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Determinants of objectively measured physical activity in rural East Timorese children

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Abstract

Objectives: The human juvenile period evolved as a period of learning and physical development in a family environment that subsidizes the costs of these processes. Children allocate energy to physical activity, maintenance, and growth. How energy is allocated has consequences for adult body size and other life-history traits. In subsistence agriculture populations, where child contributions to the household economy are common and energy availability is low, trade-offs in energy expenditure between activity and growth may help explain poor growth.

Methods: Using accelerometry, we measured physical activity over two years in 88 free-living children aged 5-19 years in two ecologically varying communities in rural Timor-Leste. We model characteristics related to variation in activity and, subsequently, activity is modeled against growth, illness, and aspects of household and local ecology using linear mixed models.

Results: Physical activity in Timorese children is characterized by high levels of moderate ($\bar{x}$ = 8.8 hrs/day), no sustained vigorous, and little sedentary activity ($\bar{x}$ = 4.6 hrs/day). Children in the mountainous community show a slight trade-off between activity and growth (p = .077). Males down-regulate both growth and activity relative to females. Variation in household characteristics does not predict child activity. Both activity and growth are lower in the mountainous community than in the flat, coastal community.

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Conclusions: Household demands on child behavior may constrain children's ability to moderate activity relative to nutritional status. Activity in this population is high relative to other subsistence populations, possibly because children face the dual pressures of contributing to household subsistence and attending school.
Key words: physical activity, trade-offs, subsistence agriculture, child growth.

Introduction

The relationship between environment and child growth is complex, and is mediated by a range of biological and socio-cultural factors (Eveleth and Tanner, 1990). This complex relationship can be conceptualized as a question of energy availability and allocation, that is, how much energy the child receives and how they partition available energy among various biological functions. For a child, energy expenditure can be allocated to growth, maintenance (including immune function), and physical activity (Ulijaszek, 1995). Where energy is limited, trade-offs in allocations must be made (Stearns, 1992). Under conditions of low energy intake (e.g., subsistence agriculture) and high disease load, physical activity levels may be reduced to facilitate energy allocation to growth. Alternatively, energy costs from requisite high activity levels may necessitate a reduced allocation to growth, resulting in growth deficits. Under conditions of both low and high energy intake, inverse relationships have been found between child physical activity and height, weight and BMI (Hawamdeh and Spencer, 2003; Jiménez-Pavón, Kelly, & Reilly, 2010; Urlacher and Kramer, 2018). Thus, the child's physical activity can contribute to growth variation both within and among populations. Understanding the nature of these trade-offs in allocations, and the patterns of prioritization under various social and environmental conditions, provides insight into causes of poor child growth.

Evolutionarily, physical activity is an element of human behavior and is subject to selection; it is both necessary for individual survival and a component of energy trade-offs. Thus, physical activity is inherently linked to the evolution of human life-history stages. The extended human juvenile period has, in part, evolved as an apprenticeship period in which juveniles can learn the cognitive skills needed to succeed in a difficult foraging niche (Kaplan, Hill, Lancaster, & Hurtado, 2000). Physical activity during childhood improves cognitive development (Sibley and Etnier, 2003). Juvenile physical activity is also associated with normal physical development; children's musculoskeletal health is improved by interventions that increase moderate-to-high intensity physical activity (Janssen and LeBlanc, 2010; Strong et al., 2005).

Physical activity also provides a medium through which children learn the physical skills required for adult survival, for example, those related to provisioning. Juvenile physical activity often manifests as play (Pellegrini and Smith, 1998). Patterns of play are responsive to local ecology, particularly to forms of subsistence. In Botswana, children's play is related to their household's types of subsistence activity, e.g., projectile aim games in hunting-based families (Bock and Johnson, 2004). Play pounding of grain is unique to young girls, as is the real grain processing activity among Botswanan women (Bock, 2002). In Belize, children imitate adult subsistence-related activities (building fires and chopping) in their play (Zarger, 2002). There is strong evidence to indicate the functional significance of childhood physical activity as preparation for adult survival and success; thus, reduced activity is likely to have long-term consequences.

Trade-offs in children's energy allocations are most likely observed in populations with limited energy availability. In times of acute energy stress, when survival is prioritized over other longer-term opportunities, reduced physical activity may be necessary for immediate survival, as may a reduction in growth. Adults under energy restriction in controlled conditions reduce their activity level (Gorsky and Calloway, 1983). However, in subsistence populations where household members work to produce food, individuals, including children, may have obligatory physical activity levels. In such economies, children are often involved in productive contributions to the household (Kaplan et al., 2000; Kramer, 2002; Ndiaye and Benefice, 2007). In Senegalese subsistence farmers, physical activity level does not differ by child nutritional status, suggesting that malnourished children are unable reduce activity levels (Benefice, 1992). Thus, in some contexts, household factors rather than individual energy balance may be a stronger determinant of activity and, therefore, the nature of energetic trade-offs.

