What is the Cost of Action? Energetic Analysis of Subsistence Activities Performed by the Baka Forager-Horticulturalists of Southeastern Cameroon and its Archaeological Implications

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CHAPTER 1 - INTRODUCTION

1.1 - INTRODUCTION

The Baka are an ethnic group who inhabit the dense tropical rainforests of southern Cameroon, Gabon, the Central African Republic, and the Republic of Congo (Leonard, 1997, p. 8-9). They are among the largest groups within the broader family of Central African Foragers, who are likely the original inhabitants of the region. Both genetic studies of mitochondrial DNA (Soares et al., 2009), as well as sociocultural and linguistic evidence (Güldemann & Winkhart, 2020), support an especially deep history of occupation of the region by Central African Forager populations, predating the arrival of other groups into the same area.

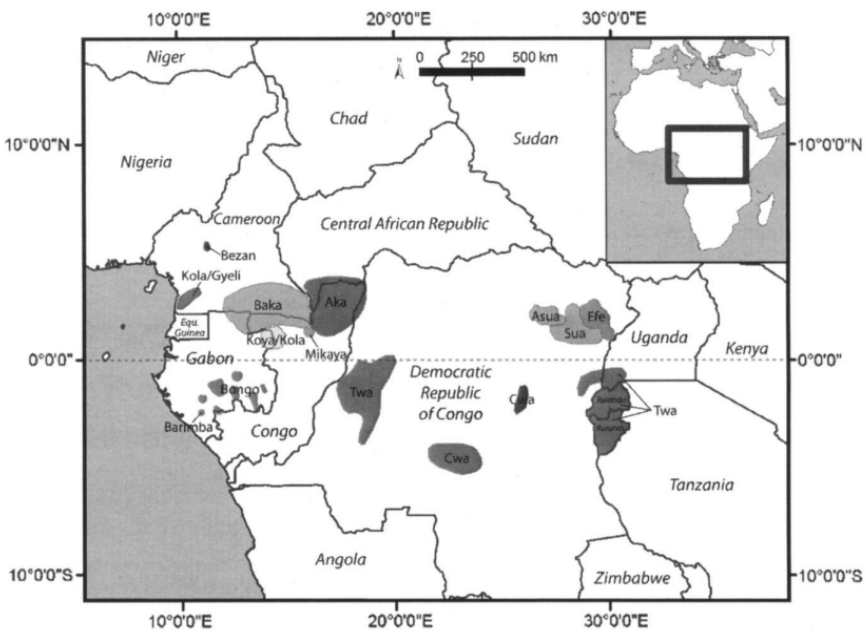

Figure 1: Approximate present-day distribution of Central African Forager groups (Bahuchet, 2012, p. 12).

Every society throughout the vast majority of human history has practised a hunter-gatherer lifestyle, the ancestors of the Baka included. While much of the world adopted food production and eventually urbanism during the Holocene, many Central African Foragers maintained their traditional way of life into the present day. These societies have been documented anthropologically since the 1950s (Turnbull, 1961). However, much like every other documented forager society in the tropics, the Baka do not practise a purely hunter-gatherer way of life. Horticultural practices, accompanied by trade with neighbouring agriculturalists and pastoralists, contribute greatly to their diet. Since this subsistence strategy has been practised by every tropical forager group in recorded history, questions relating to the initial adoption of food production techniques in the region remain difficult to answer.

Forager-horticulturalist societies represent a unique subsistence strategy which incorporates agricultural food production in conjunction with hunting and gathering. Since forager-horticulturalism has proven to be a sustainable, stable subsistence strategy that represents an intermediate step between agriculture and hunting/gathering, it provides a unique opportunity to challenge the widespread perception of the adoption of agriculture as a unilinear progression towards food production. Rather, as the continued success of the Central African Foragers can attest, the most effective subsistence strategy for a given group can instead be viewed through the lens of rational choice based on specific environmental and societal contexts. This paper, which utilises multiple categories of subsistence data gathered in cooperation with the Baka, attempts to illuminate the relative difficulty of these tasks by building a base of knowledge for Optimal Foraging Theory (OFT) models.

Optimal Foraging Theory relies on a set of basic inputs from which to construct models of human behaviour. Traditionally, these inputs have included caloric returns (or another currency), search and handling time, and the number of units of a given resource encountered in a certain unit time. Costs have traditionally been understood in terms of time as a currency, and the energetic cost per unit time has generally, as a simplifying assumption, been regarded as negligible. With a better understanding of the energetic costs of different activity types, it can be ascertained whether these assumptions are founded, or whether these models should be reworked to more accurately reflect optimal decision-making.

1.2 - AIMS AND RESEARCH QUESTIONS

This thesis will analyse the data gained through accelerometry among contemporary forager-horticulturalists to draw conclusions about the relative difficulty of subsistence activities in their everyday lives. I will then use this data to hypothesise how the differences in energetic costs per unit time between subsistence activities may have impacted the origin and spread of food production in the Central African rainforest.

My primary research question is:

- What is the difference in energy expenditure between hunting, gathering, and agricultural activities for the Baka people of Cameroon?

In addition, I will explore the following sub-questions:

- How can these differences in energy expenditure be used to improve optimal foraging models for the adoption of food production in the past?

- What differences can be noted in energy expenditure during subsistence activities between men and women, and between villages?
- Do these results line up with the associated heart rate data published in Henry and Gallois (2021), and what does this say about triaxial accelerometry as an approach?
- How can these results be used to strengthen our understanding of the archaeological record in the region?

Due to the unique challenges of conducting archaeology in regions with sparse archaeological records, ethnographic data is invaluable for constructing accurate and testable models of human decision-making in the past.

CHAPTER 2 - THEORY AND BACKGROUND

2.1 - INTRODUCTION

This chapter will introduce the theoretical and historical context through which the research questions must be understood. To start, it will explore the unique difficulties of conducting archaeological and anthropological research relating to hunter-gatherer societies in the past and present. It will also summarise the evolution of archaeological paradigms over time, and how this influenced the ways in which hunter-gatherer societies were studied and understood. Then, it will investigate the evolution of Optimal Foraging Theory as a concept since its inception in the 1970s, and its influence on the modern scientific understanding of human decision-making as it relates to subsistence strategies. Next, it will consider the evidence relating to the controversial “Wild Yam Question”, which has called into question the feasibility of hunter-gatherer lifestyles in tropical rainforest environments. Finally, it will discuss the purpose of the study of energy expenditure in the context of Optimal Foraging Theory models, and will explore the precedent of conducting research using these methods in similar contexts.

2.2 - HUNTER-GATHERERS IN ARCHAEOLOGY

Although the study of past hunter-gatherers is a subfield of archaeology, it is distinguished from others by a number of unique challenges. For one, population densities in hunter-gatherer societies are generally significantly lower than their settled agricultural counterparts (Milner & Boldsen, 2023). In addition, the mobile nature of many hunter-gatherer subsistence strategies does not lend itself to a significant buildup of materials at any given location (e.g., tools, structures, etc.). Even in contexts where these materials have been deposited and preserved, the mobile and seasonably-variable nature of hunter-gatherer habitation patterns can introduce seasonal and spatial biases that make interpretation and comparison of these groups especially difficult (Brooks & Yellen, 1987, p. 63-106). To confound the problem, tropical rainforests, such as those found in the Central African interior, are generally among the worst environments for the preservation of archaeological materials (Zhuang & Lane, 2022). These factors result in an archaeological record that is often too scant to draw decisive conclusions about hunter-gatherers, especially in tropical climates (Bahuchet et al., 1991, p. 220).

Due to the difficulty in acquiring accurate and usable data from past hunter-gatherer societies, theories about these groups were historically left to grow without the constraints of accuracy or testability. In its early stages, this resulted in the emergence of the Social Darwinist concept of cultural evolution. Early models, pioneered by the works of late 19th-century scholars like L. H. Morgan and Fredrich Engels, asserted that all human societies are subject to universal, unilinear processes of cultural evolution (Steward & Shimkin, 1961, p. 477). Later developments in anthropological and archaeological theory, especially those of early 20th-century Marxist archaeologists such as Gordon Childe, constructed more advanced models of technological advancement in society as a natural, inevitable, unilinear 'homotaxic' progression (Childe, 1944). On an individual level, they asserted that hunter-gatherers remain(ed) 'primitive' due to an ignorance of the benefits bestowed by agriculture and/or pastoralism. At the same time, the work of anthropologists Franz Boas and Bronislaw Malinowski, among the peoples of British Columbia and Papua New Guinea respectively (Helm, 2001), laid the groundwork for cultural relativism and empirical research in anthropology (Steward & Shimkin, 1961, p. 477). Consequently, a new wave of anthropological research in the early 20th century shattered the central implicit assumption of the unilinear cultural evolutionary paradigm - that technological 'advancement' (understood as a progression towards the Western conception of modernity) is and has always been desirable to the individual. This new paradigm, dubbed "cultural particularism", was built in large part by students of Franz Boas, including Ruth Benedict and Margaret Mead (Britannica). These studies revealed that the lives of most hunter-gatherers were not the hostile and difficult existence once imagined, and the benefits originally thought to be associated with the transition to food production were not as straightforward as previously assumed.

In order to reconcile earlier models with these new revelations, theoretical paradigms have spent the last six decades in a constant state of flux, strongly influenced by the evolving discourse of other disciplines. The middle 20th century witnessed the rise of ethnoarchaeological approaches, which sought to utilise taphonomy and knowledge gathered through anthropological research to reconstruct societies from the remains they left behind (Bettinger, 1987, p. 125-132). New approaches were particularly inspired by advancements in ecological theory, such as the seminal ideas of cultural ecology put forward by Julian Steward (Steward & Shimkin, 1961). Unfortunately, as evidence of the incredible diversity between hunter-gatherer societies mounted, it became clear that cultural ecology in its original form was not suited to accurately encompass these differences in the scope of present-day anthropology - much less to examine the even broader array of cultures that have been described in the archaeological record (Smith, 1983, p. 625-626).

The formulation and popularisation of Binford's New Archaeology of the 1960s brought about an important step towards an accurate and representative theory of hunter-gatherer lifestyles. This paradigm was centred on a definitively materialist, analytical basis for understanding hunter-gatherer behaviour, which was at odds with the cultural emphasis held by many previous archaeologists. New Archaeology led the way towards a scientific frame of reference through which hunter-gatherers could be studied. Binford's work also revolutionised the way that the bounds of "archaeological" research were understood, as it placed a heavy emphasis on the value of ethnographic and environmental data in moulding accurate models of behaviour. By searching for patterns in the interaction of these inputs, he attempted to construct models of human behaviour to explain a number of processes in the archaeological record. Much of the work done under this new Processual paradigm related to the intensification of food procurement in hunter-gatherer societies. In Chapter 6 of Binford's 2001 book "Constructing Frames of Reference: An Analytical Method for Archaeological Theory Building Using Ethnographic and Environmental Data Sets", he laid out his theory for how, using the cost of procuring wild resources as an input, one can make predictions about how and when domesticates are adopted (Binford, 2001).

2.3 - OPTIMAL FORAGING THEORY

Drawing from the ideas of the New Archaeology movement, theories of rational agents from biology and economics, and the concepts brought to light through cultural ecology, Optimal Foraging Theory (OFT) made its debut in the field of anthropology during the 1970s and early 1980s. The fundamental principle of OFT is that, through an understanding of the costs and returns of each individual food source in an environment, human subsistence behaviour can be modelled mathematically. OFT represented a formalist, materialist, and easily testable theory which could provide one of the most powerful tools for understanding the reasons behind the subsistence strategies employed by hunter-gatherer groups (Bettinger, 1987, p. 133-134). It also promised something which every other theory in the study of hunter-gatherers at the time could not convincingly provide: a synthesis between a generalised theory of behaviour and an understanding on the level of individual agents (Smith, 1983, p. 626).

