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Physical Activity and Pregnancy Norms Among Daasanach Semi-Nomadic Pastoralist Women in Northern Kenya

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ABSTRACT

Objectives: In subsistence populations, high physical activity is typically maintained throughout pregnancy. Market integration shifts activity patterns to resemble industrialized populations, with more time allocated to sedentary behavior. Daasanach semi-nomadic pastoralists living in northern Kenya face lifestyle heterogeneity due to the emergence of a market center. We investigate how Daasanach women manage the energetic demands of pregnancy with subsistence labor tasks and how market integration relates to variation in energetic demands, physical activity, and coping strategies.

Methods: We conducted nine focus group discussions with 72 pregnant women. We also deployed wrist-worn fitness trackers with 21 pregnant women in two community types: central or peripheral to the market center to capture variation in market integration. Data from focus group discussions were analyzed using thematic analysis. We used multiple linear regression to examine the relationship between gestational age and physical activity.

Results: We identified themes of increased fatigue, diet restrictions, and assistance with labor tasks during pregnancy. Gestational age negatively predicted mean daily steps, with a decrease of 1160 ± 437 steps per day with each consecutive pregnancy month. Stratified by community type, gestational age only negatively predicted mean daily steps for peripheral communities, with a decrease of 1443 ± 629 steps per day with each consecutive pregnancy month.

Conclusions: Results suggest that physical activity differs with market integration early, but not late, in pregnancy. Daasanach women cope with the energetic demands of pregnancy by reducing physical activity late in pregnancy and receiving assistance with labor tasks from family and neighbors.

1 | Introduction

In small-scale, subsistence-based economies, where daily activity is tied directly to food procurement and other labor-intensive household tasks, physical activity (PA) may be a competing energy cost with pregnancy. The degree to which PA can be modified may be more dependent on available kin and social support compared to industrialized populations (Madimenos et al. 2011). The high energy requirements of pregnancy and lactation (Butte and King 2005; Forsum and Löf 2007; Savard et al. 2021), coupled in some cases with decreased productivity by the pregnant individual (Madimenos et al. 2011), are offset by increased energy input from nonpregnant, nonlactating group members. This phenomenon has been observed among several subsistence-based populations, such as the Shuar forager-horticulturalists (Madimenos et al. 2011), Hadza foragers (Marlowe 2003), and Brazilian Ribeirinho horticulturalists (Piperata 2009). Provisioning by older female kin, male partners, and other kin members is central to hypotheses for human longevity (the grandmother hypothesis and the embodied capital hypothesis); intergenerational transfer of energy, resources, and knowledge (the embodied capital hypothesis and the pooled energy budget hypothesis); and human pair bonding patterns (Hawkes et al. 1998; Kaplan et al. 2000; Kramer and Ellison 2010; Marlowe 2003; Reiches et al. 2009). Thus, PA patterns during pregnancy, through changing modes of provisioning within the social group, relate to the evolution of unique human life history and behavioral traits.

There are two non-mutually exclusive strategies proposed for managing the high costs of human pregnancy: (1) metabolic strategies, which involve changes to maternal physiology and energy metabolism, and (2) behavioral strategies, which involves changes to PA and other lifestyle factors and increasing food intake (Madimenos et al. 2011). It is likely that both strategies work in tandem. Reducing PA volume and/or intensity may alter the pattern of energy allocation in the maternal system to devote more energy to pregnancy, particularly directed toward the products of conception and maternal fat stores.

One of the most comprehensive characterizations of PA patterns and energy costs during pregnancy in subsistence populations was in the Tamang population of rural Nepal (Panter-Brick 1989; Panter-Brick, Lotstein, and Ellison 1993). Researchers found that Tamang women's workloads changed very little during pregnancy when there was a high demand for labor during the harvest season (i.e., July through September). Estimated energy expenditures also remained elevated in the harvest monsoon season compared to the dry season, irrespective of reproductive status. A similar pattern was documented in measured energy expenditure (via doubly labeled water method) for rural, agricultural Gambian women. Singh et al. (1989) found these women engaged in higher workloads and had significantly higher energy expenditures compared to sedentary English women during pregnancy in analyses controlling for gestational age.

