Title: High levels of objectively measured physical activity across adolescence and adulthood among the Pokot pastoralists of Kenya

Authors: M. Katherine Sayre[1], Ivy L. Pike[1], David A. Raichlen[1]

Institution:
[1]University of Arizona, School of Anthropology, Tucson, Arizona, 85721

Abbreviated title: Physical activity among Kenyan pastoralists

Corresponding Author:
M. Katherine Sayre
School of Anthropology
University of Arizona
1009 E. South Campus Drive Room 210
Tucson, AZ 85721
Phone: 520-621-2585
Fax: 520-621-2088
mksayre@email.arizona.edu

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Abstract

Objectives: Levels of physical activity (PA) across the lifespan are important predictors of physical fitness, impacting individual health and longevity. Individuals living in industrialized societies are often characterized as more sedentary than those who live in small-scale societies, and this inactivity is generally linked with increased incidence of chronic disease, especially during aging. However, less empirical data exists regarding levels and patterns of PA across the lifespan among small-scale societies compared to industrialized societies. The goal of this study is to characterize PA among the Pokot pastoralists of rural northern Kenya.
Methods: PA was measured in 40 participants ranging in age from 14 to 78 years using ActiGraph wrist-worn accelerometers. Wear-time spanned 24 hours to 77 hours, with a modal wear time of 50 hours.
Results: We show that the Pokot spend large amounts of time in moderate-to-vigorous physical activity (MVPA), achieving an average of 99.14±7.25 minutes per day in MVPA. Males and younger participants tend to spend more time in MVPA. However, older participants are still physically active and engage in over 50 minutes per day of MVPA.
Conclusions: The Pokot are highly physically active from adolescence through adulthood. Other pastoralist groups may display a similar pattern of PA. During human evolution, lifespans increased, and lifestyles were characterized by a relatively high level of physical activity. The human aging process may be adapted for activity throughout life, and lifelong activity may have played an important role in increases in human longevity during evolution.

Key Words:
MVPA, small scale society, accelerometry, Kenya, pastoralists, aging, GGIR

Introduction

Levels of physical activity (PA) across the lifespan are important predictors of physical fitness, impacting individual health and longevity. A sedentary lifestyle, especially during older ages, is linked strongly with increased risk of developing chronic diseases such as cardiovascular disease (CVD), metabolic disease, obesity, several forms of cancer, hypertension, and premature death (Ekelund et al., 1988; Ekelund et al., 2015; Garber et al., 2011; Myers et al., 2004; Warburton et al., 2006). Engaging in a lifestyle characterized by even moderate levels of PA can lead to increases in and preservation of cardiovascular and cognitive function, and overall psychological well-being (Emery and Blumenthal, 1990; McAuley and Rudolph, 1995; Stewart, 2005; Wei, Liu & Rosenzweig, 2015). PA is also associated with decreased risk of disability, morbidity, dementia, and all-cause mortality*,* especially during older ages (Blumenthal et al., 1989; Chakravarty, Hubert, Lingala, and Fries, 2008; Mazzeo et al., 1998; Shephard, 1993; Stewart, 2005).

In order to gain the substantial health benefits associated with PA, the US Department of Health and Human Services recommends engaging in moderate-to-vigorous physical activity (MVPA) for at least 30 minutes per day on at least 5 days per week, for a total of at least 150 minutes per week, accumulated in bouts of 10 minutes or more (US DHHS, 2008). MVPA is defined as physical activity at intensities equal to 40 to 85% of maximum aerobic capacity, or VO_2 max (Norton, Norton, and Sadgrove, 2010). Analyses of datasets from the National Health and Nutrition Examination Survey (NHANES), a large, representative sample of community-dwelling participants from the US, indicate that fewer than 10% of US adults achieve this recommended level of PA, with declines in PA across age (Troiano et al., 2008; Tucker et al., 2011). The rise of chronic disease and incidence of frailty among older adults in the US over the past several decades may be linked to, or exacerbated by, lifestyles characterized by low levels of PA (Bortz, 2002; Mokdad, Marks, Stroup, and Gerberding, 2000; Rubenstein, 2006). Several researchers have hypothesized that human physiology is adapted to consistent levels of MVPA, and that recent shifts towards sedentary behavior represent an evolutionary mismatch (Bramble and Lieberman, 2004; Leonard and Robertson, 1997; Lieberman, 2013; 2015; Lieberman, Bramble, Raichlen & Shea, 2009; Malina and Little, 2008; Pontzer, 2012; Raichlen and Alexander, 2017; Raichlen and Polk, 2013).

Individuals living in small-scale societies are often characterized as more physically active than those living in industrialized societies (Caldwell, 2016). Physical activity among small-scale societies is often reported in terms of a population's physical activity level, or PAL, which is a ratio of total energy expenditure (TEE) to basal metabolic rate (BMR) (i.e., energy spent above that required to maintain body tissue at rest). Current reports of PALs indicate that individuals living in small-scale societies engage in a wide range of levels and patterns of physical activity across age and sex, though they are generally more physically active than industrialized populations (see Caldwell, 2016 for review). The variety of levels and patterns of PA reported for modern-day small-scale societies suggests that a given subsistence strategy may not be associated with one corresponding level or pattern of PA. For example, high PALs of more than 2.0 can be found among hunter-gatherers, foragers, pastoralists, or agriculturalists, and low PALs can similarly be found among different subsistence strategies (Caldwell, 2016; Gurven, Jaeggi, Kaplan, and Cummings, 2013).

While its use is widespread, PAL may not be a highly accurate measurement of population physical activity. PAL relies on the ratio of TEE to BMR, the latter of which can only be indirectly estimated in non-clinical settings (Frankenfield et al., 2005; Wang et al., 2001). In addition, TEE may not be a reliable estimate of physical activity. A recent study by Pontzer and colleagues (2016) shows that while TEE and PA increase together linearly at low levels of PA, above moderate levels of PA, TEE plateaus. Therefore, at higher levels of PA, as are expected among several small-scale societies, other methods of reporting PA may be more appropriate.