Measurement of physical activity in children, especially under free-living conditions, is difficult (Welk, Corbin, & Dale, 2000). Accelerometry provides a simple and low-cost method to measure activity (Troiano, McClain, Brychta, & Chen, 2014). The ActiGraph accelerometer (Pensacola, FL) has been validated for children and adolescents (Hänggi, Phillips, & Rowlands, 2013; Romanzini, Petroski, Ohara, Dourado, & Reichert, 2014). The ActiGraph GT3X measures acceleration in the vertical, antero-posterior and medio-lateral planes, allowing the calculation of activity level using combined vector magnitude (Sasaki, John, & Freedson, 2011). Activity level can then be classified into intensities: sedentary, light, moderate, vigorous and very vigorous (Freedson, Pober, & Janz, 2005). Activity intensities are based on METs (metabolic equivalent of task), which express activity cost as a multiple of resting metabolic rate based on child age. Accelerometer counts can be used to estimate physical activity energy expenditure in adults; however, prediction equations are not accurate in children (Janssen et al., 2013; Trost, Way, & Okely, 2006). As such, accelerometry provides a good tool to estimate physical activity level, but not to quantify actual energy expenditure in children. Nevertheless, variation in activity levels relative to growth among children may still provide insights into energetic trade-offs.

In rural Timor-Leste, child growth is well below international standards (National Statistics Directorate [Timor-Leste], Ministry of Finance, & ICF Macro, 2010; Reghupathy, Judge, Sanders, Amaral, & Schmitt, 2012; Sanders, Judge, Pauli, Amaral, & Schmitt, 2014; Spencer, Sanders, & Judge, 2018a). Most households grow food for their own consumption; however, participation in a cash economy is also possible for some through small business ownership and salaried work (Spencer, Sanders, & Judge, 2018b). Children in households with salaries have better growth, and we suggest one pathway for this relationship is through differences in child physical activity requirements (Spencer et al., 2018b). Children contribute productively to households; in child self-recall of daily activities, 75% of all activities were work-related, including collecting water and firewood, and helping on the family farm (Spencer, 2014).

In this paper, we first characterize the physical activity patterns of rural Timorese children under free-living conditions though accelerometry, and determine the relationship of activity to growth. We then examine the regional and household-level determinants of physical activity in a subsistence agriculture setting across two geophysically and ecologically different rural locations (coastal Natarbora and mountainous Ossu) with demonstrated variation in children's growth (Spencer et al., 2017; Judge, Sanders, Spencer & Sumich, 2017).

We hypothesize that energetic trade-offs between activity and growth will explain some variation in child growth in this population. We further hypothesize that children living in households with salaries will have lower activity levels than children in agricultural households due to lower demands on child productive contributions.

Finally, we predict that poorer child growth observed in the Ossu subdistrict (compared with the Natarbora subdistrict) will be related to higher activity levels in Ossu.

Methods

Data collection

Data were collected in the Natarbora subdistrict of Timor-Leste in July-August, 2015, and May, 2016, and in the Ossu subdistrict in November, 2015, and June, 2016. Natarbora is located on the south coastal plains (5-50 m above sea level), and Ossu is in the mountains of the country's central east (600-1000 m above sea level). Maximum daily temperature in the wet season in Natarbora is 32 °C, whereas Ossu is cooler at 28 °C (Seeds of Life, 2012). Subjects were recruited from children participating in an ongoing longitudinal study of family ecology and growth by Judge and colleagues (Reghupathy et al., 2012; Spencer, Sanders, Canisio Amaral, & Judge, 2017). At six month to annual intervals, resident children were measured for height and weight, and socio-ecological data on the household were collected via interview. A sub-sample of households (n = 23; 8 Ossu, 15 Natarbora) from the longitudinal study was selected to participate in the activity study based on having a larger number of school-aged children (5-18 years; n = 88) living in the household. For logistical reasons, all participating households in this sub-study were located in the sub-community in each site closest to the community center (health care clinic and market). Where possible, the same children participated in 2015 and in 2016. Verbal consent was obtained from parents and children the day prior to the commencement of recording. Human Ethics approval was granted by the University of Western Australia (RA/4/1/2401) and the Ministry of Health, Timor-Leste.

Children wore an ActiGraph wGT3X-BT fixed on the wrist with the ActiGraph band. The ActiGraph records movement as acceleration in three planes, which are then filtered into "counts" that represent the frequency and intensity of the acceleration. It records ambient light (lux; lumens per m^2) and has a capacitive proximity sensor that detects if the device is in contact with the skin. We predicted compliance would be higher with wrist placement rather than hip placement as the devices did not have to be removed when changing clothes, bathing, etc. ActiGraphs were attached before 7am and programmed to begin recording at 7am. Children and their parents were instructed that the devices were not to be removed, and that they should be worn for all activities, including sleep, going to school, and bathing (devices are water resistant to 1m for 30min). ActiGraphs were removed at approximately 6pm three days later (e.g., 7am Monday to 6pm Wednesday), with the exception of recording periods that included a Sunday, when devices were worn for four days, to ensure three school days were recorded. Trade-offs between activity and growth (height and BMI) have been observed from as few as 1-2 days of objectively measured activity (Jiménez-Pavón et al., 2010; Urlacher and Kramer, 2018).