Extrapolating from the work of biologist Nikolaas Tinbergen, many early proponents of OFT based their support on its ability to provide "ultimate causation" (Tinbergen, 1963) behind processes such as the adoption of agriculture; i.e., explaining the specific reasons behind its development, adoption, or rejection in particular circumstances (Simms et al., 2014, p. 3). Even in its infancy as an anthropological subfield, OFT was effectively employed in a number of settings to explain the decision making of both hunter-gatherers and horticulturalists

(Keegan, 1986, p. 94). Pioneering research, such as a 1982 study of the Aché of eastern Paraguay, demonstrated that the diet breadth model of OFT can produce accurate and testable predictions when applied correctly (Hawkes et al., 1982). Even earlier, Frank Bayham's research in the late 1970s (Bayham, 1979) employed a diet breadth model in an archaeological context to understand changes in hunting patterns during the North American archaic period. In doing so, he showed that OFT models can be used to account for similarities and differences in these patterns at three caves in the American South, Midwest, and Great Basin.

Almost from its inception, however, OFT has been scrutinised by proponents of other theories. In its early years, many New Archaeologists, including Binford himself, criticised OFT for relying too heavily on the assumption of rational choice, as rationality is in some sense engendered by cultural norms and attitudes (Bettinger, 1987, p. 134-135). Although this criticism is based in truth, it does not extend so far as to refute the formalist understanding of cultural practices as behaviours based in material circumstances. In recent years, it has also been asserted by some that OFT fails to accurately predict the origins of food production, preferring instead other models such as Cultural Niche Construction (Smith, 2015).

Despite these criticisms, OFT has remained a frequently applied tool in the study of past hunter-gatherers, and recent studies have continued to support its accuracy in other tropical regions of the world. Research in the South American Neotropics has provided evidence that initial food production was likely more energetically efficient than the earlier foraging-exclusive techniques (Piperno et al., 2017). The same study asserted that OFT would predict some level of resource depression as a catalyst for the development of food production. Using palaeoenvironmental data to reconstruct vegetation changes, this prediction turned out to be accurate, while predictions made by other theories were definitively inaccurate. Another study used OFT to explore the economics behind the adoption of maize as a staple crop in the American Southwest, and concluded that farming maize was of similar economic efficiency to the foraging of moderately-ranked local flora. They therefore concluded that the adoption of agriculture would only have been an effective subsistence strategy to whatever extent that higher-ranked wild foods decreased in abundance (Barlow, 2002). Evidently, OFT represents a uniquely effective technique for understanding the processual reasons behind the past and present adoption of food production techniques.

2.4 - CENTRAL AFRICA AND THE WILD YAM QUESTION

Stemming from ethnographic research among the Agta of the Philippines and Central African Foragers in the 1980s (Headland, 1999), it began to be called into question whether any past group could have subsisted exclusively off the wild resources available in tropical rainforests. This debate was dubbed the "Wild Yam Question" (Headland, 1987), as it considered the relative scarcity of energy-dense starchy plants, like wild yams, a major hardship for any hunter-gatherer who may have called such environments home. Recently, anthropologists have explored this question in a number of ways. Due to the aforementioned limitations of the archaeological record for studying hunter-gatherers in tropical climates (see Section 2.2), refutations to the Cultivated Calories Hypothesis, which asserted that non-agricultural lifestyles in tropical climates are untenable, must instead be built on the grounds of ecological, ethnohistoric, and linguistic data.

As early as 1991, it was evident that many of the assumptions made in the formulation of the Cultivated Calories Hypothesis were unfounded. It has since been established that energy-dense resources were both more abundant and more easily foragable than previously assumed; deeper research into historical records revealed a number of instances in recorded history where groups subsisted off of wild foods for extended periods; and linguistic evidence points to a shared, foraging-exclusive subsistence strategy shared at some point in the past between the Baka and Aka peoples (Bahuchet et al., 1991, p. 223-234). Among the Baka in particular, researchers have accompanied groups of volunteers into the forest and asked them to rely only on foraged foods, measuring calories collected and changes in weight over two 20-day study periods (Sato et al., 2011). The results were promising for the prospect of pre-agricultural societies in the Central African rainforest: energy intake remained near or above 2500 Kcal/person/day during both the rainy and dry seasons, and none of the participants lost any weight due to insufficient caloric intake. Since scientific consensus once again considers the possibility of hunter-gatherer societies in the Central African Rainforest plausible, the question of how and why these societies may have adopted some level of food production has re-emerged.

2.5 - ENERGY EXPENDITURE

Despite its numerous successes, both in predicting the behaviour of hunter-gatherer groups and in understanding the adoption of food production techniques, there remain a number of limitations restricting the efficacy of OFT methods. For one, the exact "currency" for which tasks are optimised is difficult to ascertain - calories are certainly an important factor, but what level of importance should be assigned to protein or iron, for example? More applicable to this paper is the question of the energetic cost of an activity. Much of the literature focuses on how caloric returns can be maximised over a given period, without considering the equally important cost of an activity over that same period. This is an essential factor to note; without understanding the level of physical effort expended to acquire a resource, the true net rate of return will not be accurate, and resources that are calorically dense but which require intensive labour to access will be ranked unrealistically high.

The lack of data available on the topic has been a cause of difficulty for decades, and many researchers have called for more data on the costs of foraging to be collected (Bailey & Headland, 1991; Sato et al., 2011). Thus far, OFT models usually rely on the implicit simplifying assumption that "the energetic costs per unit of time do not differ significantly for exploiting different resource types" (Hawkes, 1982; Charnov & Orians, 1973). Work has recently been done to collect this data, especially with the use of heart rate monitors (Henry & Gallois, 2021). To illustrate the benefit of measuring these values, consider the equations derived by Charnov and Orians (1973), which determined that an optimal forager would maximise:

$$E/T = \frac{\Sigma\lambda_i \cdot E_i \cdot T_s}{T_s + \Sigma\lambda_i \cdot h_i \cdot T_s} = \frac{\Sigma\lambda_i \cdot E_i}{1 + \Sigma\lambda_i \cdot h_i}$$

Where:

- E = Total Calories acquired foraging
- T = Foraging time
- E_i = Calories available in a unit of resource *i*
- T_s = Search time
- h_i = Handling time per unit of resource *i*
- λ_i = The number of units of resource *i* encountered in a unit of search time (T_s)
- $T = T_s + \Sigma h_i$

Within this equation, energetic costs per unit time are assumed to not differ significantly by resource type and are therefore absent. If it can be conclusively proven that there are non-negligible, significant differences in the cost of exploiting various resource types, it could guide future models to consider the importance of the energetic costs of resource-gathering.

2.6 - CONCLUSION

The study of past and present societies that practise(d) non-agricultural subsistence strategies is a discipline which has, as a result of its unique difficulties, been frequently subject to controversy and competing schools of thought. Within this context, one method which has proven consistently effective at producing accurate, testable hypotheses about human behaviour on both a processual and an individual level is Optimal Foraging Theory. Conducting research along this vein among the Baka forager-horticulturalists of Central Africa, who likely have a history as hunter-gatherers in similar environments but who now practise a stable, longstanding forager-horticulturalist lifestyle, could provide invaluable insights. However, in order to create accurate Optimal Foraging models, it is necessary to be cognizant of the differences in intensity between different subsistence activities.

CHAPTER 3 - METHODS AND MATERIALS

3.1 - INTRODUCTION

This chapter will outline the methods and materials used to collect, process, analyse, and interpret the accelerometer data for the purposes of understanding the differences in intensity between subsistence activities. First, it will delve into the evidence behind the use of triaxial accelerometry as a proxy for energy expenditure. Next, it will explain the methods used to collect the data in the field, and will outline the scope of the study. Third, it will clarify the steps taken in processing and categorising the data, including nominal variables such as vector magnitude and time spent, as well as categorical data such as village and gender, into a useful and interpretable format. It will also justify the use of certain variables for specific reasons, and will explain the removal of periods of rest from the data for comparative purposes. Finally, it will explain the statistical analyses which will be conducted on the data to determine whether there are any significant differences between activity types, villages, or genders.

3.2 - ACCELEROMETRY AND HEART RATE DATA

The heart rate data from the same fieldwork has been previously published (Henry & Gallois, 2021), and will thus be used for cross-referencing.

Previous research has consistently supported hip-worn accelerometry as an effective method for estimating energy expenditure. Stec and Rawson (2012) measured acceleration data at 1-second increments during resistance training through uniaxial accelerometry on the hip, wrist, and ankle, alongside measurements of total energy expenditure using a portable indirect calorimeter. They then analysed the relationship between the accelerometer data and total energy expenditure, finding a strong positive correlation when the accelerometers were worn on the hip ($r = 0.50$, $p = 0.005$). The correlation for wrist-worn ($r = -0.25$, $p = 0.18$) and ankle-worn ($r = -0.07$, $p = 0.72$) accelerometers were not significant at $p < 0.05$ (Stec & Rawson, 2012). The use of triaxial accelerometers is also supported by research, as previous studies have observed that triaxial accelerometry is much better at predicting energy expenditure (oxygen uptake) in adults, especially when measuring activities with variable range of motion (Bouten et al., 1994).

Another study attempted to create an accurate algorithm for estimating energy expenditure utilising a mixture of accelerometer and heart rate data. Using the same equipment as this study (a hip-worn ActiGraph GT3X+), they found that a *Multivariate Adaptive Regression Splines* (MARS) model could be constructed using accelerometer vector magnitudes which matched closely with the real energy expenditure measured through calorimetry (R^2 = 0.86, p = 0.001). They also found that, using only the three axes of acceleration data as the input, predicted awake energy expenditure values using their model were within ±10 % of the true value for 96 % of individuals tested. These results were even closer to the true measured values (±10 % of the true value for 98 % of individuals) when heart rate data was taken into account (Zakeri et al., 2013).

Even without the use of algorithms, hip-worn triaxial accelerometers have been shown to be effective tools for predicting energy expenditure. A 1998 study which compared the relationship between sVO_2 and a number of measurement methods, including triaxial accelerometry, uniaxial accelerometer, pedometry, and heart rate monitoring, found that although all methods showed a strong linear relationship, the best single predictor was the triaxial accelerometer. The correlation coefficient for the triaxial accelerometer vector magnitude relative to sVO_2 was 0.908 for all activities ($P < 0.001$) (Eston et al., 1998).

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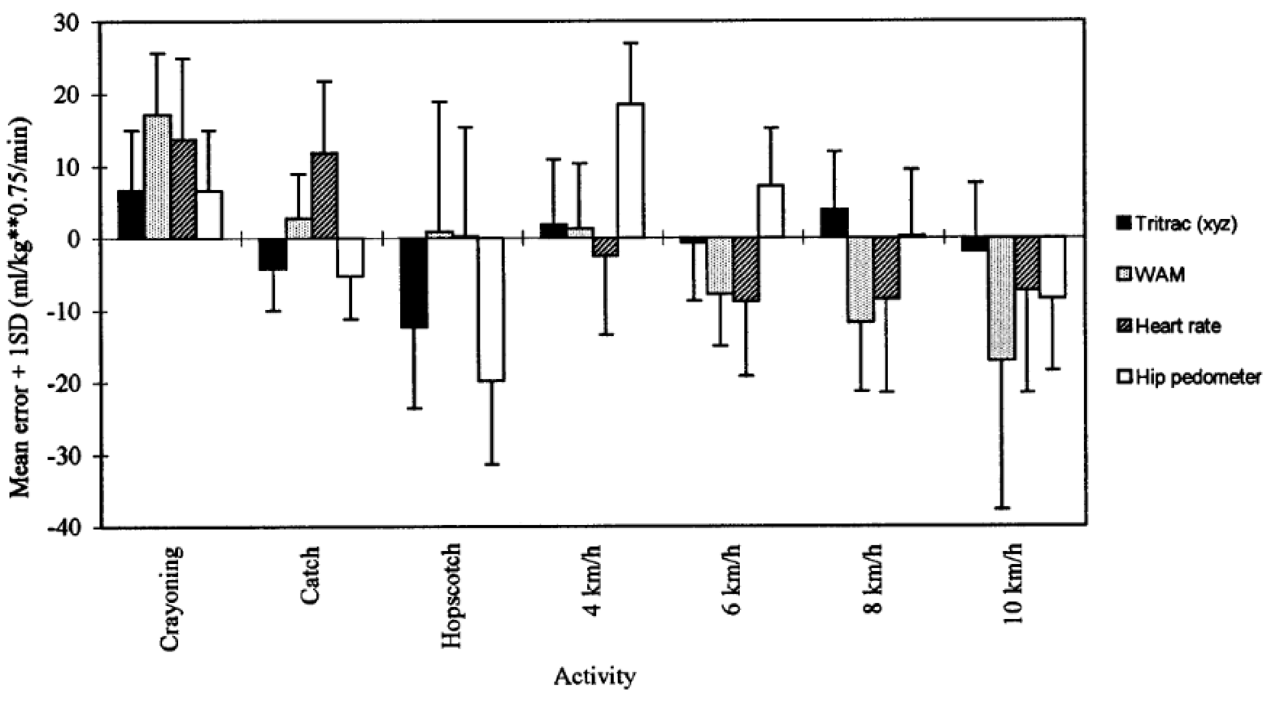


Figure 2: Difference between actual and predicted sVO_2 for each activity measured by Tritrac (Triaxial Accelerometer), WAM (Uniaxial Accelerometer), heart rate, and hip pedometer (Eston et al., 1998, p. 367).