Recent analyses of objectively-measured time spent in PA among people living in small-scale societies may provide a more robust measure of activity levels, and indicate that individuals living in small-scale societies are more physically active than individuals living in industrialized societies (see Caldwell, 2016; Gurven, Jaeggi, Kaplan, and Cummings, 2013; Madimenos, Snodgrass, Blackwell, Liebert, and Sugiyama, 2011; Raichlen et al., 2017). For example, while adults in the US engage in an average of only 10 minutes per day of MVPA (Dugas et al., 2014; Troiano et al., 2008; Tucker, Welk, and Beyler, 2011), Hadza hunter-gatherers of Tanzania spend approximately 75 minutes per day in MVPA (Raichlen et al., 2017). Documenting PA among individuals living in small-scale societies will increase our understanding of global variation in levels and patterns of PA, and further help us determine how PA and health are related across human evolutionary history.

In this study, PA is objectively measured using wearable accelerometers among the Pokot, pastoralists living in northern Kenya who engage in multi-species livestock herding and small-scale agriculture. Previous work documenting PA among a pastoralist population, the Maasai living in southern Kenya, indicate time spent in MVPA is high for men and women, who spend approximately three hours per day in MVPA (Christensen et al., 2012). However, this study did not calculate time spent in MVPA directly from accelerometry. Instead, Christensen and colleagues (2012) indirectly calculated time spent in MVPA based on an estimate of PAL and did not detail how time spent in MVPA changes across the lifespan (Christensen et al., 2012). The Pokot offer important insights into how PA differs among individuals of different ages, and how PA may change with age in the context of a subsistence-based pastoralist lifestyle. The Pokot may also offer insight into how lifelong PA in small-scale societies compares with activity levels in other small-scale societies, and in industrialized societies. In addition, objective measures of MVPA from the Pokot will help confirm the high levels of activity estimated in the Maasai.

The objectives of this study are to **(1)** characterize levels and patterns of age-related differences in PA among members of a small-scale society practicing a more traditional subsistence strategy (the Pokot pastoralists of rural northern Kenya), and **(2)** compare PA across adulthood among the Pokot with PA reported for individuals living in an industrialized society (the United States) using objective measures from accelerometry data analysis. Based on previous work in hunting and gathering and forager-horticulturalist populations (Gurven, Jaeggi, Kaplan, and Cummings, 2013; Raichlen et al., 2017), we hypothesized that Pokot pastoralists would have levels of PA similar to other small-scale societies and that PA levels will remain high across the lifespan.

Methods

Participants: the Pokot

The Pokot are one of several pastoralist groups who live in northern Kenya. Humans have engaged in pastoralism for around 10,000 years (Little, 1989), but the pastoralist way of life in East Africa has been changing over the past several decades. Before recent social, geographical and political changes, Pokot pastoralism was characterized by high mobility and subsistence-oriented cattle herding (Bollig, 1992; Österle, 2008). As access to grazing areas has diminished for all pastoralist groups of northern Kenya, the Pokot have transitioned away from nomadic pastoralism and toward a mixed-model of pastoralism (Greiner, Alvarez & Becker, 2013; Greiner and Mwaka, 2016; Greiner, 2017; Little, 1989; Österle, 2008). Now, many Pokot communities herd cattle, camels, goats, sheep and donkeys, and also cultivating maize, millet, beans, and vegetables on a semi-arid landscape characterized by uneven and hilly terrain (Greiner, Alvarez & Becker, 2013; Greiner and Mwaka, 2016; Greiner, 2017; Österle, 2008). For the communities in which this research was conducted, the Pokot engage in some seasonal rain-fed agriculture, but they identify as herders and their primary livelihood is livestock management.

Pokot sites are organized around homesteads, which are both family and livestock management units (Bollig, 2000). Each homestead is comprised of the patriarch of the family, who is the head of the homestead and owns the herd, as well as the herd owner's wife (or wives), children, and extended kin. The Pokot livelihood revolves around herd and household management, with a clear sex- and age- based division of labor (Bollig, 2000). As a general rule, males tend to the livestock and walk long distances with the herd to feed the animals, as is found across pastoralist communities (Curran and Galvin, 1999). With age, males become responsible for herd management decisions. Although older males still walk long distances with the animals, they pass on more physically intense tasks, such as chasing stray animals, to younger boys and men (Bollig, 2000). Females are responsible for all household tasks, which include watering and walking the animals, maintaining the structures of the homestead, and food preparation (Bollig, 2000). Similar to the pattern seen in males, older females remain active in household tasks, but delegate the especially strenuous tasks of carrying heavy loads, such as water and firewood, to girls and younger females (Bollig, 2000).

We recruited participants from a Pokot community within the Nginyang catchment area in rural northern Kenya. This smaller community is composed of approximately 100-200 households and includes approximately 3,000 people. Residents of this community do not have access to electricity or running water. Residents of this community have more recently begun to grow maize and squash in household kitchen gardens to supplement food. Some energy-saving tools, such as machetes and hoes, are common. Because shoes have the potential to change gait patterns (for example, see Lieberman et al., 2010), it is worth noting that most Pokot wear sandals or shoes to protect against acacia thorns.

We recruited 46 participants (n_{male} = 23, n_{female} = 23) whose ages ranged from 14 to 78 years of age ($\text{mean}_{\text{age}}\pm\text{SEM}_{\text{age}}$ = 36.63±2.83 years). Recruitment occurred after a community meeting with the Pokot elders, who passed on word that we were looking to recruit men and women of all ages for the study. We specified that we were hoping to recruit 5 to 10 men and 5 to 10 women for each of four general age categories: adolescents (~12 to 19 years old), young adults (~20 to 35 years old), mature adults (~35-50 years old) and older adults (50+ years old). We recruited those individuals who expressed interest in participating. One of the young women in the sample was pregnant, and she was later removed from analysis due to insufficient wear time (see below). The sample was therefore purposeful and also reflects the residents in this community area. Data collection took place in June 2016, during the short-rains. Approval was acquired from all appropriate agencies (Institutional Review Board of the University of Arizona, National Commission on Science and Technology and Innovation in Kenya). All participants provided their informed consent at recruitment, before participating in this study.

Data Collection

Accelerometers, worn on the hip or wrist, provide a low-cost, non-invasive method for assessing PA directly, by measuring overall individual movements through the summed magnitude of the acceleration vector (Schutz, Weinsier, and Hunter, 2001). PA was measured in participants using triaxial accelerometers (ActiGraph wGT3X-BT) worn on the non-dominant wrist. Hand dominance was determined by asking participants which hand they used to write (if he/she knew how to write) or which hand they used to throw something (if he/she did not know how to write). Accelerometers were initialized through ActiGraph's ActiLife software (version 6.13.3) and set to collect data continuously at 100 Hz. Participants were instructed to wear the accelerometer at all times, and to return the accelerometer after two days. Raw accelerometer data were downloaded through ActiLife immediately upon participant return.