Many subsistence-based populations are currently undergoing market integration with regional and national market economies and the associated commodification of food, goods, and labor (Lu 2007). As a result, PA becomes decoupled from direct food procurement when market goods and labor-saving technologies are introduced. Exposure to processed market foods may alter health biomarkers and influence disease outcomes (Lea et al. 2020; Liebert et al. 2013; Snodgrass et al. 2010). There is also evidence for increased sedentarism with market integration, particularly greater decreases in female PA compared to male PA and the associated increase in female fertility (Bocquet-Appel 2011; Kraft et al. 2021; Page et al. 2016; Shephard and Rode 1996; Snodgrass et al. 2006). Labor-saving technologies introduced to Mayan subsistence agriculturist and Ethiopian agropastoralist populations during the transition to a market economy were associated with increased female fertility, indicating more energy available for reproduction with decreased PA (Gibson and Mace 2002, 2006; Kramer and McMillan 1998). Shifting energy away from PA and allocating it toward reproduction not only increases fertility, but may also increase investment in each individual pregnancy and offspring (Sadhir and Pontzer 2023). By studying dietary and PA patterns during pregnancy in populations undergoing market integration, we may further understand how in utero exposures may influence health in later life, especially as overweight, obesity, and metabolic syndrome become prevalent in populations experiencing market integration (i.e., the developmental origins of health and disease hypothesis) (Lea et al. 2020; Liebert et al. 2013; Snodgrass et al. 2010).

In this paper, we examined PA patterns and strategies used to manage subsistence-based PA among pregnant Daasanach women living varied degrees of their traditional lifestyle. We were primarily interested in two research questions: (1) how do Daasanach women behaviorally accommodate the energy costs of pregnancy alongside subsistence labor tasks, and (2) how does market integration influence these strategies? To address these questions, we used a mixed methods approach to obtain qualitative perspectives on pregnancy norms from pregnant Daasanach women and quantitative PA measurements at different stages of pregnancy.

2 | Materials And Methods

2.1 | Study Population

The Daasanach are a semi-nomadic pastoralist population living in northern Kenya and southern Ethiopia. We focused on a subset of the population who reside in Kenya, on the northeast shore and inland east of Lake Turkana, in a hot and arid environment. Monthly average daytime maximum temperatures for the closest weather station at Lodwar (149.2 km southeast of Illeret) ranged 32°C–36°C over the last 12 years (World Weather Online 2023). The region experiences two rainy seasons (March–May; October–December) and two dry seasons (May–October; December–March) per year. Overall, the region remains relatively dry, with an average yearly rainfall of 216.77 mm between 1950 and 2012, concentrated during the two rainy seasons (Opiyo et al. 2014; World Weather Online 2023). In addition, this region experienced an extreme, prolonged drought during the study duration.

This research was conducted as part of the Daasanach Health and Life History Project, which has been ongoing since 2017 in association with the Koobi Fora Research and Training Program.

Overall, this project aims to characterize health, well-being, nutrition, water and food insecurity, and socioecological stressors longitudinally in the Daasanach population as they become more market integrated (Bethancourt et al. 2021, 2023; Ford et al. 2023; McGrosky et al. 2024; Rosinger et al. 2021a, 2021b, 2024; Swanson, Bethancourt, et al. 2023; Swanson, Nzunza, et al. 2023).

For this study, we dichotomize communities as either central or peripheral, distinguished by proximity to the market center, Illeret as a way to capture exposure to market integration, which comes with differential access to food, aid, education, and healthcare. Distance to market has been used previously in studies of small-scale populations to define market integration (Lea et al. 2020; Swanson, Bethancourt, et al. 2023). GPS coordinates for communities were previously collected during 2018–2020 field seasons and were used to determine distance to Illeret. Central communities were classified if they existed within a 4 km radius of Illeret; that is, the market is easily accessible on foot (Figure 1).