Upon retrieving the device, children were asked if they had removed it at any stage. We then asked the child questions relating to their health in the previous seven days. Health questions began as, "Have you been sick this week?" then proceeded with questions about the presence or absence of a set of symptoms (fever, stomach ache (diarrhea or other), cough, or runny nose). The reference to symptoms was included to gain more accurate illness data because previous findings indicated that participants might not consider the above symptoms as illness. The child's mother was asked to recall food eaten by the child in the previous 24 hours, which was coded as a food variety score (FVS) and used as a proxy for dietary intake; see Spencer, Sanders and Judge (2018b) for detailed methodology. GPS waypoints of each household participating in the study were recorded, as were major landmarks in each subdistrict including road intersections and schools. Distance to school was calculated in Garmin BaseCamp by taking straight-line distances from each child's house to their school along known routes.

Data processing & analyses

ActiLife software was used to post-process activity data. To validate wear time of the device, periods of 60 minutes with no counts were recorded as "non-wear" time (Troiano et al., 2008). This was crosschecked with data from the wear sensor on the device, which detects if the device is in contact with the skin. As children wore the device overnight, if the software flagged an hour as "non-wear" during the night, this was recorded as "wear," provided it was evident when viewing the wear sensor data that the child had not removed the device for the whole night. The same software was used to calculate percentage of time in activity levels. The cut points for different activity levels were calculated using the "Freedson children equation" (Freedson et al., 2005). This equation is based on MET cut-offs of 3 for moderate activity and 6 for vigorous activity. The calculation of these cut points uses counts per minute (cpm) from the vertical axis:

Sedentary: 0 – 149 cpm

Light: 150 – 499 cpm

Moderate: 500 – 3999 cpm

Vigorous: 4000 – 7599 cpm

Very vigorous: 7600 - ∞ cpm

Validated cut points using combined vector magnitude from all three axes is currently not available in the ActiLife software, and evidence from other brands of devices suggests time in activity levels are similar when comparing single axis counts to triaxial counts (Crouter, Horton, & Bassett, 2013). Cut points are based on 60-second epochs, so when making calculations based on 10-second epoch recordings, file length was scaled up to 60 seconds. For example, if a 60-second period contained two 10-second bursts of moderate activity and 40 seconds of sedentary activity, the entire period was recorded as "sedentary." This process may underestimate higher intensity physical activity, which tends to occur in short bursts. All other data processing and analyses were carried out in IBM SPSS Statistics Version 22.

To separate sleep time from wake time, we used a combination of the calculated percentage time spent in sedentary activity and the intensity of light (lux) as measured by the device. If percentage of time for any given hour spent in sedentary activity was greater than 85%, and the average lux for that hour was less than 50 (light level in a family living room), that hour was coded as "sleep." Children in Timor-Leste spend little time in sedentary activity; between 07:00 and 20:00, children spent between 19 and 47% in sedentary activity. Between 23:00 and 04:00, sedentary activity rose to about 90%. Using this methodology, awake time between 23:00 and 04:00 was only 0.9% in Natarbora and 0.8% in Ossu. This is likely a true representation of the sleep patterns of the sample.

Sleep time was removed, allowing aggregation of hourly physical activity into daily physical activity. Days were removed if total valid activity during wake time was less than 10 hours, that is, where children had removed devices for a large period of time (n = 18 days). Non-school days were also removed (n = 4 days). As the time spent awake varied among children, time in each activity level was converted to a percentage of each child's waking day. However, awake day length was positively correlated with sedentary activity and negatively with moderate activity. Activity was, therefore, standardized for length of waking day by regressing activity on day length with child ID as a random factor to account for repeat measures. For each child, standardized daily activity was averaged over their valid activity days (89% of children had 3 valid days). Height and weight were converted to z-height-for-age (HAZ) and z-BMI-for-age (BAZ) scores using WHO AnthroPlus software. WHO provides standards to age 18 for these values but only to age 10 for weight. While weight-for-age or weight-for-height might be a better measure, it would constrain the sample to a substantially shorter age range.

Linear mixed models were used to relate child growth to moderate physical activity. Models used child ID as a random factor to account for repeated measures of the same child. Age and sex were included as covariates. Linear mixed models were also used to relate local and household ecology to moderate physical activity. Variables relating to household ecology were selected based on previous findings of household factors that demonstrated relationships with child growth, and that we hypothesized were related to growth via demands on child activity (Spencer et al., 2018b). Included variables were: household receives a salary (yes/no), number of productive age residents adults (i.e., not children or grandparents), number of resident biological children, number of crops grown by the household, number of electrical appliances, food variety score (FVS; a proxy of dietary intake), and distance traveled by the child to school. Household was included as a random factor to account for the clustering of children within households. Mother's height was included due to its known relationship to child growth and interaction with local ecology (Spencer et al., 2018b). The inclusion of mother's height excluded 27 activity measurements due to missing data, as most mothers of fostered children could not be measured. Ossu and Natarbora were modeled separately for growth and ecology models, as both growth and the interactions between growth and household ecology differ between the two locations (Judge et al., 2017; Spencer et al., 2017; Spencer et al., 2018b).