Participant height, weight, and age estimates were also collected for analysis (Table 1). Age estimation is notoriously difficult in pastoralist communities. Our Pokot research assistant estimated participant age based on discussing life events with participants (e.g., how many children a female participant had and how young those children were). For participants with government-issued identification cards, age was taken from the birth date given on the ID card, and participants' knowledge of their age relative to those with ID cards was also used to inform age estimates.

Data Processing

Raw accelerometer data were first downloaded through ActiLife, then converted to 5-second epoch csv files to process outside of ActiLife software. The accelerometry data were then analyzed in R Studio version 1.1.453 (R Core Team, 2016), using the GGIR package (version 1.5-12; Van Hees, 2017) to assess average daily time spent in moderate-to-vigorous physical activity (MVPA). GGIR analyzes raw wrist-worn accelerometry data using a method described by Van Hees and colleagues (2014). First, non-wear time was determined following the method described by Van Hees and colleagues (2013). For this method, non-wear time is classified as any period of 60 minutes or more where at least two of three axes of raw accelerometry data either (a) have standard deviations of less than 13.0 mg or (b) have a range of values less than 50 mg (Van Hees et al., 2013). Next, accelerometry data were analyzed for time spent in MVPA. Values from each of the three accelerometer axes were first combined into a 3-dimensional vector magnitude (VM). Acceleration due to earth's gravity (1g) was subtracted from the VM, with negative values set to zero, to calculate ENMO values (Euclidean Norm Minus One) (Van Hees et al., 2013). Five-second and one-minute epochs were calculated as the average ENMO during these periods. MVPA was defined as time spent with ENMO above 100 mg, based on a validation study by Hildebrand and colleagues (2014) using wrist-worn ActiGraph accelerometers. Average daily time spent in MVPA was assessed in one-minute epochs and in accumulations of MVPA in ten-minute bouts calculated from five-second epochs. Bouts were defined as a period of time (either one or ten minutes) in which 80% or more of ENMO values were above the 100 mg threshold.

Among the 46 recruited participants, wear time ranged from 11 hours to 96 hours, with a modal wear time of 50 hours. Participants who wore the accelerometer for less than one complete day were removed from the sample for analysis. After removing participants from the analysis with less than one complete day (24 hours) of wear time, 40 participants (n_{male} = 22, n_{female} = 18, mean_{age}±SEM_{age} 36.58±2.86 years, range=14–78) were analyzed for time spent in MVPA. Wear time among these 40 participants ranged from 24 to 77 hours, with an average wear time [mean±SEM] of 50.48±2.04 hours (Table 1).

[Table 1 here]

Table 1: Pokot participant descriptive statistics

	All participants n = 40		Females n = 18		Males n = 22s		Older adults (60+ years) n = 5	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Age	36.575	2.859	35.944	4.102	37.091	3.967	70.400	0.931
Height (cm)	164.265	1.325	158.617	1.686	168.886	1.320	165.480	2.511
Weight (kg)	50.465	1.115	46.578	1.507	53.645	1.253	55.440	1.773
BMI	18.646	0.279	18.468	0.457	18.791	0.340	20.049	0.271
Wear time (hrs)	50.475	2.043	49.694	3.534	51.114	2.322	45.250	0.338

Comparative Dataset

We used accelerometer data from the National Health and Nutrition Examination Survey (NHANES) as a comparative sample from an industrialized society. NHANES is a large, stratified, multistage probability sample that is nationally representative of the community-dwelling US population spanning the lifespan from 6 to over 85 years of age. Beginning in 2003, participants were asked to wear an ActiGraph AM-7164 activity monitor on the right hip for 7 consecutive days. Data are publicly available for 2003-4 and for 2005-6. Note that the NHANES comparative dataset assesses time in MVPA using hip-worn accelerometry, while this study assesses time spent in MVPA using wrist-worn accelerometry (see discussion section for further description of limitations of this comparison).

Statistical Analysis

To characterize PA levels across sex and age for the Pokot, time spent in MVPA was assessed using a general linear model in R Studio version 1.1.453 (R Core Team, 2016), with the following covariates modeled as fixed effects: sex, age, BMI, duration of wear time. Covariates were chosen to reflect variables known to associate with MVPA and that were collected in both cohorts (see Dowda et al., 2003; Harris et al., 2009). Due to the large difference in sample size and average time spent in MVPA between the Pokot and NHANES datasets, we first took a subset of the 2003-4 and 2005-6 NHANES datasets that included only those participants in the top quartile of MVPA output (n=4260; we include a comparison with the full NHANES sample in Supplementary Information). We then compared time spent in MVPA between Pokot and US participants using a general linear model with the following covariates modeled as fixed effects: sex, age, group membership (Pokot or NHANES), BMI, duration of wear time.

Results

Pokot time spent in MVPA

Daily time spent in MVPA for the Pokot was high. Figure 1 shows average daily minutes in MVPA by age for Pokot participants, in one-minute epochs and accumulated in ten-minute bouts. Daily time spent in MVPA among all Pokot participants was 99.14±7.25 minutes per day when measured in ten-minute bouts (Table 2). Males spent an average of 121.32±8.97 minutes per day in MVPA, and females spent an average of 72.04±8.08 minutes per day in MVPA. As found in other populations (Dugas et al., 2014; Raichlen et al., 2017), time spent in MVPA among all participants was higher when reported in one-minute epochs (Table 2; see Supplementary Table 1 for MVPA measures for all participants).

The effects of model covariates on time spent in MVPA differed only slightly depending on how time spent in MVPA was calculated. Males spent significantly more time in MVPA than did females in both one-minute epochs and ten-minute bouts (Tables 3, 4). Older participants spent significantly less time in MVPA in one-minute epochs (Table 3), but age did not have a significant effect on time spent in MVPA in ten-minute bouts (Table 4). In both models of MVPA, neither BMI nor duration of wear time had significant effects on time spent in MVPA (Tables 3, 4).