One major limitation of all previous studies on the efficacy of estimating energy expenditure through triaxial accelerometry is the character of the recorded activities, which almost always involve a great deal of movement for the whole body. This is a major difficulty for the interpretation of data in this study, as some activities may consist of less time moving the whole body and more time moving the arms. Although few studies have explored this topic with triaxial accelerometers, one has been conducted on the topic, and found that these methods significantly overestimated the intensity of walking, and underestimated the intensity of most activities with arm movements (Ceaser, 2012). Other studies, however, have found that in some situations, triaxial accelerometry can be a very effective method for estimating these values (Daniel et al., 2022, p. 1-6). It is therefore wise to consider triaxial accelerometry data in conjunction with other forms of energy expenditure data when attempting to draw conclusions for the purposes of OFT analysis. The results presented within this paper should be regarded as part of a greater effort to measure the intensity of activities related to human subsistence behaviours.

Previous data has therefore proven hip-worn activity monitors to be a relatively effective tool for estimating energy expenditure during activities. Due to the limitations of the data used for this study, a full analysis making use of algorithms (MARS or otherwise) in order to match the accelerometer data to a certain level of real energy expenditure is not possible. Instead, the vector magnitude of the accelerometers will be used as a proxy. Therefore, although the results are likely correlated with real energy expenditure, they will not be connected to a specific caloric value but will instead only be useful in relation to each other.

3.3 - METHODS AND MATERIALS

The collection of the raw data used for this study was conducted during three fieldwork periods of 7 weeks, during which three seasons were documented: the major dry season (January–February 2018), the major rainy season (October–November 2018), and the minor rainy season (April–May 2019). During this time, Dr. Sandrine Gallois, two research assistants (Appolinaire Ambassa and Ernest Isidore Simpoh), and driver Alain Hyppolite Fezeu travelled to four small Baka villages in the East Region of Cameroon. In each of these villages they provided heart rate monitors and ActiGraph GT3X+ triaxial accelerometers to volunteers and requested that they wear them for the duration of the day as they went about their everyday life. Once they returned to the village, the volunteers were asked to recount what activities they had done that day, and for how long. This information was then compiled alongside GPS data to help separate the accelerometer and heart rate data into activity-specific files. For the purposes of this paper, only the accelerometer data collected during the study was analysed.

Data was collected from a total of 98 participants. The number of participants per village is as follows: Bosquet (n=22), Elonda (n=21), Kungu (n=28), and Mombokola (n=27). The data collected from these individuals was split into 129 individual usable activities. The number of recorded activities (that fit the criteria of this study) per village is as follows: Bosquet (n=23), Mombokola (n=35), Elonda (n=44) and Kungu (n=27). The accelerometer data consists of three vector measurements based on the direction and magnitude of acceleration, which are recorded once per second. These values are then conglomerated into a single unified vector magnitude, which shows the overall acceleration of the accelerometer at a given second.

Since accelerometer vector magnitudes provide quantitative data about the total acceleration performed by a person over a given period of time, the median of these values will be used as a proxy to represent the approximate effort exerted during that same period. Values of zero for vector magnitude often represent periods of rest (wherein the motion of the accelerometer is too slow to be detected), and as such all calculations will be conducted both including and excluding these values to provide a full picture. Some activities may have periods of rest that are likely the result of a failure of the accelerometer to detect motion, and such limitations must be taken into account when analysing the results wherein rest periods are included. The ratio of time spent at rest to active effort will also be investigated. Prior to statistical tests, five values will be calculated for each group that is being compared: the median of all median vector magnitudes in the group excluding rest (MMVM no rest); the median of all interquartile ranges in the group excluding rest (MIQR no rest); the median of all median vector magnitudes in the group including rest (MMVM with rest); the median of all interquartile ranges in the group including rest (MIQR with rest); and the percentage of time spent resting (% at Rest). MMVM values will be the primary variable that carries information about the average intensity of a given activity. MIQR values will show the average variability within these intensities for a given activity. The median was chosen to represent the average of these values because it diminishes the effect of noise that may affect the mean from large spikes in magnitude caused by limitations of the hardware. In order to fully understand the intensity of these activities it is important to collect data on the overall total average intensity, as periods of rest should, for some purposes, be considered part of the overall activity. However, as explained in Section 4.2, it is better to use MMVM without rest for comparative purposes when exploring the differences in intensity during the active portion of activities, and to avoid complications caused by the confounding variable of time spent on an activity. The percentage of time spent at rest is a useful tool when compared against MMVM without rest as this provides an understanding of the full scope of the activity and the periods of rest taken by the participant. All values for each category will be rounded to three significant digits.

In order to test the statistical significance of the discrepancy in activity levels between groups, the median vector magnitude for each activity (both including and excluding resting time) will be tested through a non-parametric one-way analysis of variance (i.e., Mann-Whitney U test or Kruskal-Wallis test). This is done because the data does not necessarily fall into a normal distribution. The nominal variable groups that will have their median vector magnitudes compared are as follows: village (Bosquet, Mombokola, Elonda, or Kungu), gender (male or female), and activity type (hunting, gathering, and agricultural work). During fieldwork, activity measurements were separated into 11 activity groups, categorised as follows: hunting, gathering, agricultural work, crop harvesting, fishing, water collection, firewood collection, eating, food preparation, and other (miscellaneous tasks). For the purposes of this analysis, the categories have been altered: non-subsistence related activities are excluded; agricultural work and crop harvesting are grouped together, as they both pertain to types of agricultural labour; and hunting and fishing have been grouped together and categorised as simply "hunting", as they both pertain to the exploitation of wild animal resources. Activities which were marked as belonging to multiple of these groups were also excluded from the analysis.

Additional categories, which include mixed activities and non-subsistence related activities, are also considered in some sections, particularly Section 4.8. In addition, I will perform the same non-parametric one-way analysis of variance on the percentage of time spent at rest, with the activities divided by the same nominal variable groups. The null hypothesis is that there is no difference between the groups tested, while the alternative hypothesis is that there is a difference. In line with archaeological convention, p-values < 0.05 will be considered significant for individual comparisons. However, due to the necessity to perform multiple testing on the same data, a Bonferroni multiple testing correction will be done to find more accurate significant p-values. Since each set of categories is compared through statistical testing in 4 different variables (MMVM with rest, MMVM without rest, % at rest, and total time spent), the new p-value which indicates statistical significance is < 0.01250. The first three of these variables will be henceforth referred to as the principal variables since they will be the primary points of comparison between categories.

The data will be visually displayed through the use of boxplots, scatter plots, and bar charts.

3.4 - CONCLUSION

Although it has some major drawbacks, notably the probable underestimation of intensity for activities that involve a significant degree of arm movement, hip-worn triaxial accelerometry has been demonstrated to provide crucial insights into the degree of movement performed during a given activity. Alongside other methods, it also provides invaluable data for the construction of models of energy expenditure when more accurate but difficult methods of data collection are not possible. With this in mind, triaxial accelerometry data was collected from a group of 98 Baka volunteers split among four villages. It was then processed, median values were calculated for each nominal variable (both including and excluding periods of rest), and non-parametric one-way analyses of variance were conducted to determine significant differences between the medians of these values among the three recorded categorical variables (village, gender, and activity type).

CHAPTER 4 - RESULTS

4.1 - INTRODUCTION

This chapter contains the results of the processes outlined in Chapter 3. First, it analyses the potential relationship between the time spent on an activity and the average intensity of movement during that activity, to determine whether time spent may act as a confounding variable. Second, it outlines the median time spent on activities and, using non-parametric one-way analyses of variance, it explores differences in the median time spent on activities between genders, villages, and activity types. Next, it lists the cumulative time spent and the total number of tasks recorded, divided by these same categories. After this, it statistically tests the correlations between the intensity of movement (with and without rest) and the percent of time spent at rest; first between villages, then between genders, and finally between activity types. Finally, it quickly examines outliers, as well as the different values by category for non-subsistence related activities.

4.2 - AVERAGE TIME SPENT

Since activities were performed for natural durations during fieldwork, different activities lasted different amounts of time, ranging from as short as nine minutes to as long as nine hours. It is therefore important to ensure that differences in activity difficulty are actually resulting from differences between activities, rather than from being related to differences in the recorded length of activities. For example, it may be that certain activities are generally recorded for shorter periods of time, and thus a greater level of exertion may be possible to maintain during that period.

In order to test if time spent on an activity is correlated with its MVM (with or without rest) or its % at rest with regards to the entire sample, the Pearson Correlation Coefficient for each of these variable pairings will be calculated, and from this a *p*-value will be determined. These are displayed in Figure 2:

	MVM no rest	MVM with rest	% at rest
R (Coefficient of Correlation)	0.1016	-0.239	0.2287
R^2 (Coefficient of Determination)	0.0103	0.0571	0.0523
p-Value	0.251924	**0.006377**	**0.009137**

Table 1: Correlation between average time spent and principal variables.

Overall, time spent on an activity has a significant weak positive correlation with the proportion of time spent at rest (and consequently a significant weak negative correlation with the total intensity of movement when periods of rest are included). The intensity of movement during non-rest periods is, however, not significantly correlated with the duration of the activity. It is therefore more useful for most purposes henceforth to remove periods of rest from the data (and therefore to use MMVM without rest), although MMVM with rest will still be included for comparative purposes.

There is no significant difference between the median time spent on the three subsistence activities ([Kruskal-Wallis] H = 4.3404, df = 2, N = 77, p = 0.11415), nor between the time spent by village ([Kruskal-Wallis] H = 6.0983 df = 3, N = 129, p = 0.10692). However, men spend significantly longer on average per activity than women ([Mann-Whitney U] H = 7.3467, df = 1, N = 129, p = 0.00672).

TIME SPENT BY ACTIVITY TYPE

Activity Type	Agriculture	Gathering	Hunting
Median Time Spent (s)	12518	6810	14893
Median Time Spent (h:m:s)	3:28:38	1:53:30	4:08:13
n	49	18	10

TIME SPENT BY GENDER

Gender	Female (0)	Male (1)
Median Time Spent (s)	7501	14879
Median Time Spent (h:m:s)	2:05:01	4:07:59
n	92	37

TIME SPENT BY VILLAGE

Village	Bosquet	Elonda	Kungu	Mombokola
Median Time Spent (s)	10981	9592	16081	6923
Median Time Spent (h:m:s)	3:03:01	2:39:52	4:28:01	1:55:23
n	23	44	27	35

Table 2: Time spent by activity type, gender, and village.

