear based on this limited assessment of the dietary intake of meat by hunter gatherers that creatine levels roughly match levels that are desirable in supplementation to achieve the benefits of creatine levels above endogenously produced levels. Further, there is evidence that a vegetarian or vegan diet may be lacking in creatine as it pertains to both individual health and in relation to its concentrations in breast milk.

The Meat Connection - PUFAs, Taurine, Creatine

Aside from calculating the percentage of hunter-gatherer subsistence composed of animal source foods Cordain et al. (2000) has made arguments concerning the role of polyunsaturated fatty acids (PUFAs) in this diet. The two PUFAs Cordain and colleagues

focus on are docosahexaenoic acid (DHA) and arachidonic acid (AA) (2000). The argument is that a diet containing substantial quantities of vertebrate meat supplies either these PUFAs or their precursors which are critical in the growth of brain tissue and hence relevant to encephalization (Cordain et al. 2002). While the human body can manufacture limited quantities of DHA and AA, Cordain et al. (2002) argue these endogenously produced levels are lower than what is desirable for brain growth and maintenance. During human evolution, dietary intake of AA and DHA through meat consumption is argued to have relaxed constraints on selection for the growth of larger brains. Brain tissue in all mammals contain the same percentage of DHA and AA per unit mass and this means that larger brains require larger quantities of DHA and AA (Cordain et al. 2001). A brain could not be grown without dietary or endogenously produced sources of DHA and AA to match these requirements (Cordain et al. 2001).

A similar argument can be made for taurine as previously mentioned as it is also produced endogenously by humans but only in limited quantities (Chesney et al. 1998). Carnivores in comparison to humans cannot endogenously produce taurine and rely on meat consumption to provide enough taurine to maintain health (Knopf et al. 1978; MacDonald et al. 1984). Taurine is not a trivial substance as it composes approximately 0.1% the human body (Huxtable 1992). Similar to the argument behind the dietary consumption of PUFAs an argument can be made that perhaps humans do not need to endogenously produce entirely adequate amounts of taurine because they are able to get it through meat consumption (Cordain et al. 2002; Milton 1999).

An argument for dietary creatine intake as critical to brain evolution in hominids is similar to arguments presented by Cordain et al. (2002) for taurine and PUFAs. The

body of an average sized 70 kg human will contain a pool of approximately 120 grams of creatine stored in muscle tissue with a loss of about two grams per day that may be replenished through endogenous production and dietary intake (Brosnan and Brosnan 2007). The amount of creatine lost per day as creatinine in urine is at least 30% lower in vegetarians and this has been interpreted as evidence that endogenously produced creatine levels cannot entirely make up for a lack of dietary creatine (Delanghe et al. 1989). The human body is able to produce creatine (Brosnan and Brosnan 2007) just as it is able to produce PUFAs like DHA and AA (Carlson and Kingston 2007), however this does not preclude exogenous intake of PUFAs or creatine as an important component of diet. Anthropologists investigating the role of meat consumption during human evolution have consistently pointed to the benefits of including meat in the diet as a means of providing vitamins, nutrients, and other important chemicals relevant to health and the costs associated with our species large brains in particular (Leonard et al. 2003; Milton 1999; Stanford et al. 1996). Creatine may be one more example of a compound found in meat that reinforces the evidence in favor of the idea that increasing meat consumption played a critical role in human brain evolution.

Creatine and Babies. Creatine, like PUFAs, are important dietary components of adults and they may be even more important for children and infants. Creatine is critical to fetal and infant brain development and so it may not be all that surprising that it is also a component of breast milk (Wyss and Schulze 2002). Pregnant women and new mothers provide either all or a significant quantity of the total creatine used by fetuses and infants and diets containing creatine are believed to be important to the health of all three groups (Schulze 2003; Wallimann et al. 2011). Before modern chemistry the only way to

increase dietary creatine intake would have been through increased consumption of either meat or milk. If meat played a critical role in human brain evolution by providing the nutrients that allowed selection to favor increased brain size then provisioning women and babies with meat products may be considered of special importance.

It has previously been mentioned that a number of anthropologists have found nutritional requirements of infants to be particularly important (Bogin 2001; Leonard et al. 2007b). One reason for this is that Infants have the highest portion of their RMR going to grow and maintain the brains and brain tissue is not only sensitive to energy deprecation but it is also energetically and nutritionally expensive (Peters et al. 2004). A number of studies on mice and rats are relevant to creatine's role in brain function for infants and fetuses. Both in vivo and in the brains of rat pups creatine has been found to protect against hypoxia which increased the likelihood of survival (Adcock et al. 2002; Ireland et al. 2008). Also relevant are studies that found creatine is beneficial to traumatic brain injuries in both animals and children (Sakellaris et al. 2006; Sullivan et al. 2000). Beneficial effects in the reduction of intra-partum-hypoxia-induced damage to newborn spiny mice have also been observed when the mother is supplemented with creatine (Cannata et al. 2010). Other beneficial effects of creatine on pregnant mothers such as through its role in strengthening the uterus in the last few months of pregnancy (Wallimann and Hemmer 1994). These and other findings have lead Wallimann et al. (2011:1286) to conclude, "it may be legitimate to propose that Cr supplementation should be a standard regimen during pregnancy, as well as after birth, borth for the pregnant and lactating mother, as well as for the baby." This would particularly true of vegan and

vegetarian mothers whose serum creatine levels are significantly below those of omnivores (Wallimann et al. 2011).

In relation to breast milk and cow milk current figures of the creatine content of breast milk may be too low because creatine decays into creatinine over time and when put through pasteurization (Wallimann et al. 2011). The figures for creatine in breast milk are approximately 0.2 ml (Huselman 1987). An infant of approximately four months old drinks about 800 ml of breast milk per day (Huselman 1987). If these figures are translated into adult levels then creatine intake from breast milk would range from 0.3-1.2 grams per day. However, as mentioned this figure is likely too low and an accurate measure could be two or three times as high (Wallimann et al. 2011) putting the figure between 0.6 and 3.6 grams per day. With further research into the subject Wallimann et al. (2011) predicts further evidence will point to supplementation of creatine as reducing a metabolic burden on mothers and infants.