[Figure 1 here]

Figure 1: Pokot average daily time spent in MVPA

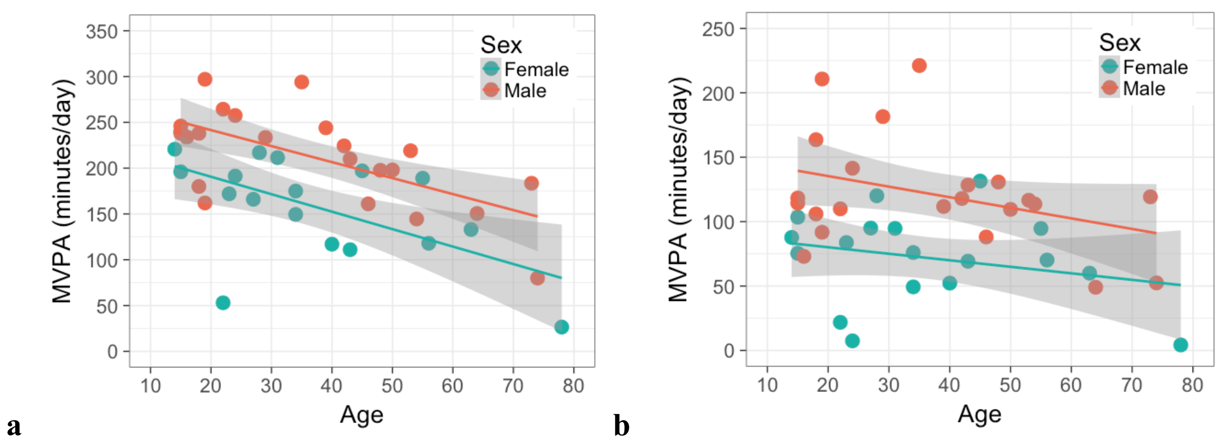

Figure 1. MVPA by age among male and female Pokot participants. Each data point represents average daily minutes of MVPA for one individual. Shaded region is the 95% confidence interval for the regression line. **a.** Average daily MVPA in one-minute epochs, without bouts. **b.** Average daily MVPA in five-second epochs accumulated in ten-minute bouts.

[Table 2 here]

Table 2: Pokot time spent in MVPA[1]

	All participants $n = 40$		Females $n = 18$		Males $n = 22$		Older adults (60+ years) $n = 5$	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM

1-min epoch	188.517	9.348	160.213	13.270	211.674	10.808	114.700	8.756
10-min bouts	99.143	7.251	72.041	8.078	121.318	8.970	56.992	5.810

[1]Time given is average minutes per day. MVPA is moderate-to-vigorous physical activity

[Table 3 here]
Table 3: General linear model of Pokot time spent in MVPA, in one-minute epochs

Parameter	Estimate	Std. Error	t-value	p-value
Intercept	171.942	83.195	2.067	**0.046**
Sex (M)	52.195	14.040	3.718	**7.01e-4**
Age	-1.766	0.419	-4.210	**1.69e-4**
BMI	0.912	4.293	0.212	0.833
Wear time	16.859	13.131	1.284	0.208

Table 4: General linear model of Pokot time spent in MVPA, in ten-minute bouts

Parameter	Estimate	Std. Error	t-value	p-value
Intercept	148.382	72.868	2.036	**0.049**
Sex (M)	51.291	12.297	4.171	**1.90e-4**
Age	-0.709	0.367	-1.930	0.062
BMI	-1.229	3.760	-0.327	0.746
Wear time	-13.601	11.501	-1.183	0.245

Pokot and US time spent in MVPA
We compared daily time spent in MVPA accumulated in ten-minute bouts between the Pokot and a US population. The US population was represented by a subset of the NHANES dataset (2003-4, 2005-6) that included the top quartile in each age category of time spent in MVPA (n=4260). A comparison of daily time spent in MVPA between the Pokot and US populations indicates that the Pokot participants spent significantly more time in MVPA than did US adults and teenagers (Table 5). The results did not change when Pokot time in MVPA was represented using one-minute epochs, nor did the results change when we used the full NHANES dataset (see Supplementary Table 2). Figure 2 shows average daily time spent in MVPA for the Pokot and the US populations, broken down by age groups.

[Figure 2 here]
Figure 2: Pokot vs. USA (NHANES) time in MVPA by age group

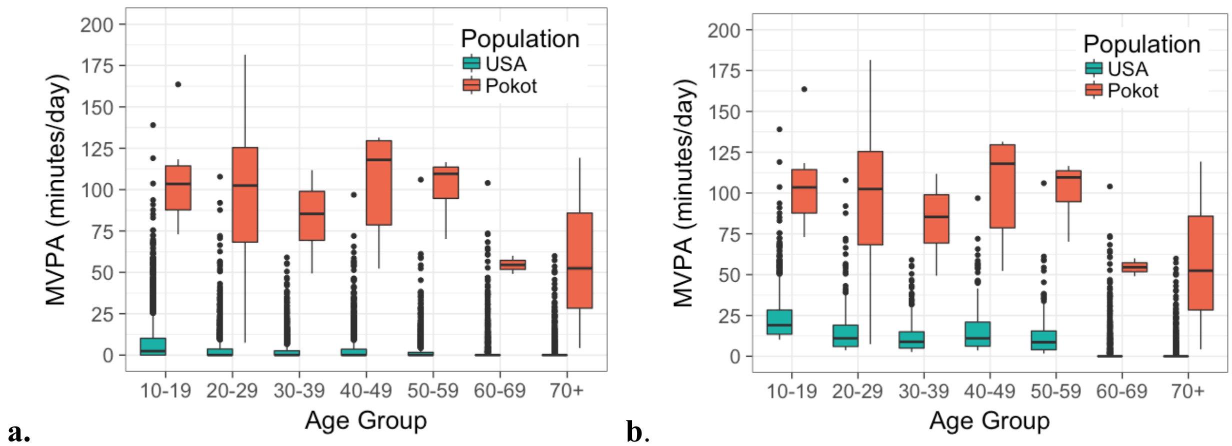

Figure 2. Comparison of MVPA among Pokot participants and a US population. Time spent in MVPA is given as average minutes per day. Boxes represent 2nd and 3rd quartiles, and variance lines represent 1st and 4th quartile. The US population sample is represented by physical activity data from the National Health and Nutrition Examination Survey (NHANES) publicly available data from 2003-4, 2005-6. Pokot data are only available for ages 14 and older. The current study assessed time spent in MVPA using wrist-worn accelerometry, and NHANES used hip-worn accelerometry. **a.** Comparison of MVPA among Pokot and full NHANES sample (n=10,923). **b.** Comparison of MVPA among Pokot and top quartile of each age group of NHANES sample (n=4260).