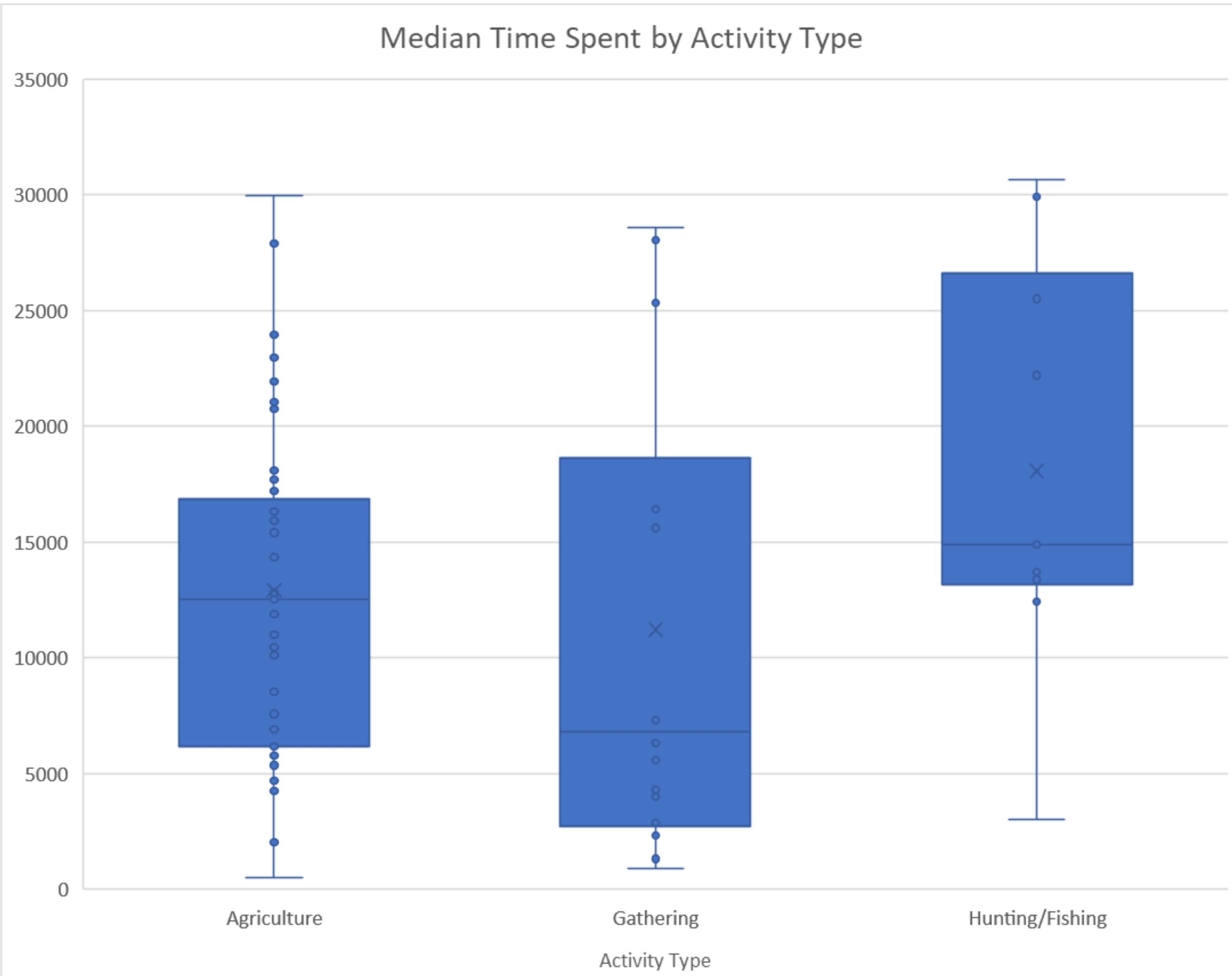


Figure 3: Median duration of activities by activity type.

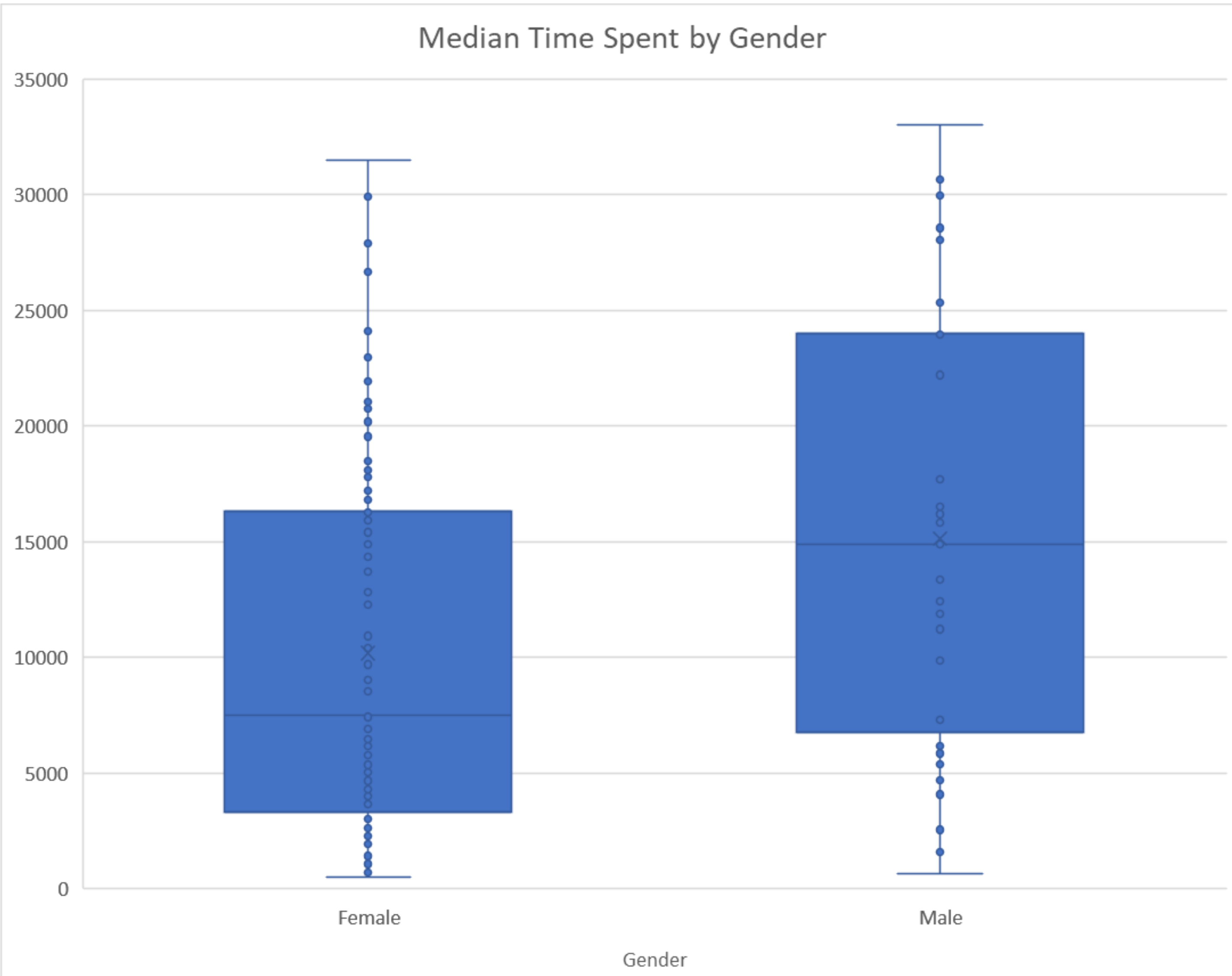


Figure 4: Median duration of activities by gender.

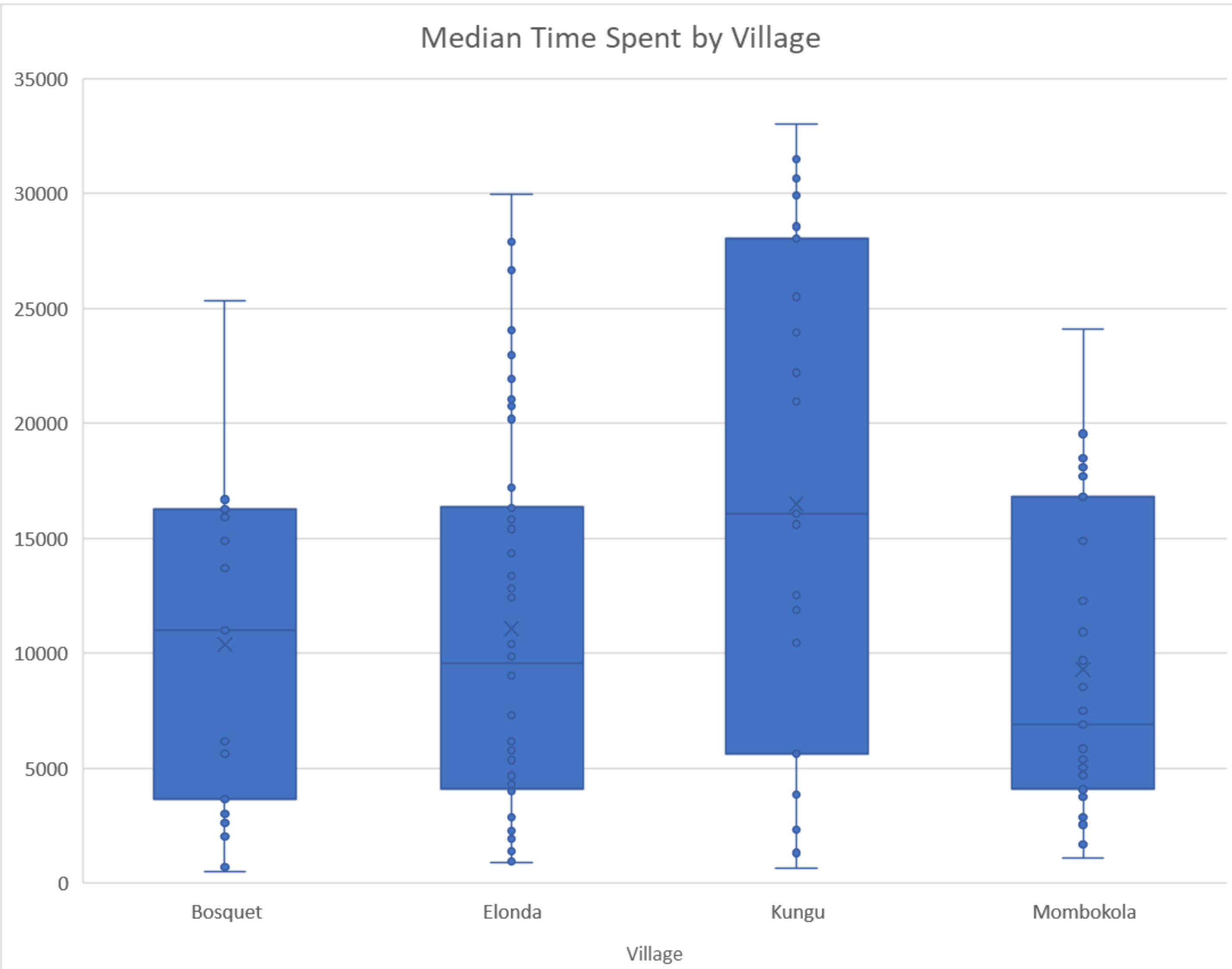


Figure 5: Median duration of activities by village.

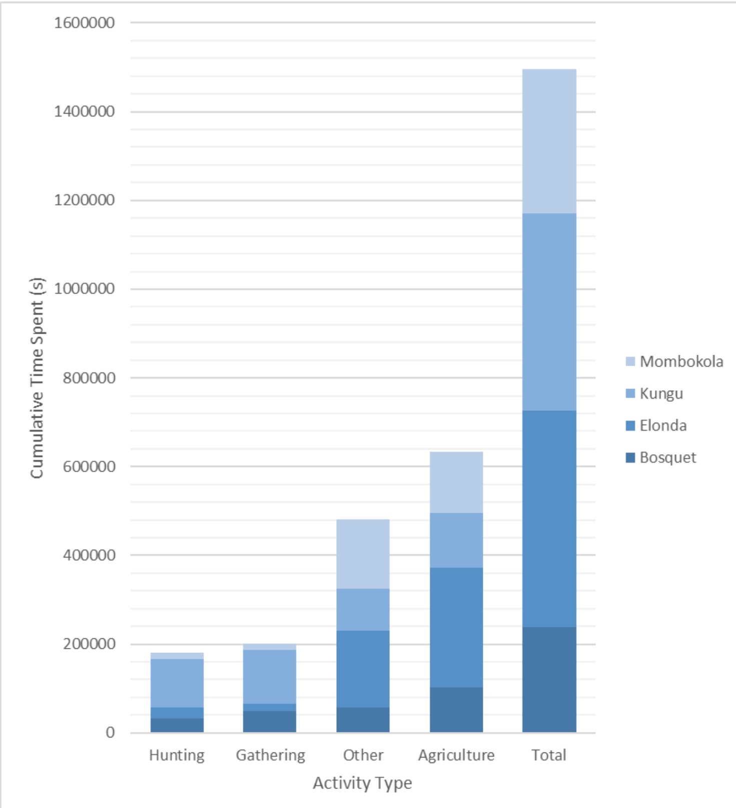
4.3 - CUMULATIVE TIME SPENT

Comparisons of cumulative time spent between categories of activity are especially difficult to draw conclusions from in the scope of this study due to the sampling method employed for choosing participants (as explained in greater detail in Section 5.2). However, it remains important to understand these values to guide our understanding of the data that is being used to analyse other variables. Values for cumulative time spent are therefore calculated within a comparison between the activity type and the two other variables; first gender and then village.