Permanent ("central") settlements can be found in and around the town of Illeret, the emerging market center with permanent buildings, including the Illeret Health Clinic (IHC) and a few shops selling food and essential household items. Labor tasks for women in central communities are more confined to the immediate area, since the goods and services are easily accessible. Since central communities are more permanently situated, women are not expected to spend as much time building houses and other structures.

Beyond the market center (>4 km radius) are traditional, nomadic ("peripheral") settlements and the fora, the Daasanach word for unsettled grazing land with scattered, small satellite camps. Labor tasks for women in peripheral communities requires further travel to access water, food resources, firewood, and home building materials, as well as labor tasks required for more frequent moves and home construction. Though we define a dichotomous central–peripheral distinction, there remains an overlap between the two community types, and a continuum exists between permanent and nomadic lifestyles.

Several patterns of movement are apparent among the Daasanach. Most households have at least a few members (men and teenaged boys) who travel periodically to the fora to graze livestock. Some households are entirely nomadic and move periodically. Pastoralism is the main source of subsistence in this population, though some agricultural activities have been attempted in the past (Almagor 1983; Tosco 2001). Much of the plant-based foods in the diet are purchased from shops in the market center, markets across the border in Ethiopia, and/or traveling merchants. Daasanach practice traditional gendered roles and norms, and a polygynous family structure. Women often marry in their late teenaged years and assume all domestic roles within their families (Almagor 1983).

2.2 | Ethical Approval and Consent

This research was approved by the Institutional Review Board of Pennsylvania State University (STUDY00009589) and the Kenya Medical Research Institute (KEMRI 3739, 4942) and conforms to human research standards outlined in the Declaration of Helsinki. Permission was also obtained from the Director of Health in the county government of Marsabit, Kenya and from community leaders.

All participants provided written and verbal informed consent. Both English and Daasanach consent forms were available for

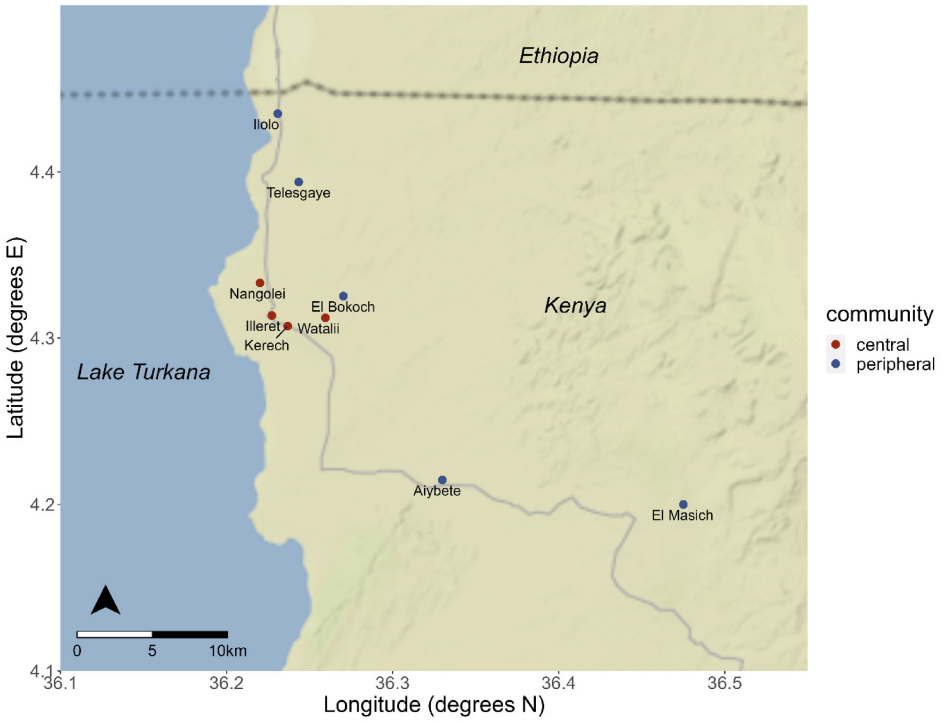

FIGURE 1 | Map of the study region, with communities where data collection took place, designated by central (red) and peripheral (purple) community types.