[Table 5 here]

Table 5: General linear model of Pokot and US[1,2] time spent in MVPA[3]

Parameter	Estimate	Std. Error	t-value	p-value
Intercept	34.83	0.993	35.090	**<2e-16**
Sex (F)	-2.212	0.386	-5.723	**1.12e-08**
Age	-0.310	0.009	-32.899	**<2e-16**
BMI	-0.227	0.034	-6.750	**1.68e-11**
Wear time	-0.440	0.110	-3.989	**6.75e-05**
Group (Pokot)	81.783	2.007	40.757	**<2e-16**

[1]The US population is represented by physical activity data from the National Health and Nutrition Examination Survey (NHANES) publicly available data from 2003-4, 2005-6.
[2]US sample is subset of full NHANES sample with only top quartile per age group included, n=4260
[3]MVPA is moderate-to-vigorous physical activity.

We compared Pokot time spent in MVPA to that reported for another small-scale society (the Hadza) and an industrialized society (the US). The Pokot participants spent a similar amount of time in MVPA as do the Hadza (Figure 3), and both small-scale societies engaged in high levels of PA compared with the NHANES sample. Of the groups represented, only the US did not achieve the recommended 150 minutes per week of MVPA (represented in Figure 3 as 30 minutes per day). Note that the three samples represented in Figure 3 used three different methods to assess time spent in MVPA: wrist-worn accelerometry (Pokot), heart-rate monitors (Hadza) and hip-worn accelerometry (USA).

[Figure 3 here]

Figure 3: Average daily time (minutes) spent in MVPA across three populations: the Pokot (this study, pastoralists), the Hadza (hunter-gatherers), and the US (industrialized population)

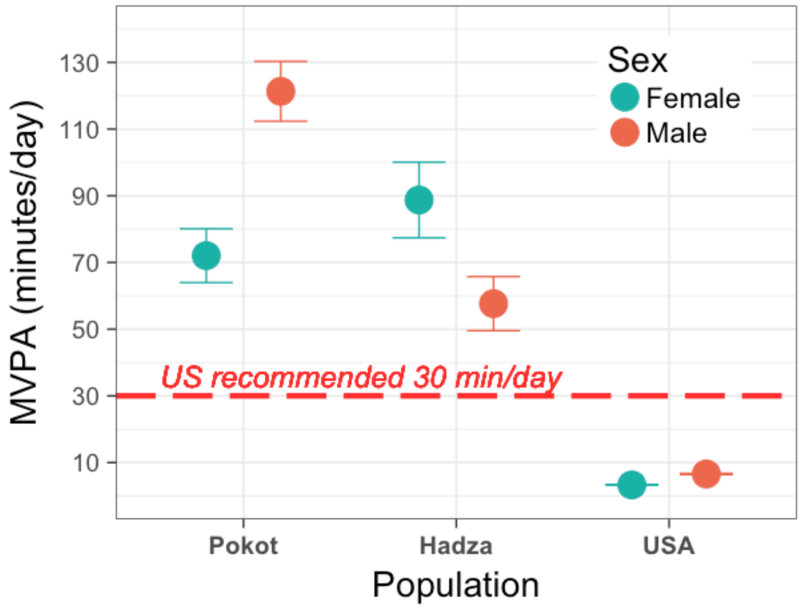

Figure 3. Comparison of MVPA among the Pokot, Hadza, and US populations. Time spent in MVPA is average minutes per day, with variance represented as standard error. Dashed red line represents a daily estimate (30 minutes per day) of the US CDC recommendation of 150 minutes MVPA per week. The Pokot pastoralist population is represented by data from this study, and MVPA was assessed using wrist-worn accelerometry. The Hadza hunter-gatherer population is represented by data from Raichlen and colleagues (2017), and MVPA was assessed using heart-rate monitors. The US industrialized population is represented by publicly available physical activity data from the NHANES 2003-4, 2005-6 dataset, and MVPA was assessed using hip-worn accelerometry.

Discussion

The Pokot pastoralists of northern Kenya are highly physically active. Pokot PA levels are significantly higher in each age group than those reported for a nationally representative US sample, and they are similar to levels reported for a hunting and gathering population. Our findings therefore support our overall hypothesis that Pokot PA would be similar to that of other small-scale societies and higher than that of industrialized societies.

Average daily minutes of MVPA vary based on whether or not MVPA is accumulated in bouts of activity. Time spent in MVPA reported in one-minute epochs is higher for all participants when compared to MVPA accumulated in bouts of ten minutes or more (Table 2). If a person is active in shorter bursts of activity throughout the day, we would expect time in MVPA to be lower when considering only those minutes during the day that are a part of a longer bout of activity. The finding that Pokot time in MVPA in one-minute epochs is higher than time in MVPA in ten-minute bouts suggests that Pokot participants are active in small bursts of activity throughout the day that do not always last at least ten minutes.

The effect of age but not sex on time spent in MVPA varies by MVPA measure. Males spent significantly more time in MVPA than did females in both one-minute epochs and ten-minute bouts of MVPA (Tables 3, 4). When considering time spent in MVPA accumulated across the day *without* taking into account bouts of activity, age has a significant effect (Table 3). However, when considering time spent in MVPA accumulated in ten-minute bouts of activity, age does not have a significant effect; there is only a trend toward older participants spending less time in MVPA ($p=0.062$, Table 4). These findings both complement and supplement existing knowledge about divisions of labor among the Pokot.

Among the Pokot, males are responsible for herding animals, which involves walking long distances over uneven terrain to find food and water for the animals (Bollig, 2000). Pokot females water and milk the animals, and are responsible for all household chores, including the more strenuous tasks of collecting and carrying water and firewood to the homestead (Bollig, 2000). The Pokot display a clear sex-based division of labor, and both males and females engage in physically demanding lifestyles. While our findings suggest that males engage in more physical activity than do females, more work is needed to assess the nuance of the differences between male and female activity. Accelerometers may inaccurately classify the intensity of some activities (Broderick, Ryan, O'Donnell and Hussey, 2013; Kozey et al., 2010), and the addition of a heart-rate monitor could help create a more comprehensive view of daily activities among Pokot men and women.