Cumulative Time Spent	Agriculture	Gathering	Hunting	Other	Total
Men	191991 (53:19:51)	126598 (35:09:58)	119044 (33:04:04)	122646 (34:04:06)	560279 (155:37:59)
Women	440573 (122:22:53)	75208 (20:53:28)	61554 (17:05:54)	358861 (99:41:01)	936196 (260:03:16)
Total	632564 (175:42:44)	201806 (56:03:26)	180598 (50:09:58)	481507 (133:45:07)	1496475 (415:41:15)

Cumulative Time Spent	Agriculture	Gathering	Hunting	Other	Total
Bosquet	102765 (28:32:45)	48018 (13:20:18)	31628 (8:47:08)	56272 (15:37:52)	238683 (66:18:03)
Elonda	268620 (74:37:00)	18124 (5:02:04)	25804 (7:10:04)	174318 (48:25:18)	486866 (135:14:26)
Kungu	123454 (34:17:34)	119699 (33:14:59)	108287 (30:04:47)	93764 (26:02:44)	445204 (123:40:04)
Mombokola	137725 (38:15:25)	15965 (4:26:05)	14879 (4:07:59)	157153 (43:39:13)	325722 (90:28:42)
Total	632564 (175:42:44)	201806 (56:03:26)	180598 (50:09:58)	481507 (133:45:07)	1496475 (415:41:15)

Table 3: Cumulative time spent by gender and activity type, and by village and activity type.



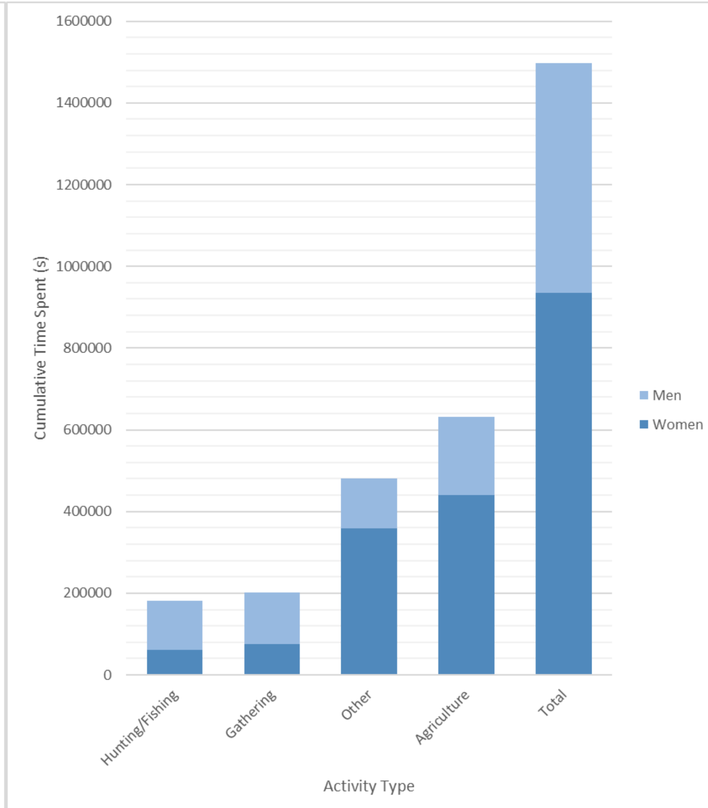


Figure 6: Cumulative time spent by village and activity type

Figure 7: Cumulative time spent by gender and activity type

Among the activity categories, agriculture and other (mixed and/or non-subsistence activities) constitute a significantly larger portion of the total recorded time than hunting and gathering activities. Women are responsible for a majority of the cumulative time spent on agriculture and other activities, while men are responsible for most of the time spent gathering or hunting (although women contribute all of the fishing activities recorded). Women are also responsible for the majority of time recorded overall. The distribution of time spent in certain villages varies wildly by activity type. Some villages, including Mombokola and Elonda, were massively underrepresented in cumulative time spent on hunting and gathering activities, while the opposite was true for the forest camp Kungu.

4.4 - DIVISION OF TASKS

Number of Activities by Gender and Type	Women	Men
Agriculture	35	14
Gathering	11	7
Hunting	4	6
Other	42	10

Table 4: Division of tasks by gender and activity type.

Number of Activities by Village and Type	Bosquet	Elonda	Kungu	Mombokola
Agriculture	11	16	9	13
Gathering	3	5	7	3
Hunting	3	2	4	1
Other	6	21	7	18
Total	23	44	27	35

Table 5: Number of activities by village and activity type.

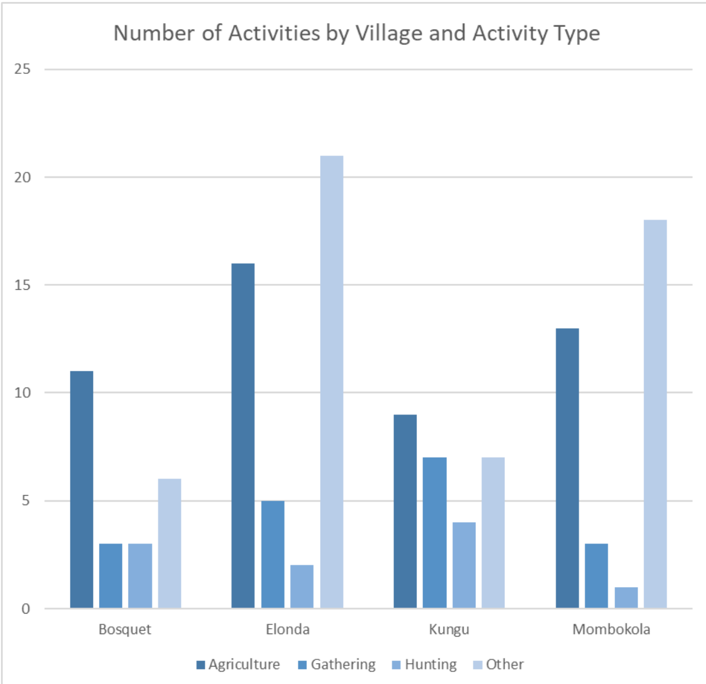


Figure 8: Number of activities by village and activity type.

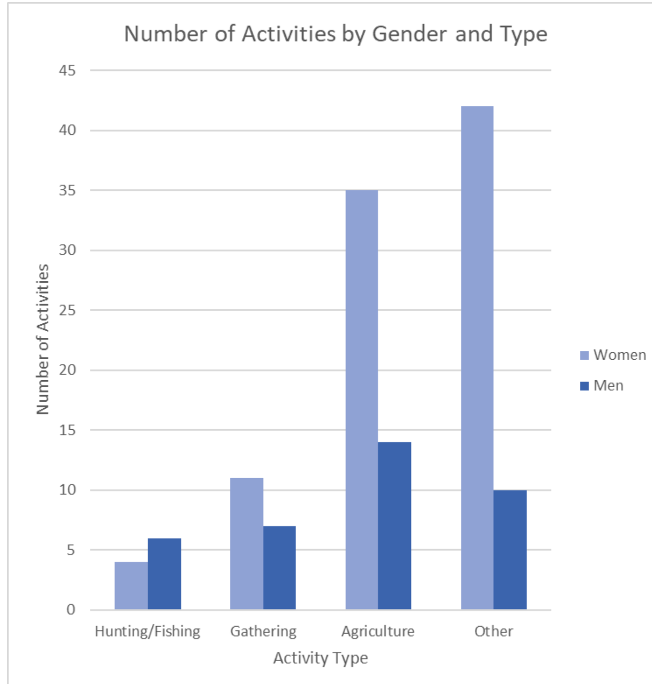


Figure 9: Number of activities by gender and activity type.

Women were responsible for 71.4 % of agricultural activities, 61.1 % of gathering, 40 % of hunting (mostly in the form of fishing), and 80.8 % of all other activities (fire collecting, food preparation, water fetching, mixed activities, etc.) Women were responsible for 71.3 % of all activities. Women were thus overrepresented in the miscellaneous (other) activities relative to all activities, while men were overrepresented in hunting as well as gathering relative to all activities. In terms of absolute numbers, men are underrepresented in gathering, agriculture, and miscellaneous activities, and are overrepresented in hunting.

4.5 - VILLAGES

The four villages are each occupied by less than 1000 people, with the estimated population of each as follows: Bosquet ≈ 800, Mombokola ≈ 600, Elonda ≈ 500, and Kungu ≈ 200. Three of the four villages (Bosquet, Mombokola, and Elonda) are permanent settlements, while Kungu is a forest camp that is occupied intermittently. This difference explains the overrepresentation of Kungu in the number of hunting and gathering activities relative to agricultural activities.

Group	Bosquet	Elonda	Kungu	Mombokola
MMVM no rest ($H = 1.3303$, $p = 0.72194$)	47.460	47.565	50.560	48.870
MIQR no rest	38.745	37.324	39.020	41.103
MMVM with rest ($H = 6.0625$, $p = 0.10861$)	32.390	12.510	23.430	27.780
MIQR with rest	50.240	49.809	52.240	53.785
% at Rest ($H = 5.0452$, $p = 0.16852$)	30.670	39.865	38.320	31.850
n	23	44	27	35

Table 6: Comparison of principal variables by village.

There is no significant difference between villages in the average intensity of movement performed by villagers including rest ([Kruskal-Wallis] $H = 6.0625$, $df = 3$, $N = 129$, $p = 0.10861$) or excluding rest ([Kruskal-Wallis] $H = 1.3303$, $df = 3$, $N = 129$ $p = 0.72194$, or in the percentage of time spent resting ($H = 5.0452$, $df = 3$, $N = 129$ $p = 0.16852$).