The above information is only brief summary of some of the findings relevant to creatine's role in fetal and infant brain development. The relevance of this body of literature to the subject at hand has to do with the provisioning of group members with animal source foods during human evolution. If creatine and potentially other compounds in meat are so critical to the health of pregnant women, fetal development, and infant brain growth then selection pressures in the past promoting meat sharing behavior and group cooperation can be connected to a shift in diet to higher quality foods.

Creatine and Cognitive Performance

There are a number of studies which have found a relationship between increased dietary creatine intake and benefits to cognitive performance (Benton and Donohoe 2011;

Laakso et al. 2002; McMorriss et al. 2006; McMorriss et al. 2007; Rae et al. 2003;Watanabe et al. 2001). Benefits have been found in a variety of areas including general intelligence, memory, mood, and cognitive fatigue resistance (McMorriss et al. 2006; Rae et al. 2003). These areas of cognitive performance are relevant to the cognitive abilities that Liebenberg (1990) describes as beneficial to tracking. This raises a question as to whether increased meat consumption would improve hunting success through benefits to cognitive performance.

In previous sections of this work the mental and physical costs of hunting have been explained in relation to the art of tracking hypothesis and the running hypothesis. The running hypothesis argues that humans were under selective pressure to be highly capable long distance runners in hot weather which allowed them to increase diet quality by hunting and scavenging (Carrier et al. 1984). The art of tracking hypothesis argues that the cognitive abilities used in tracking by modern hunter gatherers are the same used in sciences like physics (Liebenberg 1990). Additionally, the art of tracking posits that the evolution of these cognitive abilities may have partially occurred under selection pressure to improve hunting success which would then increase diet quality (Liebenberg 1990). It could be that nutrients in animal source foods, such as creatine, played a role in this process by improving cognitive performance relevant in hunting. The evidence for cognitive performance benefits from creatine supplementation can be examined in relation to the argument for the evolution of tracking and scientific thinking.

Rae et al. (2003) conducted a study involving the effects of creatine supplementation on Raven's Advanced Progressive matrices which is a common means of measuring fluid intelligence, and the Wechsler Auditory backward digit span test

(BDS) which is used as a measure of working memory. In the study 45 young adult vegetarian subjects were given five grams of creatine per day for 6 weeks, followed by a 6 week washout period and then another 6-week creatine supplementation period (Rae et al. 2003). At the end of each 6-week period subjects were given a version of the Raven's Advanced Progressive Matrices test. At the end of each creatine supplementation period subjects scored significantly higher than after the 6-week wash out period ($p = 0.0004$). At the end of each 6-week period subjects were also given the BDS for which subjects scored significantly higher at the end of each 6-week creatine supplementation period (Rae et al. 2003).

Both fluid intelligence and working memory are important in scientific thinking as described in a previous section (see Cognitive Abilities Necessary for Science). Benefits to cognitive performance would be expected to benefit individuals engaged in scientific thinking. Liebenberg's (1990) art of tracking hypothesis argues that cognitive abilities used in science are also those used in tracking which has also been described in the previous section mentioned above. It is then to be expected that increased creatine intake from diet would benefit individuals engaged in tracking as well as science at least as far as working memory and fluid intelligence are involved.

Also relevant to tracking and hunting are mood and fatigue (Liebenberg 1990). Fatigue from exercise or from sleep deprivation will reduce cognitive performance (Jennings et al. 2003; Kim et al. 2001; McMorriss et al. 2006). McMorriss et al. (2006) investigated this phenomena in relation to creatine supplementation with the hypothesis that creatine's role in energy buffering would reduce fatigue symptoms on cognitive performance variables such as mood and choice reaction time. Subjects were split into

two groups, where one group supplemented with creatine (n = 10) and the other group was given a placebo (n = 9) (McMorriss et al. 2006). Subjects supplemented with five grams of creatine or placebo for seven days and before the experiment (McMorriss et al. 2006). The experiment involved mild exercise (15 minutes of cycling at 50% of max heart rate) followed by several cognitive tests three intervals of 6, 12, and 24 hours of sleep deprivation (McMorriss et al. 2006). Subjects supplementing with creatine scored significantly higher on mood and choice reaction time compared to subjects given placebo after 24 hours of sleep deprivation (McMorriss et al. 2006). In both groups mood (specifically vigor and fatigue) worsened as time went on but the group supplementing with creatine had a significantly less decline in mood (McMorriss et al. 2006).

McMorriss et al. (2006) believes that the explanation for improved mood has to do with the increased brain activity associated with attempting to overcome increasing stress during cognitive and psychomotor activities while in a sleep deprived state. Creatine supplementation is thought to have buffered against this increased brain activity preventing further mood deterioration (McMorriss et al. 2006). Other research relating creatine to mood has found links between creatine deficiency syndromes and depression (Kato et al. 1992) and schizophrenia (Öngür et al. 2009) both of which improved with creatine supplementation. Sleep deprivation is associated with depression and fatigue and other studies involving creatine supplementation have found beneficial effects on fatigue resistance (Rawson et al. 1999; Rawson and Venezia 2011) and improvements to performance of daily living activities in elderly individuals (Canete et al. 2006).

Mood is an important factor in hunting as it is relevant to motivation and cooperation (Liebenberg 1990). If a hunter does not believe the hunt will end

successfully, then further effort pursing an animal would be a waste in terms of time and energy (Liebenberg 1990). If a hunter is depressed or fatigued and prone to a more negative outlook then this attitude could negatively impact the communication or moral of a group of hunters working together. If creatine does prevent deterioration of mood it may improve a hunter's prospects of success by preventing loss in motivation to continue pursuit.