Analysis of time spent in MVPA among the Pokot reveals that age has a significant effect on time spent in MVPA in one-minute epochs (Table 3), but not on time spent in MVPA in ten-minute bouts (Table 4). This finding supplements current knowledge of the age-based division of labor among the Pokot. With age, Pokot males and females are generally able to delegate higher intensity tasks to younger members of their communities (Bollig, 2000). The finding that age only has a significant effect on time in MVPA in one-minute epochs but not in ten-minute bouts suggests that different kinds of activity may characterize the PA of younger and older participants. Our finding suggests that short-term bursts of activity are more characteristic of PA among younger Pokot participants, while PA among older participants is characterized by moderate activity lasting at least ten minutes. Older Pokot adults are still active members of their community and regularly walk to and from the village center and far-away cattle camps (personal observation). In this study, Pokot adults aged 60 and older spend over 50 minutes per day in MVPA (Table 2), which would still put them well above the 150 minutes *per week* of MVPA recommended by the US CDC (US DHHS, 2008). Pokot older adults therefore seem to remain physically active at more moderate levels of PA into their sixth and seventh decades (Figure 1).

When compared to activity levels in another small-scale society, Pokot PA is comparable to that of the Hadza hunter-gatherers, and both groups show higher PA compared to an industrialized society. Pokot time spent in MVPA in this study is lower than that reported for the Maasai pastoralists, who spend approximately three hours per day in MVPA (Christensen et al., 2012). However, Christensen et al. (2012) used PAL calculated in 30-second epochs as a measure of MVPA which makes a direct comparison with our results difficult. Reports of PALs (ratio of total energy expenditure to basal metabolic rate) from other studies in small-scale societies show a wide range of activity among subsistence strategies. For example, the Tsminae forager-horticulturalists and Hadza hunter-gatherers have PALs of over 2.0, while the Maasai pastoralists have a PAL of closer to 2.0 (Gurven, Jaeggi, Kaplan, and Cummings, 2013). While PAL reported for the Maasai is lower than that reported for the Hadza and Tsimane, Maasai time spent in MVPA is higher than that of the Hadza or Tsimane (Gurven, Jaeggi, Kaplan, and Cummings, 2013). More work is needed to document how PA differs among small-scale societies, and whether or not those differences are consistent across similar subsistence strategies. We recommend use of more objective measures of PA in future studies to overcome some of the challenges of interpreting PALs.

Most studies of PA among other small-scale societies do not report how PA changes across adolescence and adulthood. Studies that do include lifespan changes in PA often, but not always, report a decline in PAL with age (for example, see Christensen et al., 2012; Kashiwazaki et al., 2009), as is seen in the US with time spent in MVPA. Among the Tsimane forager-horticulturalists of Bolivia, for example, male PA declines with age, but Tsimane female PA peaks in the teenage years and remains relatively stable afterward (Gurven et al., 2013). Among the Hadza hunter-gatherers of Tanzania, PA may even increase with age (Raichlen et al., 2017).

The vast majority of adults in the US, especially older adults, do not achieve the 150 minutes per week of MVPA recommended by the US CDC (Troiano et al., 2008; US DHHS, 2008). In addition, chronic diseases like CVD, obesity, and type 2 diabetes are serious public health concerns in the US (Mokdad et al., 2004). The high incidence of chronic disease may be strongly linked to the prevalence of sedentary lifestyles in the US (Bortz, 2002; Mokdad et al., 2000; Rubenstein, 2006). Unlike industrialized populations today, individuals living in modern-day small-scale societies engage in more active lifestyles (Caldwell, 2016). Some studies also report low incidence of certain chronic disease among active small-scale societies. For example, the Hadza spend approximately 75 minutes per day in MVPA and show no evidence of risk factors associated with CVD across the lifespan (Raichlen et al., 2017). The Tsimane are also highly active (Gurven, Jaeggi, Kaplan, and Cummings, 2013), and have some of the lowest levels of coronary atherosclerosis reported for any population (Kaplan et al., 2017).

In addition to reporting objectively-measured MVPA in a pastoralist population, we believe our results provide more context for the evolution of PA levels in human history. Individuals living in small-scale societies often serve as analogs to help us better understand lifestyles experienced by humans during our evolutionary history. Likely beginning with the adoption of a hunting and gathering foraging strategy around two million years ago, lifestyles were characterized by some degree of PA throughout life (Aiello and Wells, 2002; Gurven and Kaplan, 2007; Hawkes and O'Connell, 2005; Lieberman, 2013; Weisdorf, 2005). The incorporation of more agriculture-based subsistence strategies around 10,000 BCE resulted in even more physically demanding lifestyles (Lieberman, 2013; Weisdorf, 2005). The results of this study suggest that the pastoralist lifeway was also likely to have been characterized by high levels of PA. In addition, our results support the growing body of evidence that large reductions in MVPA are not a universal aspect of aging, but instead, aging in small-scale societies may be characterized by relatively high MVPA (e.g., Raichlen et al., 2017).

Given humans' exceptionally long lifespans compared to other mammals (Charnov, 1993; Charnov and Berrigan, 1993), and the evidence that MVPA is a key element of healthy aging (Garber et al., 2011; Warburton et al., 2006), it is reasonable to hypothesize that maintenance of physical activity across the lifespan could have played a role in the evolution of increasingly long lives in humans. Thus, the evolution of healthy aging and productive engagement in communities may be tied to maintenance of PA levels into old age (Raichlen and Alexander, 2014; 2017). The physiology of *modern* humans reflects the importance PA may have played during our evolutionary history, since prolonged *in*activity results in increased health risks during aging, while physically *active* lifestyles are associated with decreases in negative health outcomes during aging and reductions in all-cause mortality (Garber et al., 2011; Warburton et al., 2006). Our physiology may therefore be poorly adapted for a more sedentary lifestyle across seven or more decades, thus leading to increased prevalence of negative health outcomes especially among older individuals in more sedentary societies (Lieberman, 2013; Lieberman, 2015; Raichlen and Alexander, 2017).