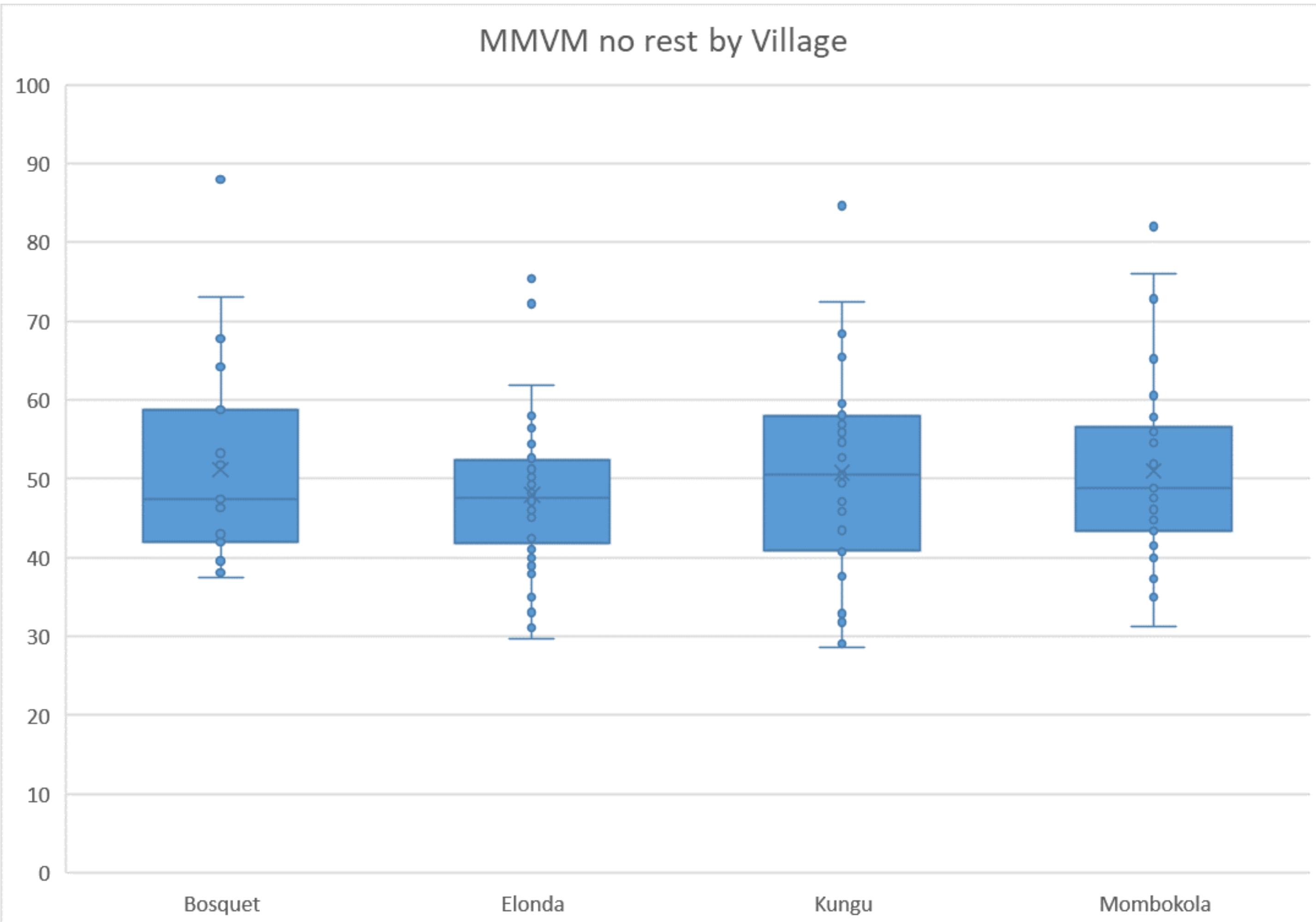


Figure 10: MMVM without rest by village.

4.6 - MEN AND WOMEN

Group	Women (all)	Men (all)
MMVM no rest (H = 10.8485, p = **0.00099**)	46.920	51.820
MIQR no rest	37.775	41.235
MMVM with rest (H = 0.001, p = 0.97507)	20.270	24.920
MIQR with rest	50.470	54.420
% at Rest (H= 0.6942, p = 0.40474)	34.700	40.840
n	92	37

Table 7: Comparison of principal variables by gender.

As a whole, women (n=92) had a median median vector magnitude 10.44 % lower than men (n=37) when rest is not included, and 18.66 % lower than men when rest is included. On the other hand, women spent a median of 15.03 % less time at rest than men during their activities. On average, men and women have similar average intensities of movement over the totality of an activity ([Mann-Whitney U] H = 0.001, df = 1, N = 129, p = 0.97507) and spend similar percentages of time at rest ([Mann-Whitney U] H= 0.6942, df = 1, N = 129, p = 0.40474). When periods of rest are not included, men perform significantly greater amounts of movement per unit time than women ([Mann-Whitney U] H = 10.8485, df = 1, N = 129, p = 0.00099).

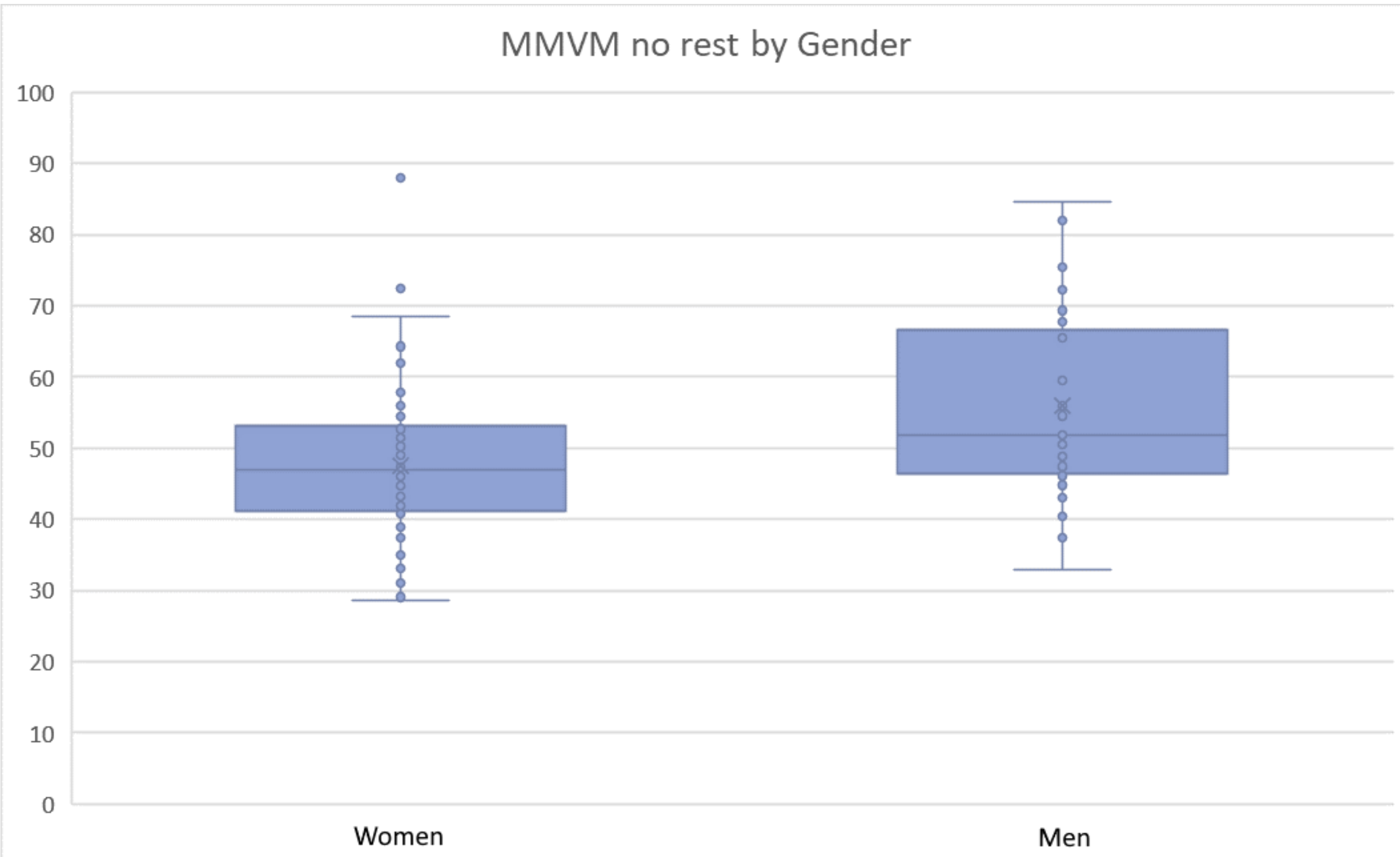


Figure 11: MMVM without rest by gender.

4.7 - SUBSISTENCE ACTIVITY TYPES

Group	Agriculture	Gathering	Hunting
MMVM no rest (H = 17.026, p = **0.0002**)	46.360	43.725	64.2875
MIQR no rest	41.235	36.915	39.065
MMVM with rest (H = 11.5258, p = **0.00314**)	17.000	5.830	40.775
MIQR with rest	51.700	46.060	62.305
% at Rest (H = 7.912, p = 0.01914)	37.690	46.515	28.435
n	49	18	10

Table 8: Comparison of principal variables by activity type.

Although the three activity groups as a whole are significantly different, this is the result of much higher movement during hunting activities relative to their gathering/agricultural counterparts. Comparing agricultural work to gathering, we find no significant differences in the amount of movement whether rest is excluded ([Mann-Whitney U] H = 0.1861, df = 2, N = 67, p = 0.66616) or included ([Mann-Whitney U] H = 2.0008, df = 2, N = 67, p = 0.15722). We also found no significant difference in the percent of time spent at rest between these categories ([Mann-Whitney U] H = 3.7553, df = 2, N = 67, p = 0.05264). This indicates that gathering and agricultural activities involve similar levels of movement, while hunting involves significantly more movement than both of the other activity categories.

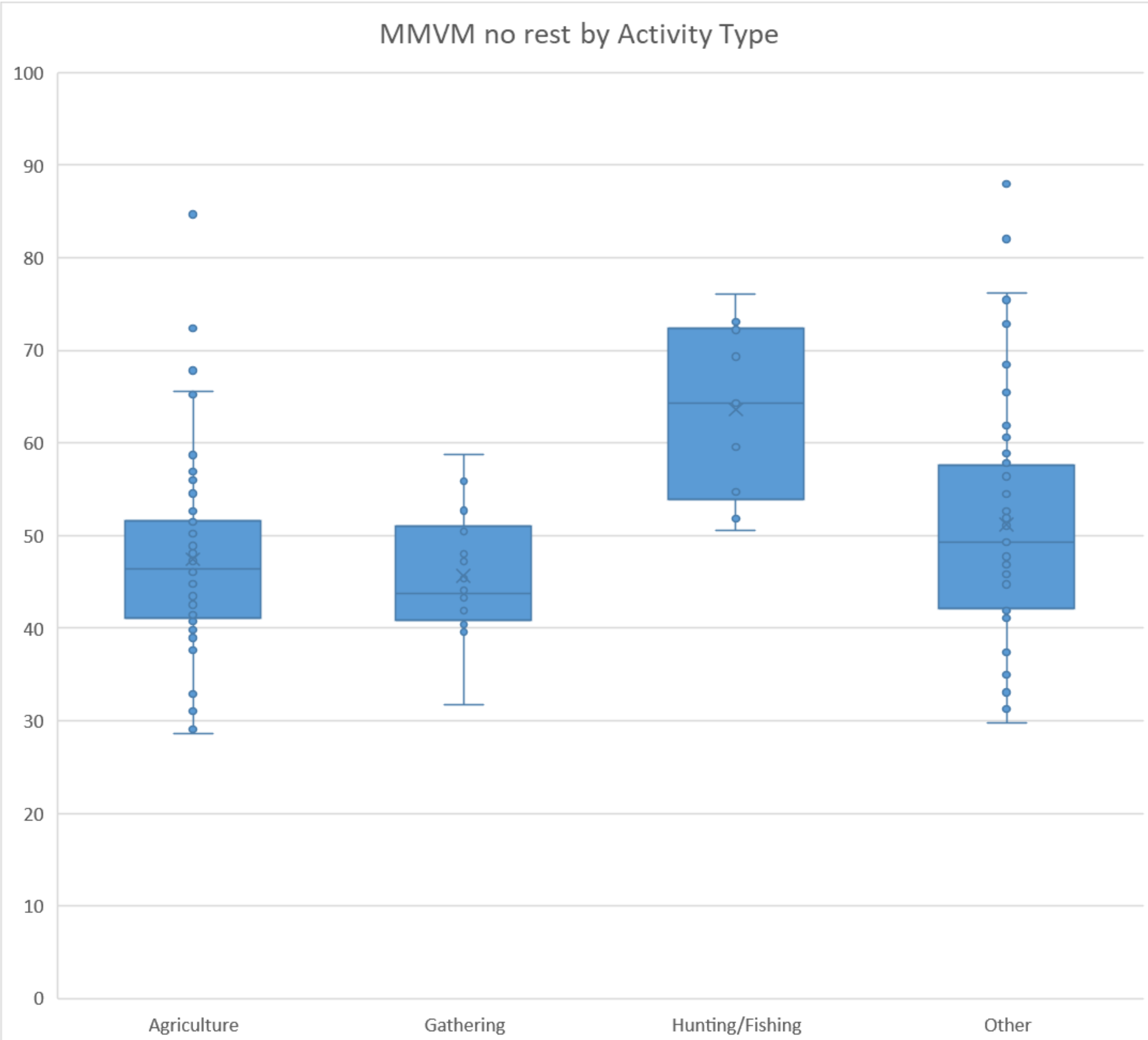


Figure 12: MMVM without rest by activity type.