Conclusion

The benefits supplied by increased dietary creatine intake through supplementation can be expected to be beneficial to individuals consuming meat since meat is the primary source of dietary creatine (Brosnan and Brosnan 2007). These benefits also appear to be related to the activities involved in a variety of areas that are relevant to hunting as described previously. These effects may be expected to be even more important when considering specific types of hunting over others, such as persistence hunting due to the high levels of fatigue that result from this activity. Persistence hunting involves running long distances usually in hot weather while consistently using the mind to identify and interpret information as to the location of an animal (Liebenberg 2006) and it may be that creatine aids in each of these areas. In relation to human evolution, various forms of persistence hunting may extend back hundreds of thousands of years in our species past (Carrier et al. 1984; Liebenberg 2006).

A hypothesis could be made that dietary creatine intake is an example of nutrient that reduces the burden on the brain and other systems in individuals who are able to gain access to it through hunting during the evolution of homo. Further benefits would be supplied by bringing back meat to share with other group members. Pregnant and

lactating women along with infants and children may be the groups most benefited by such a diet. In a sense creatine could be thought of as one type of currency that helps to pay for the cognitive faculties used in hunting. These faculties are used by humans today when they engage in cognitively demanding activities such as scientific thinking. While there are no doubt to be many factors related to the evolution of the human brain a diet comprised of quantities of animal source foods was and still is an important aspect of the this process. Hunting is one of the primary means of acquiring animal source foods and therefore can be expected to have also played an important role in human brain evolution.

Hunting, as perhaps one of the most difficult skills to learn among hunter gatherers may have been benefited by the nutrients and compounds found in object of the hunt, animal source foods. More extensive research into other components of animal source foods may yield additional cognitive benefits as well as other physiological benefits. Creatine is one example of such a compound that appears relevant to diet and human evolution.

CHAPTER 3

METHODS

Research Question

The research question for this project asks: will increased meat consumption provide cognitive performance benefits that aid in energetically costly activities such as persistence hunting?

Subjects

The subjects for this study consisted of 38 healthy adult long distance runners. Mean age, of runners was 38, (SD = 9.3, Range = 39). For the purpose of this study, "long distance runners" were defined as individuals participating in a running event of four kilometers or more. 15 participants were women (39.5%) and 23 were men (60.5%). Ethnic composition of subjects included 36 Caucasians (95%) and two Hispanics (5%). Data was collected at four different races which took place between August 7, 2013 and October 19 2013. These races varied in length from 4.5 km to 50 km. Additional details about races are contained in Table 3.1. Potential participants were approached at long distance running events, and asked to complete a survey and two cognitive performance tasks (one prior to running, and one after running). Participants received no compensation.

Table 3.1 – Descriptives For All Subjects in Sample

Descriptives				
	n = 38	n	% of n	Std. Dev.
Sex	Male	23	60.5	0.495
	Female	15	39.5	0.495
Ethnicity	Caucasian	36	94.7	0.226
	Hispanic	2	5.3	0.226
Age	Mean	Range	Std. Dev.	Min/Max
n = 38	38.6	39	9.3	20-59

Materials

Materials included an informed consent form, survey, and two cognitive performance tests. The survey consisted of general questions, including sex, age, height, and weight, and also several dietary questions focused on meat consumption. All subjects were required to sign informed consent forms before filling out the survey or completing either of the cognitive performance tests. All surveys were completed by subjects before each race and before starting the pre-race cognitive performance test. The cognitive performance tests were modified versions of the Raven's Advanced Progressive Matrices (RAPM), sets I and II (Raven 1965; Raven 2000). The test was reconfigured to allow for the construction of two tests, with the goal of making both tests as equal in difficulty as possible. One version of the test was given to runners immediately prior to the running event and the second version of the test was started within ten minutes of the completion of the long distance run. Tests were not counterbalanced and this procedure was considered unnecessary as counterbalancing through alternating constructed versions of

the RAPM has not been mentioned in methods from other studies utilizing multiple RAPM tests (see Rae et al 2003 in particular).

Survey

The survey for this study was designed to be brief and focus on the level of meat consumption by participants. General questions asked included sex, ethnicity, age, height, weight. Some questions on the survey were related to a separate study conducted by another researcher, so not all survey items are detailed here. Meat consumption was assessed by a two items. The first of these two items asked subjects to write down an average figure for how many meals eaten each day contained meat. The second measure of meat consumption asked subjects to write down the number of meals containing meat that were eaten the day before the race. Other relevant questions asked subjects whether they had consumed protein supplements, creatine, or multivitamins. Creatine affects brain function and exercise performance and could have been an important confound (Bemben and Lamont 2005; Owen and Sunram-Lea 2011). In addition to the specified supplements an "Other" category was also offered. Each option for the supplements list had an empty line next to it so that subjects could write in additional information. In an attempt to control for other possible issues that may have affected the runner's cognitive performance several additional questions were also asked on the survey. These questions included the number of hours the subject slept the night before the running event and the length of time subjects have considered themselves to be long distance runners.

Cognitive Test Construction and Usage

The cognitive performance tests in this study used the items found in Raven's Advanced Progressive Matrices (RAPM) sets I and II (Raven 1965). This test does not

require a formal education or the ability to read in any particular language (Hamel and Schmittmann 2006; Raven 1965;). The Raven's test was chosen specifically due to its capability to measure fluid intelligence by use of matching patterns (Chiesi et al. 2012; Raven 2000). This test is a measure of general intelligence which is likely to correlate with the mental skills involved with tracking prey during a persistence hunt as they are described by Liebenberg (1990). Although fluid intelligence tests have not been given directly to persistence hunters the cognitive abilities used in tracking have been reviewed extensively in the literature review of this thesis. Studies such as this and potentially others in the future may offer further evidence linking such cognitive abilities to activities engaged in by hunter gatherers.