Results

<u>Characteristics of the sample</u>

A total of 146 measurements of average daily physical activity from 88 individuals were recorded across the two subdistricts and time periods (Table 1). In Ossu, 25 (80.6%) of the 2016 measurements were of the same child as in 2015. In Natarbora, 26 (62%) of 2016 measures were replicates.

[Table 1 here]

To proxy the nutritional and energetic impacts of illness, we recorded recent illness. Across the two time periods and two sites, 66 (45%) children reported illness in the previous week (Table 1). For those children who reported illness, the most common symptoms were cough (68.2%) and runny nose (63.6%). The prevalence of these symptoms did not differ by subdistrict ($\chi^2_{(1)}$ = .208, p = .649; $\chi^2_{(1)}$ = .311, p = .577, respectively). Illness did not differ for males and females ($\chi^2_{(1)}$ = .799, p = .377).

Patterns of physical activity

Children averaged 31.4% (±7.2) of their waking day in sedentary activity, equating to approximately 4.6 hours. Children were only in light activity for 8% (±0.6) of their day ($\bar{x}$ = 1.2 hours). Children spent 60.5% (±7.3) of their waking time in moderate activity ($\bar{x}$ = 8.8 hours). No children recorded vigorous activity. A low coefficient of variation across days (0.10 in 2016 and 0.08 in 2015) indicates child activity has low variability and thus a three-day sample is likely to reflect habitual activity levels.

Children's activity profiles differed with age (Figure 1). Moderate activity levels at ages 5-10 and 10-15 were significantly higher than in children aged >15 years (LMM F = 10.57, p = 0.023). Sedentary activity increased with age (LMM F = 10.77, p < 0.001), while light activity did not differ (LMM F = 1.34, p = 0.267).

[Figure 1 here]

Male and female children did not differ significantly in their activity profiles. For both sedentary and moderate activity, there was a significant age by sex interaction (LMM $F = 4.61$, $p = 0.001$ and $F = 4.57$, $p = 0.001$, respectively); however, there were no significant differences between the sexes within age groups. The significance of the interaction term indicates a steeper age-related decline in females than in males (Figure 2).

[Figure 2 here]

Ossu children were more sedentary (LMM $t = 2.72$, $p = 0.008$) and did less moderate activity (LMM $t = -2.73$, $p = 0.008$) than Natarbora children. Light activity did not differ by subdistrict.

Physical activity and child growth

The relationships between moderate physical activity and growth parameters (BAZ or HAZ) were modeled separately for the two subdistricts due to known growth differences between the locations (Spencer et al., 2017) resulting in 4 linear mixed models. Age group and sex were included as covariates. An age group by activity interaction term was also included. Illness was not included in models, as activity was not related to whether the child was ill in the week of activity measurements.

In Ossu, there was a trend toward shorter-for-age children spending slightly more of their waking day in moderate activity than did taller children (Table 2). In Natarbora, there was no relationship between moderate activity and HAZ (Table 3). We found no other relationships between activity and growth. The inclusion of activity in the model resulted in no effect of sex of the child on growth (in contrast to all previous work in these populations; Sanders et al., 2014; Spencer et al., 2017, 2018a).

[Table 2 here]

[Table 3 here]

Physical activity and household ecology

Children providing activity measures lived in 23 households (Table 4). All Ossu households (n = 8) participated in both years. Two Natarbora households that participated in 2015 were not included in 2016 (one household moved away from the area and the other declined to participate), and one new household was included in 2016.

[Table 4 here]

Distance to school varied within and among households; some children within the same household attended different schools. In Ossu, sampled children lived, on average, 0.92 km (1.03) from school in 2015 and 0.76 km (0.76) in 2016. Natarbora children lived 1.34 km (0.73) and 1.53 km (0.68) from school in 2015 and 2016, respectively. No household-level factor varied between years, with the exception of number of crops grown in Ossu (LMM $F = 19.20$, $p < 0.001$). More crop varieties per household in 2015 is due to seasonal timing; November marks the beginning of the wet season when households first plant crops, whereas by June most crops have been harvested.

In Ossu, no household variation was related to variation in activity level (Table 5). In Natarbora, time spent in moderate activity was slightly lower in households growing more crop varieties, and slightly higher in households with more productive age adults (Table 6).

[Table 5 here]

[Table 6 here]

Discussion

This paper is the first to characterize objectively measured physical activity in rural Timorese children, and adds to the limited literature on child physical activity in subsistence agriculture populations. Children's activity levels are high; they are spending 60% of their waking day in moderate intensity activity. Overall, poor growth in this population indicates that additional nutrient intake is not available; children are unable to buffer higher levels of energy output through increased energy consumption. There is some indication of a trade-off between activity and HAZ in Ossu. Unlike patterns in well-fed populations (Trost et al., 2002), boys are not more active than girls. Relative to biological norms, males have poorer growth than females, and lower than expected activity, suggesting that both growth and activity are being down regulated in males. We find some evidence of regional influences; Natarbora children are both more active than Ossu children and have better growth outcomes, suggesting that energy availability is greater in Natarbora.