4.7.1 - OUTLIERS

Using the medians for MVM without rest and % at rest of all activities combined, and using the Interdecile Range for these two variables, we can determine which points are outliers and examine which activities contain points at the extremes which fall outside of each variable's interdecile range. These two variables were chosen because they give us the most accurate and complete picture of the intensity of each individual activity: as explored in Section 4.2, MVM without rest provides the most accurate tool for understanding intensity; while % at rest accounts for the information which is lost due to the decision to not examine MVM with rest. For MVM without rest, the median of all activities is 47.715, and the interdecile range is 28.426, while for % at rest, the median of all activities is 38.6925 and the interdecile range is 26.106.

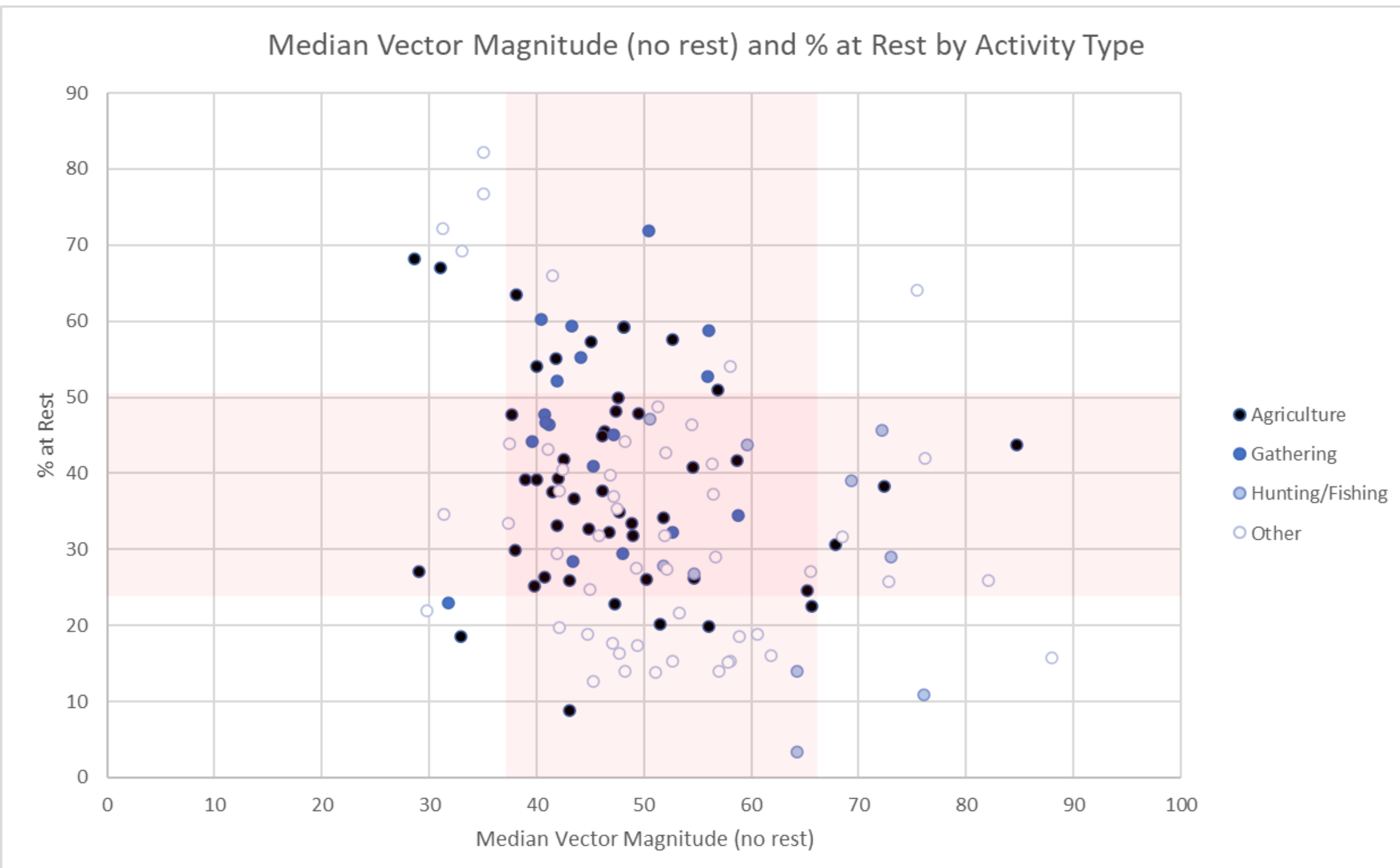


Figure 13: scatter plot of MVM without rest and % at rest by activity type (red area represents interdecile range).

Despite making up only 13.0 % of subsistence activities, when periods of rest are excluded, hunting activities represent 57.2 % (4/7) of subsistence activities with an MVM above the 9th decile (66.03). Gathering activities are completely unrepresented at MVM values in this range, with the highest MVM (no rest) for a gathering activity being 58.73. Hunting activities are also overrepresented in the lowest categories of time at rest, making up 30 % (3/10) of activities which fell into the lowest decile in this category. Gathering activities are underrepresented in this category, making up only 10 % (1/10) of subsistence activities in the bottom decile of % at rest despite representing 23.4 % (18/77) of the total for subsistence activities. Gathering is also overrepresented in the highest decile for % at rest, making up 43.8 % (7/16) of these most restful subsistence activities. Agriculture is vastly overrepresented in the lowest decile for MVM without rest, making up 80 % (4/5) of subsistence activities in this category, compared to 63.6 % of subsistence activities overall. Hunting is completely absent in both of these aforementioned deciles.

	Agriculture	Gathering	Hunting
MVM 9th decile (most active)	3	0	4
MVM 1st decile (least active)	4	1	0
Rest 9th decile (most restful)	9	7	0
Rest 1st decile (least restful)	6	1	3

Table 9: Number of outliers by activity type.

4.8- OTHER ACTIVITY TYPES

Group	Fire Collecting	Food Preparation	Water Fetching	Other
MMVM no rest	47.423	34.995	56.788	58.060
MIQR no rest	32.403	40.444	28.376	24.723
MMVM with rest	24.000	0.000	48.600	54.600
MIQR with rest	42.940	5.000	49.333	49.435
% at Rest	29.440	72.955	25.820	18.520
n	6	4	10	5

Table 10: Median data for non-subsistence activities.

There are a number of major differences which are apparent between the data for non-subsistence related activities. Generally, food preparation activities are especially low-intensity when compared with all other types of activity, whether subsistence-related or not. Water fetching and all other miscellaneous activities are especially intense, with MMVM without rest values surpassing both gathering and agricultural activities (although still below hunting). These results are likely a result of both true contrasts in intensity, as well as limitations of the technology. Food preparation in particular, as an activity which usually requires almost no movement of the lower body, is poorly suited to study through triaxial accelerometry.

Unfortunately, due to the small sample sizes involved with these activities when analysed separately, it is difficult to draw any meaningful conclusions from these data. Within some categories, these sample sizes, along with limitations of triaxial accelerometry as a method, have caused obviously incorrect results (such as the MMVM with rest of 0 for food preparation activities).

4.9 - CONCLUSION

Through the use of non-parametric one-way analyses of variance, the possible relationships between variables have been explored. Among the four villages, no significant differences have been observed for any of the nominal variables tested (median vector magnitude with rest, median vector magnitude without rest, and percent of time spent at rest). There are also no significant differences between the villages in terms of average time spent on activities. Between men and women, there were no significant differences in the total average vector magnitude, although men performed significantly more movement per unit time when periods of rest are excluded. Men also spent significantly longer per activity, although there were no significant differences between men and women in terms of the percent of time spent at rest. Among the subsistence activity types, hunting involves significantly more movement than gathering or agricultural work, whether periods of rest are included or not. There is no significant difference between these activity types in terms of the percent of time spent at rest, although hunting activities had significantly longer average durations than the other two categories.

CHAPTER 5 - DISCUSSION

5.1 - INTRODUCTION

This chapter contains the analysis and interpretation of the results outlined in Chapter 4. First, it will outline the limitations inherent to the scope and methodology of the study. Then, it will interpret and outline the results of the analysis done on subsistence strategies, gender, and village. Next, it will examine the results of the associated research (Henry & Gallois, 2021), which used heart rate data collected during the same fieldwork for the same purpose. In doing this, it will examine whether this paper corroborates their findings, and explain the likely causes behind any discrepancies in the results. Finally, it will delve into how energetic analysis, as part of optimal foraging theory in general, and the results of this paper in particular, can be used to strengthen our understanding of the archaeological record.

5.2 - LIMITATIONS

The first limitation to address is the sampling method used to select participants for the experiment. The researchers in the field usually did not select participants who were expecting to conduct work in a non-study related capacity, such as those working as labourers under the supervision of their Bantu neighbours, or those travelling to other areas for trading or other purposes. These sampling choices may, to some extent, explain the discrepancies seen in cumulative numbers between groups, such as the large discrepancy in the number of tasks performed by women compared to men. Participants were also selected on a volunteer basis (i.e., not randomised), and as such any correlation between willingness to participate in the study and activity choice may skew the results .

In addition, as discussed in Section 3.2, triaxial accelerometry has limitations as a tool for measuring energy expenditure which are not yet fully understood. Is it very likely that activities which involve high levels of movement for the entire body or legs will be recorded as higher intensity, whereas activities which involve primarily the arms will be recorded as lower intensity, relative to the true energy expended. This may explain some of the discrepancy between the results of this paper and those of other papers which utilise heart rate monitors, such as the relatively high intensity assigned to hunting in this paper.However, it must be noted that these results are not meant to be understood in isolation, and should instead be integrated with data collected through other methods to develop a more accurate model.

5.3 - SUBSISTENCE STRATEGIES

Our data has revealed that agricultural work is the most common subsistence activity recorded among the Baka (recognizing the limitations caused by sampling biases). Less often was the gathering of wild plant resources recorded, and least of all the acquisition of wild animal resources (hunting and fishing). This is exemplified in the proportions of these activities to the total number of activities, where out of a total of 130, agriculture represents 49 (37.7 %), gathering represents 18 (13.8 %), and hunting represents 10 (7.7 %). The same order holds true when examining the cumulative time spent on each activity: out of a total of approximately 416 hours, agriculture represents 42.3 % (~176 hours) of the total time spent, gathering represents 13.5 % (~56 hours), and hunting represents 12.1 % (~50 hours). It is important to note that these values only represent the purest forms of these activities, since mixed activities (most often gathering and performing agricultural work concurrently) are subsumed under the category of "other."

Through the use of hip-worn triaxial accelerometry, a number of observations can be made about the energy expended during different activity types. Energy expenditure during hunting activities was the highest of the three groups. When periods of rest were not included, hunting activities had a median median vector magnitude 38.7 % higher than agricultural activities and 47.0 % higher than gathering activities (p = 0.0002). When periods of rest were included, these differences were even more stark. Including periods of rest, hunting activities had a median median vector magnitude more than double that of agricultural activities, and nearly six times that of gathering activities (p = 0.00314). These results are considered very significant even after multiple testing corrections, indicating that the null hypothesis is likely incorrect and that, at least through the framework of triaxial movement of the hip, hunting is more intensive than gathering or agricultural work per unit time. Due to multiple testing corrections, the differences in values for the % of time spent at rest is not significant (p = 0.01914), although further research may indeed reveal a correlation in this area.

The dispersion was similar among all the groups when rest was not included, but when rest is included, hunting has significantly more variable median vector magnitudes (MIQR = 62.305) than gathering (MIQR = 46.060) or agricultural work (MIQR = 51.700). There were stark differences in the time spent at rest between different activity types, with hunting activities exhibiting a median of only 28.44 % at rest compared to 37.69 % and 46.52 % for agriculture and gathering respectively. Due to multiple testing corrections, these results were not significant. Further research into this topic may help illuminate whether there is indeed any correlation between activity type and the percent of time spent at rest.