use and reference throughout the field season. Since the low level of literacy in the Daasanach population would preclude adequate comprehension of written documents, we delivered the terms of consent verbally in English, which were then translated to Daasanach for prospective participants. Each participant placed their thumbprint on the consent form adjacent to their printed name. Both the research team member and translator signed and dated the consent form. R. N. oversaw consent documents as representative of the Kenya Medical Research Institute.

2.3 | Participant Recruitment

Most data were collected in June and July 2022. A smaller subset of our team traveled to northern Kenya earlier in the year (February 2022) to conduct focus group discussions (see below). In total, we recruited 85 pregnant Daasanach women from nine communities (four central and five peripheral) to participate in PA monitoring and/or focus group discussions (Figure 1). The eligibility criterion for this study was women who self-reported as currently pregnant. Community health workers and translators assisted with the recruitment process. Recruitment consisted of word-of-mouth advertisement of research aims and the eligibility requirement.

2.4 | Demographic Data Collection

Demographic data included estimated maternal age, number of births, number of children, and estimated gestational age (in months). Since the Daasanach do not follow the same timekeeping system as industrialized nations, maternal age and gestational age were estimated in reference to important events and seasonal variation. To estimate gestational age, we visually assessed abdominal size and further clarified by asking participants when they expected to give birth and referenced important events and seasonal variation to identify when they first knew about their pregnancies.

2.5 | Focus Group Discussions

Before measuring PA, we (S.S., L.B.F., S.N.W., H.M., R.N.K.) obtained firsthand accounts and perspectives on pregnancy and postpartum norms from pregnant Daasanach women with assistance from Daasanach translators. Our goal was to determine the perceptions and attitudes toward domestic workload, diet, and healthcare use. We conducted nine focus group discussions, three in central communities (Illeret, Kerech, and Watalii) and six in peripheral communities (Aiyebete, El Masich, Iloro, Telesgaye, and two different groups in El Bokoch) (Figure 1) during February 2022 and June–July 2022, determined to be an adequate sample size to reach thematic saturation (Hennink and Kaiser 2022). Each focus group comprised of up to 12 pregnant women. Given the polygynous family structure, relatively small population size, and tight-knit communities, the women very likely knew one another, though we did not explicitly ask about relationships. A total of 72 women participated across all focus groups. Daasanach translators and community health workers aided by translating responses into English. Conversations were recorded with an audio recorder, and two members of the study team also took detailed notes on all responses.

We collected data on reproductive health care utilization and whether the IHC was used for antenatal care. In addition to demographic data, we asked participants to report their ideal number of children. Participants were asked as a group to list and rank daily tasks with time and difficulty for completion, as well as changes in task engagement during early pregnancy (in the first half of pregnancy), late pregnancy (in the second half of pregnancy), and the postpartum period (in the first month after giving birth). Similarly, participants were asked as a group to list and rank foods eaten based on preference and frequency of consumption, as well as changes in the frequency of consumption during early pregnancy, late pregnancy, and the postpartum period. Finally, we considered the essential water-gathering task which Daasanach women are expected to undertake. Participants were asked as a group to discuss the biggest water problems in the area, water borrowing and lending habits and attitudes, and reasons for participating in water sharing practices.

2.6 | Qualitative Analyses

Detailed written notes taken during focus group discussions were digitized and organized in Microsoft Excel to view all responses from all focus groups, and from all individuals within a focus group. We then applied thematic analysis methods to these data, where we identified key themes and phrases across focus groups (Bender and Ewbank 1994; Onwuegbuzie et al. 2009; Rabiee 2004).