Children in Timor-Leste spend most of their day (8.8 hours) in moderate activity, more than eight times the minimum recommendation of 60 minutes per day for children in highly developed countries (Janssen and LeBlanc, 2010). There are a limited number of accelerometry studies of free-living children in developing countries, and variation in methodology makes comparisons between studies difficult. In Mayan children in a traditional subsistence agriculture economy, time in moderate and greater activity (>3 METs; "work" and "active play" categories) was approximately 6.2 hours for females and 8.2 hours for males, in an 11-hour day

(Urlacher and Kramer, 2018). Activity levels in Africa tend to be lower, even when children contribute to household production. In Mozambique, girls aged 12-16 years spent 2.3 hours in moderate activity, and boys 2.4 hours (Prista et al., 2009). Kenyan rural adolescents spent only 68 mins (males) and 62 mins (females) of their time in moderate and above activity (Ojiambo et al., 2012). Thus, Timorese children have a high level of daily physical activity, even compared to other populations where children both attend school and contribute to household subsistence.

Timorese children did not record any vigorous activity, which appears unusual given the high levels of daily activity. Vigorous activity includes running, very fast walking, and competitive sports (Butte et al., 2018). Observations during fieldwork indicate that children, especially males, do run and play high intensity games such as soccer. The scaling of accelerometer output to 60-second epochs means short peaks of vigorous activity are smoothed and vigorous activity may be underestimated (Edwardson and Gorely, 2010). However, using accelerometry, normal, healthy US boys (4.4-7 years old) perform 38 mins of vigorous activity per day, and girls 28 mins (Janz et al., 2004). No vigorous activity in this population may suggest constraints on children's total energy available for activity. As vigorous activity is energetically costly (≥6 METS), Timorese children may be moderating their overall energy costs by reducing vigorous activity.

In Ossu (but not in Natarbora), there was a trend for shorter-for-age children to spend more time in moderate activity. As HAZ is a measure of long-term growth, this relationship suggests a long-term trade-off between growth and activity. This relationship was neither strong nor consistent across the two field sites. In Mayan children, where activity levels are similar to those of Timorese children, activity is inversely related to body size, indicating the presence of a trade-off (Urlacher and Kramer, 2018). However, in sub-Saharan Africa, no trade-off was found between nutritional status and activity level in either a transitioning economy (Prista, Maia, Damasceno, & Beunen, 2003) or a subsistence population (Benefice, 1992), nor was it demonstrated in urban poor children in Colombia (Spurr, Reina, & Barac-Nieto, 1986). In the context of subsistence agriculture, where children contribute to domestic tasks and attend school, they may have inflexible demands on their physical activity, regardless of nutritional status. The 60% of waking time that Timorese children spend in moderate activity and the lack of recorded vigorous activity suggest that, while activity budgets are energetically constrained, moderate activity may not easily be reduced.

Life history theory predicts a trade-off between immune function, growth, and physical activity when energy is limited. Evidence for a trade-off between immune function and growth has been found in the Tsimane in Bolivia (McDade, Reyes - García, Tanner, Huanca, & Leonard, 2008), and between illness, physical activity and growth in coastal Kenya (Adams, Stephenson, Latham, & Kinoti, 1994). In Timor-Leste, we found no evidence of a trade-off of activity with self-reported illness. Illness was common, with close to 50% of children ill in the previous week. With low variance in the independent variable, relationships are more difficult to discern. High activity levels may constrain energy available for maintenance allocations, thus illness may be more likely with unmediated activity. Some studies have suggested peer pressure influences physical activity level, and may interfere with responses to reduce activity (Benefice, 1992; Spurr et al., 1986). Thus, behavioral responses to common and mild illnesses may not be occurring in this population, hence the lack of a demonstrated trade-off between illness and activity.

Males typically have higher activity levels than do females (Trost et al., 2002); however, in the Timorese population, boys and girls are similarly active. Equal activity suggests males may be moderating their physical activity relative to biological norms. Timorese males consistently have poorer growth than do females (Reghupathy et al., 2012; Sanders et al., 2014; Spencer et al., 2018a). We have previously hypothesized that the sex difference in growth is due to either higher male activity level, or increased male susceptibility to disease. These results counter the activity hypothesis; male growth *and* activity are reduced compared to females in the same environment, suggesting high male energy allocation to maintenance. Males and females differ in their immune system activation throughout development, and males are more susceptible to infection than are females (Klein and Flanagan, 2016; Muehlenbein and Bribiescas, 2005). In this study, males did not report being ill more than did females; however, our measure of illness is broad and may not be discriminating well.

Most studies of children's physical activity show a decrease in activity with age, (for example, Armstrong and Welsman, 2006; Nader, Bradley, Houts, McRitchie, & O'Brien, 2008). Timorese girls experienced a steeper decline in activity with age than did boys, which contrasts with other studies' findings that the decline is greater in males (Sallis, 2000; Trost et al., 2002). In a larger sample of the children in these communities, female BMI increases considerably more than male BMI between the ages of five and 15 (Spencer et al., 2018a). Thus, females can recoup body mass at older ages through a decrease in activity. Males may be unable to reduce activity at older ages, possibly due to sex differences in subsistence demands or social behavior. This would further constrain male energy available for growth.