There are 48 items on the original test and each item contains a series of pictures that show patterns (Raven 1965). In each item there is an empty space where one picture is missing and subjects are required to choose an answer that fits in the empty space from a number of pictures in a word bank at the bottom of the page (Raven 1965). As the subject proceeds through the test the patterns become more difficult to discern (Bors et al. 1998; Hamel and Schmittmann 2006). The original test is broken into two sets with the first set (set I) containing 12 items and the second test containing 36 items (Raven 1965). However, the study conducted for this project required the use of two separate tests of equal length and difficulty which required breaking both sets into individual items and then forming two sets of equal length from both. The result was two tests each with 24 items with the goal of having both tests constructed to be as close to each other in difficulty as possible.

Each item in Set II can be rated by a measure of difficulty from the statistics provided in the RAPM manual (Rae et al. 2003; Raven 1965). With this in mind it is then possible to break the set down into individual units with a difficulty rating. The manual contains a chart which has a percentage pass rate next to each item (Raven 1965). Item one on set II, for instance, has a 98% pass rate which means that almost all individuals who take the test get the correct answer on the first time (Raven 1965). As the item number increases the percentage of individuals who gave the correct answer decreases (Arthur et al. 1999; Raven 1965). Item 33, for example, is rated as having only 24% of individuals that were able to give the correct answer (Raven 1965). This information made it possible to break the 36 item test into three sets of 12 items that were close to each other in difficulty. Breaking Set II into sets of 12 items is not an unusual practice and has been used to construct alternate shortened versions of the RAPM for various reasons (Arthur et al. 1999; Arthur and Day 1994; Bors et al. 1998; Chiesi et al.2012; Hamel and Schmittmann 2006).

A study that involved multiple versions of the RAPM was conducted by Rae et al. 2003. This study involved the use of RAPM tests that were broken down into individual items and reconstituted into tests of equivalent difficulty to suit the needs of the researchers (Rae et al. 2003). This study involved creating multiple tests from the available items based on the "published normative performance data" regarding the items on those tests (Rae et al. 2003:2148).

To make two tests, with 24 items each, it was necessary to also include the 12 items from Set I. For this set to be used it was necessary to review the literature on the usage of Set I and how it compared to the difficulty of set II. Set I has been given as a

short form of the 36 item test and comparing the difficulty of the two yielded results that Set I is a valid short version of the 36 item test (Chiesi et al. 2012). This information was then used to construct four sets of 12 items each which were approximately equal in difficulty. The difficulty levels of the tests were as close to each other as possible. The two tests that were constructed from the four sets of 12 involved shuffling two sets of 12 together to form each test. Items on each test were not mixed together randomly, rather they were placed in order of difficulty. In other words the first two items on each test were the least difficult items from the two sets that composed that test. Items three and four on each test were the second least difficult items from the two sets that composed that test and so on until reaching the final two items which were the most difficult. The result yielded two tests, each with 24 items that progressed in difficulty from easiest to most difficult.

Another factor that was important in the construction of cognitive performance tests from the RAPM (Raven 1965) was the issue of time limits (Bilker et al. 2012; Hamel and Schmittmann 2006). The first set (Set I) of the RAPM (Raven 1965) can be used as a standalone test given with a ten minute time limit as a valid measure of the longer 36 item test (Chiesi et al. 2012). Set II may be given with a time limit or without one (Hamel and Schmittmann 2006). The difference between giving a time limit for this type of test and not giving a time limit has to do with measuring two types of phenomena. An untimed test is more of a measure of something called fluid intelligence while a timed test is a measure of fluid intelligence combined with mental efficiency (Hamel and Schmittmann 2006). The role of the cognitive test as a proxy measure for cognitive abilities used in tracking make the time limit a more attractive means of measurement.

The reason for this is that persistence hunters are often under time pressure while tracking (Liebenberg 2006).

Preparations

Before collecting data it was necessary to contact race organizers and gain permission to attend events. This was done by searching online for long distance running groups in the area. Emails were sent to these groups explaining the project and asking if the group organizers would care to allow researchers to approach their members and ask if anyone would like to voluntarily participate in the study. The owners of a company called Aravapai Running (2013) gave permission to set up tables at their events and they were also assisted by making announcements before the races so that potential participants were made aware of the study.

Administration

After setting up a table with a sign that read "CSUF Research Study" we waited for subjects to approach the table. Potential volunteers were informed about what the study consisted of and how long it would take to complete. Volunteers were given informed consent forms to sign followed by a short survey that took approximately three minutes to complete. After the initial survey was completed subjects were taken to an area to participate in the first of two cognitive performance tests. Not all subjects volunteered to participate at the same time since some arrived to the event later than others. This meant that in some cases groups of participants were given the ten minute cognitive performance test as a group and in other cases individuals were given the ten minute test alone. To keep track of the time limit for participants digital clock was used to mark down the hours, minutes, and seconds that the test began. One minute before

subjects ran out of time they were given a one minute warning. A similar protocol was used for the second cognitive test. The main difference for the second cognitive performance test was that most participants arrived alone making group testing more rare.

After completion of the first cognitive performance test subjects proceeded to run the race they signed up for. There were multiple races that occurred at all of the events and each of the races was different in length. Table 3.2 contains information about racing events that were visited by researchers including race distance, temperature, humidity, elevation, and location.

Predictions

P1: Meat consumption will be associated with higher cognitive performance test scores on Raven's progressive matrices before and after a long distance run.

P2: Subjects that consumed more meat will have less deterioration in their scores between the pre-race cognitive test and the post-race cognitive test..

Statistics

The data collected from the cognitive tests and survey were entered into a database using SPSS version 20 statistical package from SPSS Inc., Chicago IL, was used for all data analysis.