2.7 | Physical Activity Monitoring

We recruited 21 pregnant women (9 from central communities and 12 from peripheral communities) for PA monitoring over 5 days during the summer field season. At recruitment, we collected demographic data on each participant (see above). We then gave each participant a wrist-worn Withings Pulse HR device, a consumer-grade fitness tracker which measures steps, distance, heart rate, sleep metrics, and exercise metrics. On Day 5, we returned to participants' homes to collect fitness trackers. Devices were synced to the Withings Health Mate application via Bluetooth on researcher smartphones. Data were downloaded from the application to a research laptop computer in the form of raw CSV files.

The Withings Pulse device series has been used and validated in existing research studies (Kooiman et al. 2015; Tedesco et al. 2019). In a longitudinal study of 20 endurance pregnant endurance athletes by the authors (S.S., A.M., H.P.), the Withing Pulse HR device was validated against the gold-standard ActiGraph wGT3X-BT accelerometer. This cohort was recruited in the United States and Canada but is of a similar maternal age to the Daasanach women enrolled for PA monitoring in the current study (endurance athletes: 32.1 ± 1.9 years; Daasanach women: 31.2 ± 7.4 years). Mean absolute percentage error for mean daily steps, the metric of

interest for this analysis, was 34.1% between Withings and ActiGraph devices. In a linear regression model, mean daily steps was 80.0% similar between Withings and ActiGraph ($\beta = 0.82$, $p < 0.001$, $R^2 = 80.0\%$) (Figure 2).

2.8 | Anthropometric Data Collection

We collected anthropometric data at the end of PA monitoring on Day 5 when the participant returned the fitness tracker to us. We measured height (cm) using a Seca 213 portable stadiometer, and we measured weight (kg), body fat (%), and total body water (%) using a Tanita BF-679W bioelectrical impedance scale. BMI was calculated from weight and height measurements.

2.9 | Quantitative Analyses

We used multiple linear regression models to test the association between gestational age (predictor) and mean daily steps (outcome), with community (dichotomous: central or peripheral) and maternal age (continuous) as covariates. We did not include heart rate data, since we did not measure heart rate at rest for each participant prior to conception, a constraint of the cross-sectional study design. We did not include "minutes of exercise" ascertained by the Withings Pulse HR fitness tracker, since this metric is not validated.

We assessed normality in residual distribution to determine the model of best fit using several methods. The QQ plot, density plot, and ECDF plot all indicated approximately normal distribution. Results from the Shapiro–Wilk test also indicate approximately normal distribution ($W = 0.98$, $p = 0.90$), so multiple linear regression (Gaussian) was chosen for the models. Because of the exploratory nature of this study, we did not have power with $n = 21$ participants to test an interaction effect between gestational age and community. Instead, we stratified the regression models by community type: central and peripheral.

3 | Results

3.1 | Focus Group Discussions

Descriptive statistics for focus group discussion participants are presented in Table 1. Participants living in central communities were slightly older (31.5 ± 6.6 years) than those living in peripheral communities (28.4 ± 6.8 years; $p = 0.05$; Table 1). Participants across both community types had a similar number of living children (5.5 ± 2.5 vs. 6.2 ± 2.7 children, $p = 0.25$ Table 1). A higher percentage of participants living in central communities used the IHC for antenatal and/or delivery care during any current and/or previous pregnancies (35.5%) than those living in peripheral communities (22.7%), but differences were not statistically significant ($p = 0.49$; Table 1).

Nearly all participants reported taking their newborns to the IHC after birth for after-delivery care and important vaccinations, regardless of how far from the market center they live. Participants stressed the importance of vaccines in preventing infectious disease outbreaks and spread, and the importance of doctors for treating diseases.