Variations in household-level ecological measures among 23 households did not strongly predict physical activity. Children in Natarbora households with more productive-age adults in the household spent slightly more time in moderate activity. Previously, we found that households with more adults and biological children were associated with poorer child growth, and suggested that this household composition may place more demands on resident children to contribute productively (Spencer et al., 2018b). Higher activity levels may be explained by demands on children's labor to underwrite higher household costs.

Environmental influences on activity were more evident at a population level. Natarbora children register more activity than Ossu children as well as better growth (Spencer et al., 2017). Higher activity and better growth in Natarbora than in Ossu suggests that current conditions are better in the former (i.e., energy availability is less constrained in Natarbora). Differences in activity between the locations are therefore not due to differential allocations of energy to growth and to activity, but due to overall resource levels. In Ossu, where conditions are poorer, children appear to down-regulate both their activity and their growth.

The estimation of activity used here has been validated in children against running, walking and free-living activities (Freedson et al., 2005). However, future research using accelerometry in subsistence populations would benefit from specific validation studies and caloric estimates of activities unique to children in these populations. Furthermore, Natarbora children in this study live at ~40 m above sea level on flat terrain, whereas Ossu children live ~650-750 m above sea level on mountain inclines. In the absence of specific validation studies, we cannot discount the possibility that the Actigraph equations used may underestimate the cost of physical activity in mountainous terrain.

In rural Timor-Leste, poor growth and high activity levels in a low energy environment indicate an inability for children to moderate their activity level in order to reduce overall energy costs. This may be because families are reliant on child contributions to subsistence through their participation in domestic and agricultural tasks, that is, child productivity is necessary for household survival.

Children's help is common across a range of subsistence modalities, and contributes to the household's ability to support multiple dependent children (Kramer, 2002; Kramer, 2005). However, in terms of the *child's* fitness, child contributions should have a low fitness cost to the child, and increase their embodied capital through providing them with skills for adult productivity (Bock, 2002; Kramer, 2005). When energy expended through helping is non-negotiable and limits energy available for growth, embodied capital may in fact decrease, as poor childhood growth can reduce adult work capacity (Spurr, 1983). Thus, where child contributions are important for their short-term survival via the household's success, but energy is limited and the energetic costs of helping are high, helping may incur adult fitness costs.

In transitioning economies like Timor-Leste, the effects of child contributions are compounded by school attendance, which increases energy expenditure through travel to school and participation in scheduled activities. In rural Ethiopia, households are faced with the conflicting decisions to either use child labor to survive, and to pass on agricultural skills to children, or to invest in a different type of embodied capital through education that will pay off only if jobs are available (Admassie, 2003). In Timor-Leste, where school attendance is compulsory, rural poor children have little option but to participate in both. Thus, children face more demands on their time and energy than children in purely subsistence ecologies, limiting their ability to reduce physical activity to preserve growth under caloric restriction.

Physical activity levels in rural Timorese children are high, and are governed by complex interactions between subsistence demands, biological factors, and local nutritional constraints. Changes that arise with the demographic and economic transition, such as lower family size, and improved infrastructure, are likely to reduce child activity, and therefore promote better growth.

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Author contributions

D.S.J. and P.R.S. designed the study. P.R.S. collected and analyzed data, and wrote the manuscript. D.S.J. and K.A.S. provided critical feedback and editorial advice on the manuscript. The authors declare that they have no conflict of interest.

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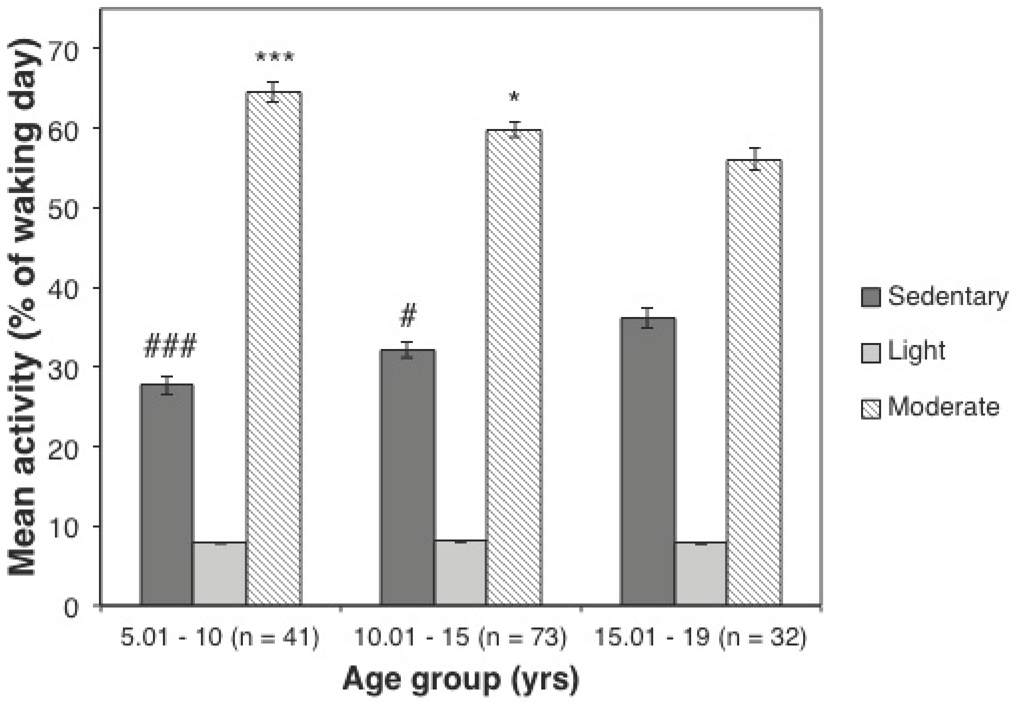
Mean activity (% of waking day)
70
60
50
40
30
20
10
0
###
***
#
*
Sedentary
Light
Moderate
5.01 - 10 (n = 41)
10.01 - 15 (n = 73)
15.01 - 19 (n = 32)
Age group (yrs)