Table 3.2. Information on Racing Events Where Data Was Collected

Location	Papago Park Tempe AZ	Buffalo Park Flaggstaff AZ	McDowell Mountain Regional Park Fountain Hills AZ	Prescott National Forest Prescott AZ	Cave Creek Regional Park Cave Creek AZ
Race Type/Name	Online Meetup	Flaggstaff Endurance Runs	Javelina Jangover	Man vs. Horse	Cave Creek Thriller
Race Distances	4.5km	80 km, 50 km	7 km 25km, 50km, 75km 100km	19.3 km, 40.2 km, 80.5 km	12 km 19 km, 31, km, 50 km
Elevation	366 m	2133.6-2743.2 m	914.4 m	1524-2316.5 m	609.6-0.932.7 m
Start Time	18:30	6:00	17:00	6:30	7:00
Temperature	38.9 °C	23 °C	36 °C	13 °C	27 °C
Humidity	19%	93%	18%	30%	11%
Date	8/7/2013	9/14/2013	9/21/2013	10/5/2013	10/19/2013
n	10	4	23	0	1

Sources. City of Tempe 2013; Taking Action 2013; Aravapai Running 2013; Maricopa County 2013a; 2013b; Man Against Horse Race 2013; City of Phoenix 2013.

CHAPTER 4

RESULTS

The results for this project are based on two predictions made regarding meat consumption and cognitive performance in relation to long distance running. Variables focused on for analysis included two means of measuring cognitive performance as the dependent variables. Combined scores of cognitive tests is the product of combining the cognitive test scores from the pre-race and post-race cognitive performance tests. The second measure of cognitive performance involved subtracting the score on subjects' pre-race test from the subjects' post-race test. In most cases this score was a negative number and is meant to measure deterioration in cognitive performance as a result of running in a long distance race. Independent variables considered in the analysis included the sex, race distance and a constructed variable based combining two measures for the number of meals consumed per day containing meat. The meat consumption variable is labeled as combined meat per day in tables and analysis. This variable is the result of averaging two other variables: meals containing meat eaten per day on average and the number of meals eaten yesterday containing meat. Averaging these two measures of meat consumption together was done with the goal of reducing self-reporting errors of subjects to improve the possibility of acquiring a normally distributed continuous variable measuring meat consumption.

Prediction 1 Results

Prediction 1: Cognitive Test Scores will be higher in individuals that consumed more meat.

The combined cognitive test scores variable used in these regressions was constructed by adding the number of correct answers from the pre-race test and the post-race test. This variable is meant to reflect the general cognitive performance of subjects. The first regression dealt with all subjects n =38 where combined cognitive test scores was the dependent variable and the independent variables included race distance and sex along with a measure of meat consumption.

P1: All Subjects. For the comparison of meals per day containing meat and combined cognitive test score p = 0.324 and therefore does not qualify as statistically significant (Table 4.1 and Figure 4.1).

Table 4.1 – All Subjects – Combined Test Scores and Combined Meat Per Day

Model $R^2 = 0.062$		Standardized Coefficients		n=38
Combined Cognitive Test Scores	Std. Error	β	t	Sig.
Combined Meat Per Day	1.455	0.178	1.001	0.324
Distance of Race in km	0.082	0.131	0.750	0.458
Sex	2.306	-0.007	-0.038	0.970

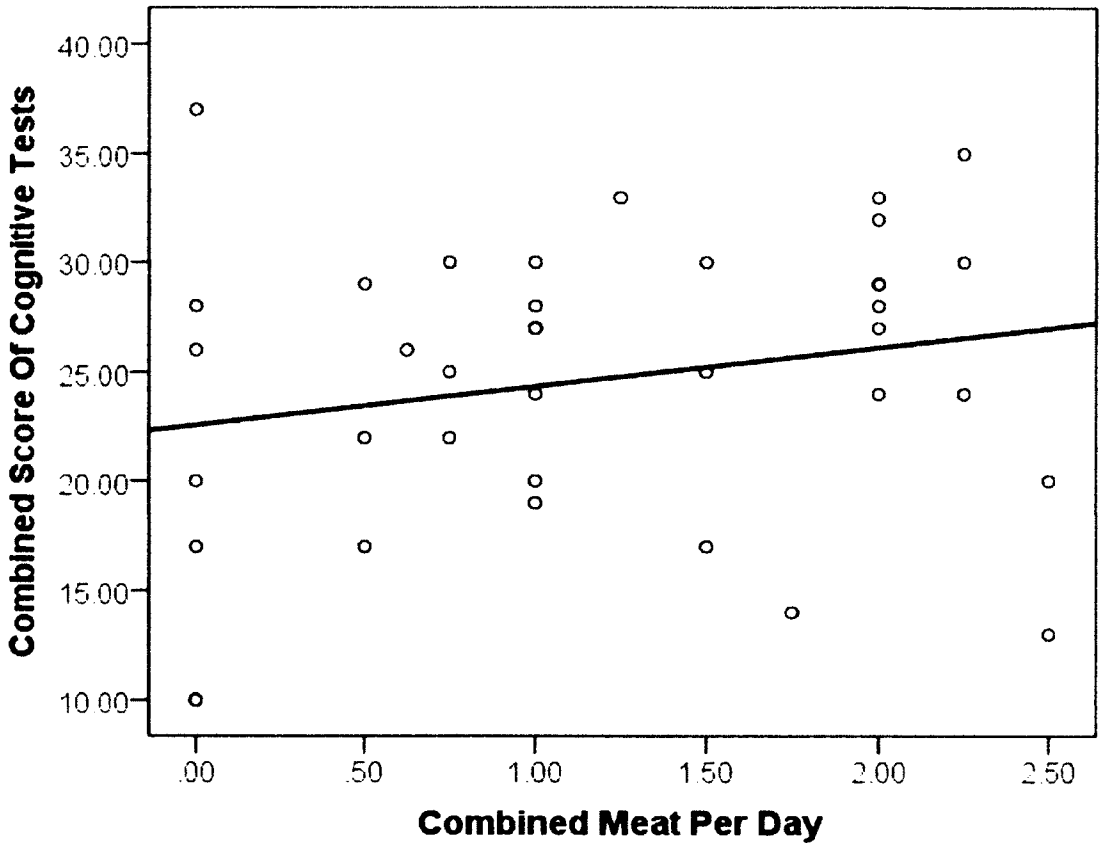

Figure 4.1 – Scatterplot Graph of Cognitive Test Scores and Combined Meat Per Day,

P1: Females Only. For the comparison of meals per day containing meat and combined cognitive test score for female subjects only p=.025 and is therefore statistically significant (Table 4.2 and Figure 4.2).