The IHC is rarely used for antenatal care and delivery, with the exception being maternal tetanus vaccination during pregnancy. Vaccines are often received via mobile clinics and community outreach by IHC staff. The greatest barrier to IHC use during pregnancy and delivery is distance to the clinic, with women living further away less likely to visit the IHC. Since the time of delivery is unpredictable, it might be impossible to get to the IHC on foot in time to deliver. One participant (age 43 years) expressed fear of "delivering in the road" if she was traveling the long distance from her home to the clinic to give birth. Another participant (age 33 years) was concerned that she would not find

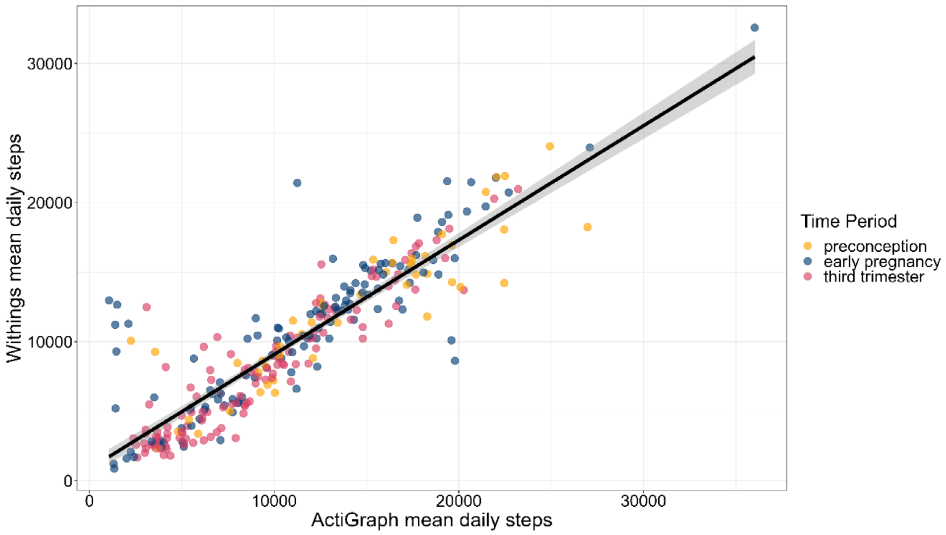

FIGURE 2 | Regression plot (with 95% confidence interval) of ActiGraph-derived mean daily steps, on the *x*-axis, and Withings-derived mean daily steps, on the *y*-axis, among pregnant endurance athletes ($n = 20$) across three weeklong measurement periods: preconception, early pregnancy (8–22 weeks), and third trimester (32–35 weeks).

TABLE 1 | Descriptive statistics for focus group discussion participants.

Measure	Central	Peripheral	*p*	Communities combined
Number of participants (*n*)	31	41		72
Maternal age (years)	31.5 (6.6)	28.4 (6.8)	0.05	30 (6.8)
Nulliparity	1 (3.2%)	1 (2.4%)	0.84	2 (2.8%)
Number of living children	5.5 (2.5)	6.2 (2.7)	0.25	5.9 (2.6)
Received antenatal and delivery care at the illeret health clinic	11 (35.5%)	5 (22.7%)[a]	0.49	16 (30.2%)[a]

Note: Data are reported in means (SD), or counts (%).
[a]Five of 22 peripheral participants answered "yes," and the remaining 18 peripheral participants did not respond to this question.

TABLE 2 | Common labor tasks reported by Daasanach women in consensus during focus group discussions.

Labor tasks	Change in early pregnancy	Changes in late pregnancy
Childcare	Decrease	Decrease
Collecting firewood	No change	Decrease
Construction of home and livestock enclosures	Decrease	Decrease
Cooking	No change	No change
Fetching water	Decrease	Decrease
Foraging and farming tasks	Decrease	Decrease
Laundry	Decrease	Decrease
Milking livestock	No change	No change
Tending livestock	No change	Decrease

Note: Women were asked to report any changes in task engagement in early pregnancy and late pregnancy, when compared to the preconception period. We report the most common response across all focus groups for each task and time period.

a doctor quickly when in labor due to the small number of physicians and nurses working at the IHC.