Overall, these results indicate that hunting is by a wide margin the most intense subsistence activity type as defined through the analysis of triaxial accelerometer data (and especially total vector magnitude), while agricultural and gathering activities are relatively similar in these aspects.

5.4 - GENDER

Overall, the tasks performed by women are of a greater number and a shorter duration than the tasks performed by men. On average, women and men had a similar intensity of movement overall during their activities and spent similar percentages of their activities at rest ($p = 0.97507$ and $p = 0.40474$ respectively). When periods of rest are excluded from the dataset, men had a significantly greater average intensity of movement during their activities than women ($p = 0.00099$).

Typically, men spent a significantly greater time on each activity than women. The median amount of time spent on each activity was 4 hours, 7 minutes, and 59 seconds for men; and 2 hours, 5 minutes, and 1 second for women. This, in conjunction with the significantly greater number of tasks performed by women, suggests that women are likely to perform a greater number of shorter-duration tasks, while men generally perform a smaller number of longer-duration tasks (such as hunting expeditions). This correlation may reflect a general pattern among Baka men and women, although it may also represent a bias in the sampling of participants performed in the field.

Cumulatively, men performed the majority of hunting tasks, both in terms of the absolute number of tasks and the total time allotted to those tasks. Men represent 6/10 (60 %) of the total hunting tasks, and the cumulative time men spent hunting represents 65.9 % of the total (~33 hours / ~50 hours). Men also represent the majority in cumulative time spent on gathering tasks, being responsible for 62.7 % of the total (~35 hours / ~56 hours), although they did not perform a majority of gathering in terms of the total number of tasks. Women represent the majority of tasks recorded for gathering, as well as the other two categories (agriculture and other activities), accounting for 11/18 (61.1 %), 35/49 (71.4 %), and 42/52 (80.8 %) of these groups of tasks respectively. Women also account for the majority of cumulative time spent on agriculture and other activities, making up 69.6 % (~122 hours / ~176 hours) of time spent on agriculture and 74.5 % (~100 hours / ~134 hours) of time spent on other activities. Overall, despite taking nearly twice as long on average to complete each task, men only account for 37.4 % of the total cumulative time spent.

5.5 - VILLAGE

Our data examined the differences between four villages, three of which are permanent settlements and one of which (Kungu) is a temporary forest camp. There are no significant differences in all three analysed factors between villages: median vector magnitude with rest, median vector magnitude without rest, and the proportion of time spent at rest ($p = 0.72194$, $p = 0.10861$, and $p = 0.16852$, respectively). In addition, the median for these villages are remarkably similar for some of the tested variables. The most striking example of this similarity is in the MMVM without rest, where the village with the lowest average intensity (Bosquet, with 47.460) is only 6.13 % lower than that with the highest average intensity (Kungu, with 50.560). This is an interesting result considering the contrast in function between Kungu and the other three villages. It is also interesting since, among the three permanent settlements, there are some major differences. For one, population numbers range from 500-800 between the least and most populated of these settlements (Elonda and Bosquet), or a difference of 62.5 %. In addition, these villages vary in their distance to wild food resources, their reliance on trade goods, and their proximity to their settled agricultural neighbours. The similarity in these variables between contexts suggests some level of universality for the results, and is evidence for the precision of the methodology when testing differences between activity types.

Despite the similarity in terms of the three aforementioned variables, there are some major differences between the sites when other factors are examined. First, the median amount of time spent on an activity varies greatly between villages. The village with the shortest median activity time, Mombokola, had a value less than half (~43.1 %) of the highest value, Kungu (1:55:23 and 4:28:01, respectively). Additionally, the proportion of activity types is extremely variable between villages. In Kungu, for example, 11/27 (40.74 %) of all recorded activities belonged to non-agricultural subsistence activities, while in Mombokola, that number is 4/35 (11.43 %). The other two villages, Bosquet and Elonda, fall in the middle of this spectrum, with 6/23 (26.09 %) and 7/44 (15.91 %) of activities relating to non-agricultural subsistence respectively.

5.6 - CORRELATION TO HEART RATE DATA

The collection of triaxial accelerometry data among the Baka was done in parallel with the collection of heart rate data from the same participants. This data has been previously analysed and published by Dr. Amanda Henry and Dr. Sandrine Gallois (2021). In their report, it was concluded that gathering and agricultural activities are the most energetically costly of the subsistence activities measured (as determined through a calculated Metabolic Equivalent of Task, or MET value). It must be noted that the scope of Henry and Gallois (2021) was larger than the scope of this paper (N = 258 and N = 129 respectively), and that the categorization of activity types employed had some differences. The large discrepancy in results between Henry and Gallois (2021) and this paper is most likely the result of the methodological limitations explored in Sections 3.2 and 5.2. Since hip-worn triaxial accelerometry underestimates the energy expenditure of activities with significant arm movement, and methods based on heart rate often overestimate these same values (see Figure 2), this is an expected outcome considering the differences in arm movement vs body movement inherent to these activities.

5.7 - ARCHAEOLOGICAL IMPLICATIONS

The results of this paper cannot ascertain in isolation the relative difficulty of different subsistence related tasks due to the aforementioned limitations. However, when considered as part of a range of research into the energetic costs of different subsistence strategies, the data contained within this paper can help elucidate the details behind the OFT framework of understanding the adoption of agriculture in the past. Optimal Foraging Theory has proven to be an extremely effective tool for understanding human decision-making, both on a macro-level theoretical scale and on a more applied scale of individual agents. However, in order to function effectively, OFT requires a broad base of accurate information to produce accurate predictions.

As an example of how this data may affect optimal foraging models for the adoption of agriculture, consider a study which investigates a possible correlation between the abundance of wild game and the adoption of agriculture. The high levels of movement observed for hunting activities relative to their agricultural counterparts may indicate that the cutoff for agriculture being more energetically efficient than hunting may occur at a higher abundance of wild game than would have been imagined otherwise, since the energetic cost of hunting per unit time is higher. This is, however, only the simplest and most straightforward application of OFT in the discipline. Archaeologists and anthropologists in the recent past have used similar models to better understand decision-making in contexts as disparate as itinerant beekeepers in Semiarid Brazil (Alves & Nascimento, 2017), or firewood-collecting among the subsistence farmers of the Kakamega forest of western Kenya (Kefa et al., 2018). In the last two decades, the scope of subjects to which these methods can be applied has expanded rapidly, to include such phenomena as high-altitude residential patterns in the American Great Basin (Morgan, 2015, p. 179-180; Morgan et al., 2012) or the adoption of pottery in Eastern California (Eerkens, 2004). In the future, as the field continues to develop and models continue to improve, the breadth of uses for Optimal Foraging Theory will only continue to expand.

Although Optimal Foraging Theory has been used for decades as a tool to expand our understanding of the lives of past peoples, in many ways it still remains in its infancy. OFT models will only benefit from a broader base of data from which to draw, whether in the form of energetic costs for collecting or processing resources, calories or nutrients gained from those resources, or palaeoenvironmental reconstructions of resource abundance. The results of this paper indicate that the simplifying assumptions made in previous research, including that energetic cost of subsistence activities per unit time is negligible, may not be correct. This insight would broaden the base of information requisite to the creation of accurate OFT models, and could also have profound positive impacts on these models of subsistence-related decision making in regards to food production. For example, if hunting is indeed significantly more intensive than agricultural work as this paper suggests, this may be an important consideration for a hunter-gatherer group deciding whether to adopt some level of food production into their diet.

Hopefully, future research will help determine the exact relative energetic cost of these activities, which will in turn steer us closer to a testable general theory that can effectively and accurately explain the adoption of agriculture on a micro and macro-scale.

CHAPTER 6 - CONCLUSION

Although the study of ancient hunter-gatherers is a discipline which fundamentally grapples with a scarcity of data from which to draw conclusions, advances in theoretical frameworks have unveiled a wealth of information which was previously invisible. As part of this advancement within the field, the application of optimal foraging models have allowed for an unprecedented understanding of the ways in which hunter-gatherers live(d). As a part of the construction of these ever more precise models, this thesis attempted to provide a better understanding of the relative intensity of different subsistence-related activities and how the gender and the village of the participant affects those intensities.

What is the difference in energy expenditure between hunting, gathering, and agricultural activities for the Baka people of Cameroon?

Through the lens of hip-worn triaxial accelerometry, hunting activities stand out as requiring a significantly higher energy expenditure than gathering or agricultural activities. This is true whether periods of rest are included or excluded. The percent of time spent at rest among these three subsistence activity types is not significantly different. Gathering and agricultural activities are not significantly different in any of the variables measured, and thus can be considered similar-intensity activities.

How can these differences in energy expenditure be used to improve optimal foraging models for the adoption of food production in the past?

Due to significantly higher levels of movement recorded for hunting activities as opposed to gathering and agricultural activities, the results of this paper reject the simplifying assumption often made in previous research that the energetic cost of collecting resources per unit time is negligible. Instead, they suggest that these differences in energetic cost per unit time may vary drastically by activity type, and any model that does not take this into account is unlikely to model optimal foraging behaviour correctly.

What differences can be noted in energy expenditure during subsistence activities between men and women, and between villages?

Between villages, none of the variables examined statistically showed any significant differences. This is despite the major differences in many aspects of these villages, including population, function, distance to wild food resources, reliance on trade goods, and proximity to settled agricultural neighbours. Between men and women, there is a significant difference in the average intensity observed when periods of rest are excluded, which indicates that men generally expend more energy per unit time than women. When periods of rest are included in the dataset, there is not a significant difference in intensity between men and women.

Do these results line up with the associated heart rate data published in Henry and Gallois (2021), and what does this say about triaxial accelerometry as an approach?

The results of this paper support the interpretation that hunting is significantly more energetically costly for the Baka than the other two categories of subsistence activity, gathering and agricultural work. These results contradict the findings of Henry and Gallois (2021), wherein it is asserted that gathering and agricultural work are the two *most* energetically costly activities. These discrepancies are not unexpected, as they likely result from the limitations of the methodology used. Triaxial accelerometry has been shown in previous research to underestimate the energetic cost of activities which involve significant levels of hand movement and overestimate the energetic cost of activities which involve mostly movement of the body as a whole, while methods based on heart rate tend to do the opposite. This is further evidence to support that it may be necessary to utilise data from multiple sources to get a more accurate assessment of these activities and their relative energetic costs.

How can these results be used to strengthen our understanding of the archaeological record in the region?

Hunter-gatherer subsistence economies have occupied the vast majority of human history, but they remain significantly under researched in most areas of the world due to the ephemeral and mobile nature of their occupation patterns, to their generally low population densities, and due to the nature of the production of material culture compared to settled agricultural societies. Despite this, understanding how and why societies may choose a certain subsistence strategy over another at a given point of time has remained one of the major questions in archaeology since its inception as a discipline. Through Optimal Foraging Theory in general, and Energetic analyses like this one in particular, an opportunity is emerging to understand this transition on both the level of macro-scale processes and individual, rational agents. Presuming that hunting is indeed so much more energetically costly per unit time than agricultural work, this may have played a role in the decision many past and present people groups have taken to alter their subsistence economies to focus more on cultivated crops, whether in the form of forager-horticulturalism or agriculturalism.

ABSTRACT

Due to the unique difficulties of studying hunter-gatherers in an archaeological context, researchers have been attempting to create accurate models to understand these contexts for decades. Although many schools of thought have emerged from this work, one of the most promising has been Optimal Foraging Theory, which attempts to model the optimal subsistence behaviour in a given context using environmental and anthropological data as inputs.

One of the major limitations of Optimal Foraging Theory is that it requires a broad base of accurate data on the costs and benefits of different subsistence activities in order to create precise models. To help address this problem, we used hip-worn Triaxial Accelerometry to estimate relative energy expenditure during specific subsistence-related activities among the Baka of southeastern Cameroon. Our results demonstrate that hunting activities among the Baka involve significantly more movement than gathering or agriculture, implying more energy expenditure, while gathering and agricultural activities involve roughly similar levels of movement. Through the analysis of other variables, we also found that men perform significantly more movement than women when periods of rest are not included. However, there is no significant difference between these values when periods of rest are included. Furthermore, there are no significant differences in the average movement performed per unit time (including or excluding rest), or in the proportion of time spent at rest, between villages.

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