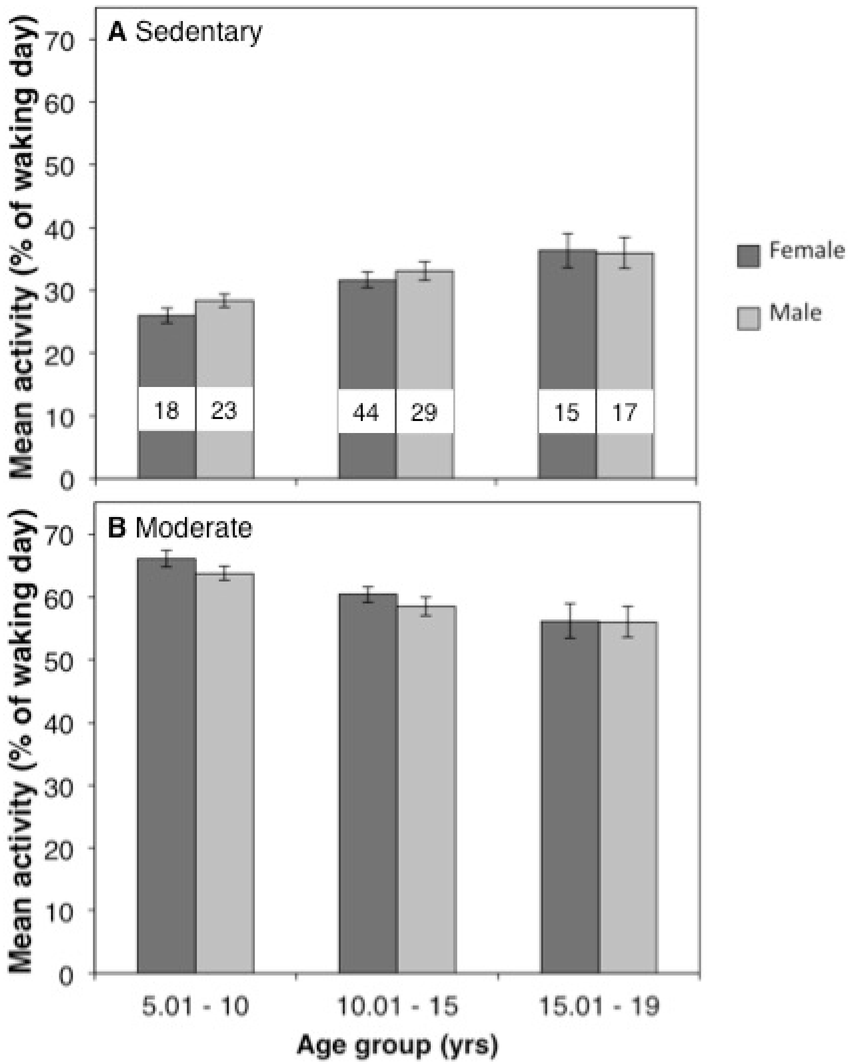
A Sedentary
B Moderate
Mean activity (% of waking day)
0
10
20
30
40
50
60
70
18
23
44
29
15
17
Female
Male
5.01 - 10
10.01 - 15
15.01 - 19
Age group (yrs)

Table 1: Characteristics of participants by location and measurement time period. Results presented are either mean (SD) or number of children.

	Ossu		Natarbora	
	2015 (Nov)	2016 (June)	2015 (Jul/Aug)	2016 (May)
n	31	31	42	42
$\bar{x}$ Age (SD)	12.03 (3.43)	11.95 (3.30)	12.38 (2.74)	12.66 (2.71)
$\bar{x}$ HAZ (SD)	-2.00 (1.05)	-1.95 (.99)	-1.77 (.74)	-1.79 (.75)
$\bar{x}$ BAZ (SD)	-1.00 (.78)	-1.00 (.66)	-1.30 (1.02)	-1.39 (1.08)
$\bar{x}$ Length of waking day (hrs; SD)	14.83 (.85)	14.38 (.56)	14.28 (.95)	14.67 (.78)
Sex (n ♀)	16 (51.6%)	12 (38.7%)	24 (57.1%)	25 (59.5%)
Reporting ill in past week (n yes)	14 (45.2%)	15 (48.4%)	20 (47.6%)	17 (40.5%)

Table 2: Linear mixed model of HAZ for Ossu children (n = 62 measurement occasions) relative to moderate activity. Results are presented as estimated marginal means (EMM) for categorical variables† and parameter estimates. Reference categories for categorical variables are in parentheses.