Table 4.2. Female Subjects - Combined Test Scores and Combined Meat Per Day

Model $R^2 = 0.352$		Standardized Coefficients		N = 15
Combined Cognitive Test Scores	Std. Error	β	t	Sig.
Combined Meat Per Day	2.575	0.715	2.554	0.025
Distance of Race in km	0.125	-0.375	-1.432	0.205

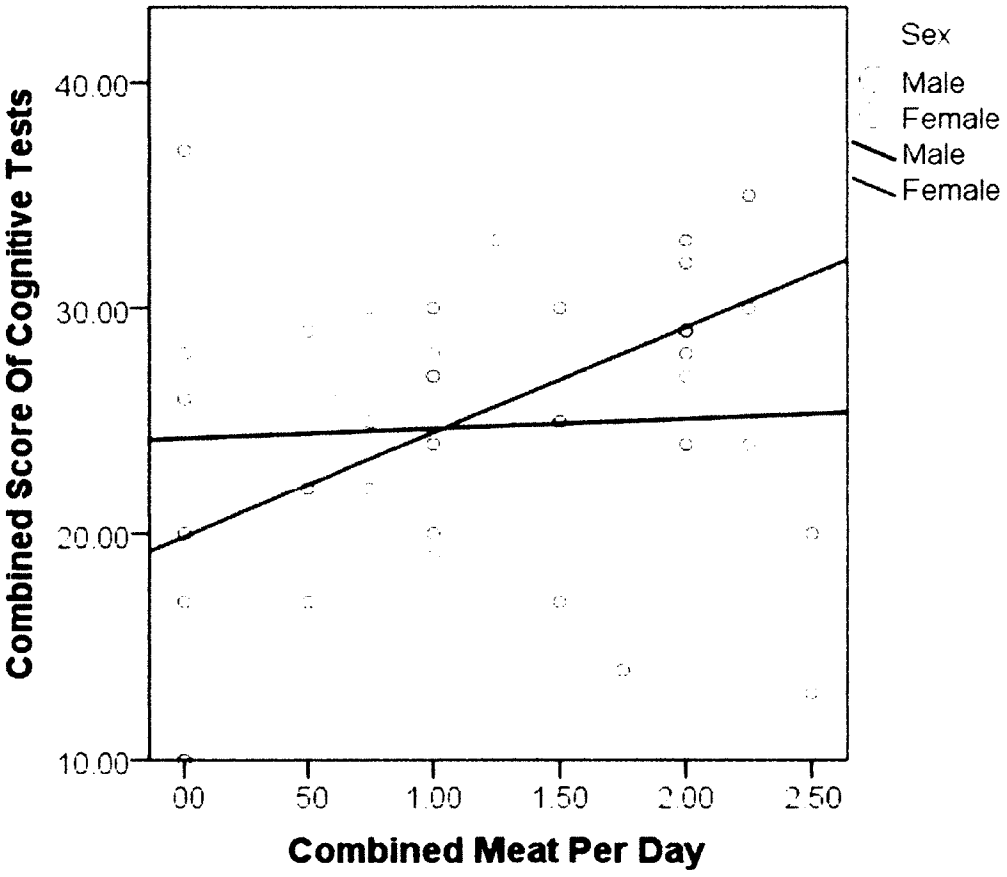

Figure 4.2 - Combined Test Scores and Combined Meat Per Day With Fit Lines By Sex

P1: Males Only. For the comparison of meals per day containing meat and combined cognitive test score p = 0. and therefore does not qualify as statistically significant (Table 4.3).

Table 4.3 - Male Subjects - Combined Test Scores and Combined Meat Per Day

Model $R^2 = 0.086$		Standardized Coefficients		n = 23
Combined Cognitive Test Scores	Std. Error	β	t	Sig.
Combined Meat Per Day	1.714	0.013	0.059	0.954
Distance of Race in km	0.106	0.292	1.350	0.192

P1: All Subjects – Alternate Models. Two additional regression models were tried in an attempt to see if there were better explanations for variation in the data collected on cognitive test scores. The first of these models (Table 4.4) used combined cognitive test scores as the dependent variable and sleep, age, and sex as the independent variables. The second model (Table 4.5) used combined cognitive test scores as the dependent variable and race distance and average number of miles per week ran on average as the independent variables. The number of miles per week ran on average was used as a variable to get at training effort of runners, it want meat to measure the amount of practice at running that runners performed on their own each week. None of the variables in either model were significant. Comparisons of R^2 from the three models using all subjects give the best explanation for variation as offered by the model containing sleep

hours, age, and sex $R^2 = .101$ (Table 4.4) compared to the R^2 value for the model containing combined meat per day, race distance, and sex at $R^2 = .062$ (Table4.1) and the model containing race distance and average miles per week ran $R^2 = .054$ (Table 4.5).

Table 4.4. All Subjects - Combined Test Scores with Sleep, Age, Sex

Model $R^2 = .101$		**Standardized Coefficients**		**n = 38**
Combined Cognitive Test Scores	Std. Error	β	t	Sig.
Hours of Sleep	0.766	-0.281	-1.691	0.100
Age	119.000	-0.107	-0.643	0.525
Sex	2.203	0.005	0.029	0.977

Table 4.5. All Subjects – Combined Test Scores with Race Distance and Average Miles Per Week Ran

Model $R^2 = .054$		Standardized Coefficients		n = 38
Combined Cognitive Test Scores	Std. Error	β	t	Sig.
Race Distance	0.079	0.213	1.261	0.216
Average Miles Per Week Ran	0.100	-0.152	-0.905	0.372

Prediction 2 Results

Prediction 2: Subjects that consumed more meat will have less deterioration in their scores between the pre-race cognitive test and the post-race cognitive test.