Study Limitations and Future Directions

As is typical with most studies of small-scale societies, the sample size for this study was relatively small, with fewer than 50 participants of all ages, and only ten participants aged 45 and older. This study was also performed over the course of ten days during the short-rains, and participants only wore accelerometers for one to four days. In order to establish reliable estimates of habitual PA using accelerometry, most studies have participants wear devices for at least 13 hours per day for at least four days, and some researchers suggest a week of wear-time (Berlin, Storti and Brach, 2006; Hart, Swartz, Cashin, and Strath, 2011; Herrmann, Barreira, Kang and Ainsworth, 2013; Matthews, 2002). However, recent work suggests that two days of wear time is adequate for robust PA estimates (Kocherginsky et al., 2017; van Schooten et al., 2015; Zhang et al., 2018), and some studies have used a single day of accelerometer wear to capture PA in ways that relate to health (Matthews et al., 2008). Pokot PA could be better characterized with a larger sample size, increased accelerometer wear time, and data collection over the course of the year, since daily activity may change according to season (Bollig, 2000). For example, during the dry season when water is scarcer, the Pokot may have to walk further each day to find food and water for their animals, and so daily activity may be higher during the dry season (e.g., Curran and Galvin 1999).

Future studies with the Pokot could include measures of health and chronic disease, as do studies with the Hadza (Raichlen et al., 2017) and the Tsimane (Kaplan et al., 2017), which may allow for a more comprehensive understanding of the interaction between Pokot PA and health. This study included only one pregnant woman, who did not wear the accelerometer for a full day and so whose data was removed from final analysis. Future studies could include women who are pregnant and/or breastfeeding to assess how PA may change with different reproductive statuses.

Accelerometry data analysis is a developing field. Using accelerometry data to determine time spent in MVPA requires setting acceleration cut-points that should approximate different MET (Metabolic Equivalent of Task) energy expenditure categories. Cut-points are determined based largely on clinical experiments with Western populations that associate an individual’s level of acceleration with a corresponding amount of energy expenditure, often during treadmill walking and running. The MVPA cut-point used for this study is based on work done by Hildebrand and colleagues (2014), who assessed raw accelerometry output for different MET levels with both wrist- and hip-worn ActiGraph accelerometers. However, it is unclear how well these MET category cut-points translate to non-Western populations, who may have different metabolic profiles.

Even if MET categories do translate well across populations, assessing population PA using a method that relies on energy expenditure may be problematic due to the complicated relationship between energy expenditure and PA. Although energy expenditure corresponds linearly to PA level for activities of moderate intensity, energy expenditure is not strongly correlated with PA level for activities of higher intensity (Pontzer et al., 2016). Future analysis of accelerometry data should take into account the complex relationship between energy expenditure and PA.

Finally, our study used wrist-worn accelerometers, while our comparative datasets used other methods for measuring MVPA. First, NHANES used hip-worn accelerometers which generate lower overall accelerometer magnitudes compared with wrist-worn devices (Hildebrand, Van Hees, Hansen, and Ekelund, 2014). In a study by Hildebrand and colleagues (2014), researchers found that accelerometers worn at the wrist produced accelerations between 30 and 90% higher than those produced by accelerometers worn at the hip. An accelerometer worn at the wrist will capture arm movements that a hip-worn accelerometer may be unable to detect (Hildebrand, Van Hees, Hansen, and Ekelund, 2014). Increasingly, the use of wrist-worn accelerometers is becoming the standard in the study of PA levels due to the increased tolerance of the devices. For example, subsequent to 2006, NHANES switched to using wrist-worn accelerometry to assess time spent in MVPA. Wrist-worn accelerometry is therefore becoming increasingly relevant for cross-sample comparisons of activity.

The difference in accelerometer placement between this study and the NHANES dataset influences our ability to directly compare raw accelerometry output between these populations. However, this study used a cut-point specific to wrist-worn accelerometry so that Pokot time spent in MVPA would be more comparable to MVPA values reported for the NHANES sample. In addition, the differences in accelerometer output between the Pokot population and the NHANES population are substantial. Even after sub-setting the NHANES sample to only the top quartile of MVPA in each age group, the Pokot still engage in significantly more MVPA per day than do the US population. However, it should be noted that since this study and NHANES used different accelerometer placement, the comparison is limited.

We also compared accelerometer-derived MVPA with MVPA derived from heart rate monitor data from the Hadza (Raichlen et al., 2017). Although the comparison is not exact because of the difference in techniques used, each study used technique-specific cut-points to report time in MVPA. The Hadza study determined MVPA using heart-rate thresholds for activity intensity (Raichlen et al., 2017). The comparison therefore broadly suggests that in general, small-scale societies spend more than the CDC-recommended 150 minutes per week of MVPA and engage in lifestyles characterized by different patterns of physical activity than we see in the United States.

A comprehensive picture of Pokot health, and the way PA may impact health across the lifespan, should include not only measures of PA and cardiovascular function, but also the social determinants of population health. In recent decades, the social environment of the Pokot and neighboring pastoralist groups in Kenya have been characterized by low-intensity armed warfare and chronic violence. This inter-community violence has had important health consequences for the Pokot, especially with regards to how nutrition over the life course impacts life-long health, resilience, and identity (Pike, Straight, Öesterle, Hilton, and Lanyasunya, 2010; Pike, Hilton, Öesterle & Olungah, 2018). The impact of Pokot PA on health across the lifespan will require placing Pokot pastoralists in a richly contextualized social, political, and geographical framework.

Conclusions
The Pokot in this study are highly physically active, even into their sixth and seventh decades. Males and younger Pokot participants tend to spend more time in MVPA than do females and older participants, and more work is needed to clarify this difference. Other pastoralist groups may have similar patterns of physical activity across adolescence and adulthood, and documenting such patterns is important to our understanding of global variation in physical activity.

The human lifespan has increased significantly during our evolutionary history, and average global life expectancy today is 70 years (Gurven and Kaplan, 2007; UN WPP, 2017). Throughout most of human evolution, the primary subsistence strategy was hunting and gathering, which requires a variety of endurance-based activities (Lieberman, 2015). The increase in human lifespan therefore likely evolved while human physiology was adapted for physically active lifestyles, and thus the human aging process may also be adapted for an active lifestyle. The ability to continue contributing to subsistence communities likely necessitates the maintenance of relatively high levels of PA well into old age. Although no living group is a perfect analog for our ancestors, explorations of PA in modern small-scale societies provide a window into the conditions present during the evolution of human physiology and longevity. A more detailed understanding of how PA in living small-scale societies interacts with health across the lifespan may allow us to more fully model the role aerobic activity may have played in the evolution of human physiology and aging.