		Estimate (SE)	EMM (SE)	t	p
Intercept		-.43 (.83)		-.52	.605
Sex	female	.12 (.33)	-1.98 (.25)	.37	.717
	(male)		-2.10 (.23)		
Age group	5.01-10	-1.61 (1.66)	-2.00 (.26)	-.97	.340
	10.01-15	.21 (1.20)	-2.24 (.22)	.17	.864
	(>15)		-1.87 (.31)		
% waking day in moderate activity		-.03 (.01)		-1.83	.077
Age x activity interaction					.438

† Covariates appearing in the model are evaluated at the following values: % waking day in moderate activity = 58.13

Table 3: Linear mixed model of HAZ for Natarbora children (n = 84 measurement occasions) relative to moderate activity. Results are presented as estimated marginal means (EMM) for categorical variables† and parameter estimates. Reference categories for categorical variables are in parentheses.

		Estimate (SE)	EMM (SE)	t	p
Intercept		-.81 (1.25)		-.65	.520
Sex	female	.16 (.21)	-1.66 (.15)	.76	.451
	(male)		-1.82 (.16)		
Age group	5.01-10	.79 (2.16)	-1.58 (.21)	.37	.716
	10.01-15	-.95 (1.60)	-1.74 (.13)	-.60	.554
	>15		-1.90 (.21)		
% waking day in moderate activity		-.02 (.02)		-.89	.380
Age x activity interaction					.667

†Covariates appearing in the model are evaluated at the following values: % waking day in moderate activity = 62.30

Table 4: Characteristics of households by location and measurement time period. Results presented are either mean (SD) or number of households.

	Ossu		Natarbora	
	2015 (Nov)	2016 (June)	2015 (Jul/Aug)	2016 (May)
N households	8	8	14	13
# productive age adults per hh ($\bar{x}$)	2.0 (.9)	1.9 (.8)	2.6 (.9)	2.5 (.7)
# biological children per hh ($\bar{x}$)	3.8 (2.2)	3.8 (2.2)	3.6 (2.0)	3.7 (1.8)
# crops grown ($\bar{x}$)	11.4 (3.7)	4.9 (2.0)	3.0 (3.9)	3.4 (3.8)
# appliances ($\bar{x}$)	5.5 (2.5)	5.3 (1.8)	4.1 (2.3)	4.3 (2.3)
Food variety score ($\bar{x}$)	5.9 (1.7)	5.7 (1.1)	4.8 (1.4)	4.1 (1.6)
Salary (% of households with salary)	62.5	62.5	35.7	46.2

Table 5: Linear mixed model of ecological predictors of moderate physical activity in Ossu with parameter estimates and estimated marginal means (EMM) for categorical variables (n = 62 measurement occasions; n = 7 households)†. Reference categories for categorical variables are in parentheses. Household and child ID are both included as random factors.

Parameter	Estimate (SE)	EMM (SE)	Sig.
Intercept	24.00 (86.06)		.811
Salary: No	13.78 (7.56)	66.61 (5.38)	.220
(Yes)		52.83 (3.62)	
# productive adults	.68 (4.58)		.890
# crops	-.18 (.26)		.491
FVS	.54 (1.24)		.680
# biological children	.77 (1.82)		.685
# appliances	1.30 (1.12)		.289
Distance to school	-.72 (1.55)		.646
Mother's height	.10 (.58)		.881

†Covariates appearing in the model are evaluated at the following values: # crops = 7.66, # biological children = 4.68, # appliances = 5.50, # productive adults = 2.32, distance to school = 0.78 km, food variety score = 5.86, mother's height = 153.79 cm.

Table 6: Linear mixed model of ecological predictors of moderate physical activity in Natarbora with parameter estimates and estimated marginal means (EMM) for categorical variables (n = 75 measurement occasions; n = 14 households)†. Reference categories for categorical variables are in parentheses. Household and child ID are both included as random factors.

Parameter	Estimate (SE)	EMM (SE)	Sig.
Intercept	57.62 (48.61)		.357
Salary: No	-1.03 (2.29)	62.06 (1.24)	.662
(Yes)		63.09 (1.76)	
# productive adults	2.16 (1.07)		.051
# crops	-.43 (.23)		.076
FVS	.52 (.34)		.129
# biological children	-.40 (.73)		.591
# appliances	.32 (.56)		.581
Distance to school	.67 (2.09)		.754
Mother's height	.06 (.32)		.861

†Covariates appearing in the model are evaluated at the following values: # crops = 3.48, # biological children = 4.20, # appliances = 4.04, # productive adults = 2.49, distance to school = 1.52 km, food variety score = 4.47, mother's height = 149.74 cm.