For the statistical analysis of prediction 2 a regression was run which considered the difference in scores between the pre-race test and the post-race test in comparison with sex, race distance, and meals containing meat per day (combined meat per day). The cognitive deterioration score was constructed by subtracting the correct number of answers from the pre-race test from the post-race test. This usually resulted in a negative number where test scores after long distance runs were lower than test scores before long distance runs. The regression included all subjects n = 38 (Table 4.6 and Figure 4.3).

P2: All Subjects. In comparing the cognitive deterioration scores with the number of meals containing meat eaten per day (combined meat) in all subjects there were no statistically significant findings.

Table 4.6. All Subjects – Cognitive Deterioration and Combined Meat Per Day

Model $R^2 = 0.089$			Standardized Coefficients		n = 38
Cognitive Deterioration Score	R Square	Std. Error	β	t	Sig.
Combined Meat Per Day	0.001	0.687	0.027	0.154	0.879
Distance of Race in km	0.035	0.039	0.159	0.925	0.361
Sex	0.061	1.088	0.239	1.413	0.167

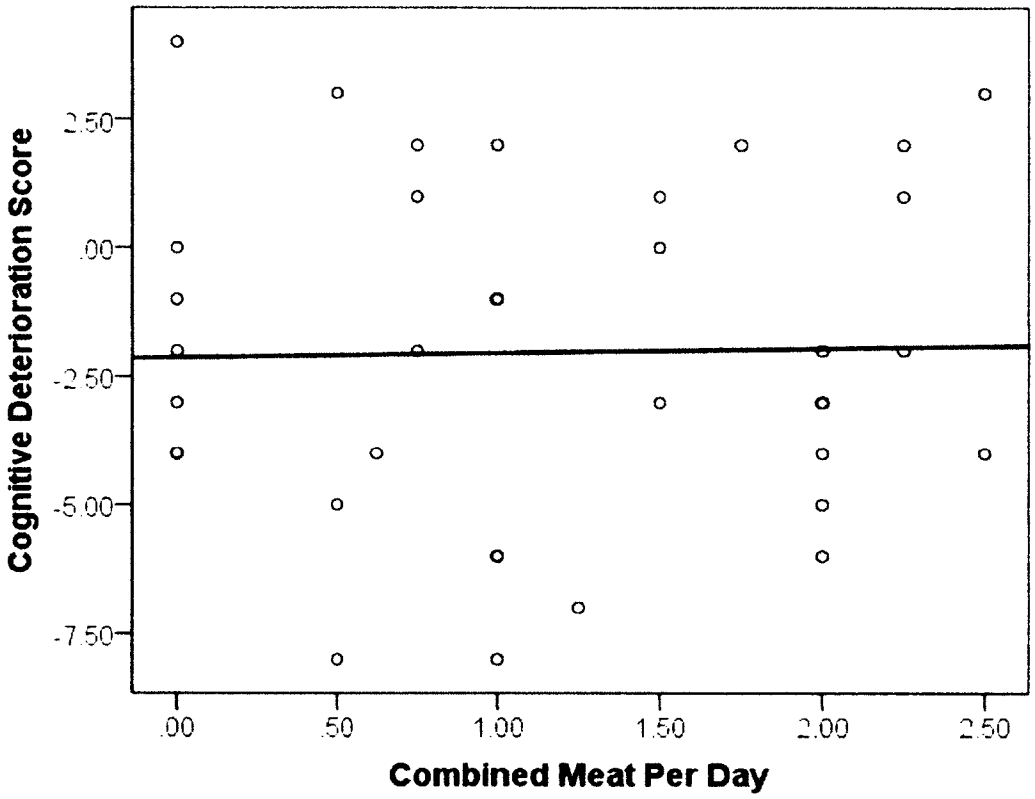

Figure 4.3. Scatterplot Graph – Cognitive Deterioration and Combined Meat Per Day.

CHAPTER 5

DATA ANALYSIS

The purpose of this section is to determine whether the hypothesis for this study should be rejected or accepted. The findings for Prediction 1 and Prediction 2 are analyzed here

Prediction 1 Analysis

Based on the linear regressions ran for prediction 1 it appears that prediction one require additional research. While the results for the regressions including all subjects were not statistically significant ($p = 0.324$ for meals containing meat per day). When only female subjects were considered there was a significant result found $p = .025$ in Table 4.2. The scatterplot graphs for combined meat per day illustrate a general increase in scores as meat consumption increases for females but not for males (Figure 4.1 and Figure 4.2).

Two alternative regression models for all subjects did not focus on meat consumption in relation to cognitive performance (Table 4.4 and Table 4.5). These models found no significant results although the model containing sleep, age, and sex was found to have a higher R^2 (Table 4.4) than the combined meat variable (Table 4.1).

Prediction 2 Analysis

The results for prediction 2 found no statistical significance for combined meat per day or for all subjects ($p = 0.879$) (Table 4.6). Increased meat consumption had been expected to reduce the negative impact that fatigue has on cognitive performance. No findings support the expectation for prediction 2.

Potential Issues

There are a number of potential issues with the data that may have affected the findings in this study. One general problem that may have plagued all regressions in the results was the amount of potential noise in the data.

Information on subjects was limited to what they wrote on the brief survey prior to taking the first cognitive test. The survey was meant to be short to improve the likelihood that subjects would volunteer for the study. The shortness of the survey had a drawback particularly in measuring meat consumption. Measuring meat consumption is difficult to measure in the diet of an individual. The amount of meat in any food item varies. If a subject remembers eating a beef burrito for example, then it is known the subject consumed meat; however, the actual amount of meat in the object is highly variable depending upon its size and composition. Consider if a subject ate a hamburger for lunch, does this include two beef patties or one? What size burger patties were used on the hamburger? Did this hamburger have bacon on it? Given the huge variety of potential answers for diet consumption, the number of meals per day containing meat was used as a quick means to assess a complex variable. It is very well likely that one meal containing meat for one subject was equivalent to multiple meals containing meat for other subjects. The result of this issue is that some subjects received a great deal more of

the nutrients that may affect cognition when compared to other subjects. This was expected to balance out through the use of statistics with a large enough sample size. However, a larger sample size was not possible to acquire for this projects timeframe.