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AUTHOR CONTRIBUTIONS

MKS, ILP, and DAR designed the study. MKS and ILP performed data collection. MKS and DAR analyzed the data. MKS drafted the manuscript. MKS, ILP, and DAR edited the manuscript for intellectual content and approved the final version of the manuscript.

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Supplementary Table 1 – Participant Descriptive Information

ID	Sex	Age	Height (cm)	Weight (kg)	BMI	Wear Time (hours)	MVPA: 1-min epoch	MVPA: 10-min bout
F1	F	14	144.8	32.6	15.55	69.5	220.67	87.72
F2	F	15	153.6	41.4	17.55	47.5	196.00	75.38
F3	F	15	158.5	42.1	16.76	69.75	240.33	103.44
F4	F	22	160.9	48.5	18.73	26	53.00	21.83
F5	F	23	159.5	41.1	16.16	46.75	172.00	83.75
F6	F	24	167.6	50.5	17.98	96.5	191.33	7.44
F7	F	27	163.5	42.3	15.82	48.25	166.00	95.00
F8	F	28	171	54.8	18.74	33.5	217.00	120.08
F9	F	31	165.8	56.3	20.48	44.25	211.50	94.71
F10	F	34	162.2	45.9	17.45	46.25	149.50	76.00
F11	F	34	152	49	21.21	41.75	175.00	49.33
F12	F	40	160.5	48.7	18.91	49.25	117.00	52.25
F13	F	43	161	48.9	18.87	47.5	111.00	69.25
F14	F	45	161.5	57.2	21.93	41.75	197.00	131.46
F15	F	55	160.7	43	16.65	44.25	189.00	94.67
F16	F	56	157.9	48.6	19.49	47.75	118.00	70.17
F17	F	63	151.7	50.9	22.12	46	133.00	60.00
F18	F	78	142.4	36.6	18.05	48	26.50	4.25
M1	M	15	173.4	49.5	16.46	46	238.00	118.33
M2	M	15	165.2	48.4	17.73	71.75	246.00	114.36
M3	M	16	169.5	53.8	18.73	46.25	234.00	73.00
M4	M	18	173.9	55	18.19	41.75	238.00	163.58
M5	M	18	158	41.4	16.58	41.5	180.00	105.96
M6	M	19	163.2	51.7	19.41	46	297.00	210.71
M7	M	19	158.1	47.6	19.04	48.25	162.00	91.75
M8	M	22	165.6	57.3	20.89	67	264.33	109.92
M9	M	24	165	52.2	19.17	54.5	257.50	141.42
M10	M	29	167.4	50	17.84	43	233.50	181.50
M11	M	35	168.5	48	16.91	48	294.00	221.17
M12	M	39	170.8	56.9	19.50	33.5	244.00	111.75
M13	M	42	168.7	52.3	18.38	69.5	224.33	117.97
M14	M	43	162.6	52.5	19.86	50.25	210.00	128.33
M15	M	46	176.6	51.6	16.55	51	161.00	88.08
M16	M	48	169.4	63.2	22.02	69.5	197.67	130.72
M17	M	50	173.4	52.9	17.59	71	198.00	109.53

M18	M	53	170.4	51.4	17.70	46.25	219.00	116.58
M19	M	54	162.5	54.8	20.75	47.25	144.50	113.63
M20	M	64	170.3	59.6	20.55	46.75	150.50	49.04
M21	M	73	182.4	60	18.03	42.75	183.50	119.25
M22	M	74	180.6	70.1	21.49	42.75	80.00	52.42

Supplementary Table 2:

Table 2a: General linear model of Pokot and US[1] time spent in MVPA[2], Full NHANES[3] dataset and Pokot MVPA in one-minute epochs

Parameter	Estimate	Std. Error	t-value	p-value
Intercept	13.327	0.484	27.553	<2e-16
Sex (F)	-3.294	0.202	-16.277	<2e-16
Age	-0.074	0.005	-13.674	<2e-16
BMI	-0.189	0.015	-12.200	<2e-16
Wear time	0.199	0.055	3.602	3.17e-4
Group (Pokot)	182.489	1.680	108.609	<2e-16

[1]The US population is represented by physical activity data from the National Health and Nutrition Examination Survey (NHANES) publicly available data from 2003-4, 2005-6.
[2]MVPA is moderate-to-vigorous physical activity
[3]US sample is full NHANES sample, n=10,923

Table 2b: General linear model of Pokot and US[1] time spent in MVPA[2], Full NHANES[3] dataset and Pokot MVPA in ten-minute bouts

Parameter	Estimate	Std. Error	t-value	p-value
Intercept	13.373	0.473	28.28	<2e-16
Sex (F)	-3.282	0.198	-16.59	<2e-16
Age	-0.070	0.005	-13.21	<2e-16
BMI	-0.192	0.015	-12.69	<2e-16
Wear time	0.176	0.054	3.26	1.12e-3
Group (Pokot)	93.022	1.643	56.62	<2e-16

[1]The US population is represented by physical activity data from the National Health and Nutrition Examination Survey (NHANES) publicly available data from 2003-4, 2005-6.
[2]MVPA is moderate-to-vigorous physical activity
[3]US sample is full NHANES sample, n=10,923

Table 2c: General linear model of Pokot and US[1] time spent in MVPA[2], Subset of NHANES dataset[3] and Pokot MVPA in one-minute epochs

Parameter	Estimate	Std. Error	t-value	p-value
Intercept	34.655	1.028	33.721	<2e-16
Sex (F)	-2.195	0.400	-5.486	4.35e-08
Age	-0.318	0.010	-32.703	<2e-16
BMI	-0.217	0.035	-6.236	4.94e-10
Wear time	-0.378	0.114	-3.309	9.43e-4
Group (Pokot)	171.344	2.077	82.492	<2e-16

[1]The US population is represented by physical activity data from the National Health and Nutrition Examination Survey (NHANES) publicly available data from 2003-4, 2005-6.
[2]MVPA is moderate-to-vigorous physical activity
[3]US sample is subset of full NHANES sample with only top quartile per age group included, n=4260