Another issue with the data in this project pertains to the length of races that subjects ran. Race distances that were too short may not have had a large enough impact in fatiguing subjects to show up in cognitive performance scores. It cannot be said at this point if prediction 2 has any merit. It is possible that the effect of cognitive deterioration is small and difficult to see without a large data set.

CHAPTER 6

CONCLUSIONS AND DISCUSSION

General Finding and Interpretation

Findings for this study offer some support for the art of tracking hypothesis as well as the running hypothesis. Meat consumption was not significant for all long distance runners that took pre-race and post-race cognitive performance tests (Table 4.1). However, once subjects were grouped for analysis based on sex, there was a statistically significant $p = .025$ finding for meat consumption level and cognitive performance score in females (Table 4.2). There was not a similar finding in males $p = .954$ (Table 4.3).

These findings indicate that females were significantly affected by consuming meat but males were not. There are a variety of possible reasons for this with the most straight forward being the small sample size for male vegetarians $n=6$. Any outlier with such a small sample size would impact the findings to a large extent. For example one vegetarian male subject scored higher than all other subjects and 23% higher than the next closest vegetarian subject. This individual had the highest score of all subjects at 37 correct answers (when both test scores were combined) while the second closest vegetarian scored a total of 30 correct answers. Given that there were only 6 male vegetarian subjects, one outlier may have a substantial impact on significance levels.

Another problem with the data for male subjects has to do with the event where half of male vegetarians participated. This event (Papago Park) was a meet-up organized

online and not an actual race. The runners for this event ran as a group and so some individuals had to run at a pace that was very easy for them so that more novice runners could keep up. This may have had a critical effect on cognitive performance scores particularly in males because out of the ten individuals that participated in this event there were only three females. Removing this group from the statistical analysis brings the number of male vegetarians down to three individuals.

One more possible reason for the lack of significance in men could be that portion sizes in meals are different between the sexes. If a man eats one meal with meat each day it might be equivalent to three such meals eaten by a small female. So it would give the impression that females that eat a lot of meat do better on cognitive tests but for men there may not be much difference between those that eat one or more meals with meat per day. The real problem for the lack of a significant finding in males may amount to the small number of male vegetarians present in the data and problems in measuring the amount of meat consumed by male subjects in particular.

Discussion Regarding The Art of Tracking Hypothesis

The art of tracking hypothesis proposes that cognitive abilities in humans that are used today in math and science may have been selected for during the evolution of *Homo* for the beneficial effect they originally had in improving hunting success. More specifically the hypothesis argues that cognitive abilities use in science are specifically relevant to tracking skills. The type of hunting methods available to early *Homo* included persistence hunting which itself requires the ability to engage in long distance running while tracking animals. The goal of hunting is to acquire animal source foods such as meat.

Meat itself has been argued in other hypotheses to have provided a nutritional basis for increased encephalization in *Homo* (Aiello and Wheeler 1995; Kaplan et al. 2000; Milton 1999). It has also been found that human brain tissue can use much larger quantities of nutrients such as creatine in comparison to other primates (Pfefferle et al. 2011). This is relevant to the notion that encephalization is related to meat consumption because animal source foods are the only source of dietary creatine. Creatine has a large number of beneficial effects on the body including the brain. Rae and colleagues (2003) found that creatine supplementation in vegetarians improved fluid intelligence test scores by approximately 12% on average which can be considered to offer support the concept that meat has beneficial effects on cognitive performance in females.

The data collected for the study presented in this work on long distance runners in relation to cognitive performance found significantly improved cognitive performance for female subjects and a lack of a similar finding in males. The findings for beneficial effects on cognitive performance in females from consuming meat are consistent with the findings for beneficial effects of creatine on cognitive performance. Given the findings of this study and others it seems likely that the creatine found in meat improves cognitive performance in activities requiring fluid intelligence. It is possible that such activities include scientific thinking as well as tracking animals during hunting. The results do not clearly add evidence in favor of the art of tracking hypothesis. It may be surmised that increased meat consumption during the evolution of the genus *Homo* may have entailed beneficial effects on cognitive function through the dietary intake of chemicals such as creatine although more study of the subject is needed.

Limitations

There were a number of limitations to this study. There has been little research to date with data on the relationship between diet and cognitive skills used in hunting. This makes it difficult to draw many conclusions concerning selective pressures for cognitive abilities pertinent to food acquisition skills like hunting.

This study had no funding and a very limited time frame for data collection. It was not possible to find persistence hunters as subjects, administer cognitive performance tests under a variety of dietary conditions, and then measure hunting success under those same conditions. In lieu using persistence hunters as subjects it was necessary to find alternate ways of measuring the costs associated with persistence hunting that would allow for easier subject recruitment. While long distance runners do have mental and physical costs that are similar to persistence hunting the two are very different in many important regards.

Future Research

While the findings in this study indicate meat improves cognitive performance in fluid intelligence there are no current studies that have investigated whether fluid intelligence scores are associated directly with hunting success among hunter gatherers. A simple idea for future research involves simply administering fluid intelligence tests to hunter gatherers and then examine the resource acquisitions of those individuals as well as their personal dietary in of foods such as meat. Data sets on the impact of diet regarding cognitive abilities is needed in future research that hopes to connect diet and brain evolution.

Another avenue of research involves studies that related cognitive abilities used in tracking and comparing them with cognitive abilities used in science. If Liebenberg (2006) is correct that tracking and science essentially use the same cognitive abilities then more testing in this area can be expected find significant overlap in brain activity for these two activities. The study conducted by Pfefferle and colleagues (2011) is one example that relates cognitive function, brain physiology, and diet but there are presently few of such studies carried out by anthropologists.

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