3.1.1 | Theme 1: Changes in Food and Water Consumption

We asked participants about dietary norms during pregnancy. Food availability was the primary determinant of which foods were eaten, but there were some dietary preferences and patterns noted. Participants unanimously agreed across focus groups that pregnant women eat less because they lack an appetite and consume more water instead. This dietary pattern was also mentioned by community members outside of focus group settings, including by men and nonpregnant people. It is unclear if the general loss of appetite is a widespread trend, or if total consumption (kcal/day) actually decreases, which would be unexpected. Participants also reported an increase in fish consumption and a decrease in sugar consumption during pregnancy, the latter only being used to sweeten tea, stating that it was a personal preference rather than a cultural value. At the time of the study, drought conditions promoted greater fish consumption across the Daasanach population, so the pattern in increased fish consumption for pregnant women might track a broader population-level trend.

3.1.2 | Theme 2: Fatigue and Concerns About Harming the Fetus During Physical Activity

We asked participants about their perspectives on PA and physical labor tasks during pregnancy. Common labor tasks and level of engagement in pregnancy are reported in Table 2. Participants explained that they feel highly fatigued in their pregnancies and are helped by their children, neighbors, and relatives, most often female adults. They still reported remaining active until delivery: walking long distances, doing a variety of household tasks, and looking after their families. There was also much discussion across focus groups about the need to reduce arduous weight-lifting and bending tasks, including firewood collection, construction of homes and livestock enclosures, fetching water, and laundry, during pregnancy. These tasks were viewed as dangerous, with widespread fear of harming the fetus.

3.1.3 | Theme 3: Assistance With Labor Tasks From Family and Friends

Participants noted that when gathering firewood during pregnancy, they are often accompanied by others for fear of having an accident. Fetching water was reported as the most physically demanding of all tasks. They reported collecting less water (5 L

or less at one time) and borrowing water from friends and relatives during their pregnancies. Water borrowing was most prevalent if a pregnancy occurred during the dry season, yielding environmental conditions that are likely associated with longer travel times to fetch water. Notably, there were no differences reported between central and peripheral communities on the expected norms of physical labor during pregnancy; that is, women were expected to continue undertaking most tasks in pregnancy.

3.2 | Physical Activity Monitoring

We measured PA in 21 participants over 5 days (105 total days) with Withings Pulse HR fitness trackers. There was a 79% adherence, yielding 83 total wear days with an average of 3.95 wear days per participant. Descriptive statistics for participants are found in Table 3. Participants living in central communities were older (36.8 years) than those living in peripheral communities (27.1 years; $p = 0.003$; Table 3). Participants across both community types had similar gestational ages, number of living children, height, and body composition measurements ($p > 0.05$ for all comparisons; Table 3).

Pregnant Daasanach women, regardless of maternal age, community, and gestational age, took an average of 6948 steps per day and traveled an average of 4.7 km per day. Mean daily steps and mean daily distance (km) did not statistically differ between central (4964 ± 2569 steps per day; 3.4 ± 1.7 km per day) and peripheral communities (8436 ± 5971 steps per day; 5.8 ± 4.0 km per day) ($p = 0.34$ for in both comparisons). However, means and sample standard deviations in the peripheral communities were nearly double that of central communities, highlighting a meaningful difference in PA patterns between community types.

The results of multiple linear regression models are found in Table 4. While maternal age was statistically significant between community types (see above), it did not significantly predict mean daily steps and was removed as a covariate from all models. For all communities combined, gestational age significantly predicted mean daily steps, with a decrease of 1160 ± 437 steps per day with each consecutive pregnancy month ($p = 0.02$) (Figure 3). When stratifying by community type, gestational age significantly predicted mean daily steps for peripheral communities, with a decrease in 1443 ± 629 steps per day with each consecutive pregnancy month ($p = 0.04$); whereas the decline in 511 ± 480 steps per day for central communities was not statistically significant ($p = 0.32$) (Figure 4).

4 | Discussion

This paper examined how Daasanach women accommodate demanding subsistence labor tasks during pregnancy, and how market integration influences these strategies. We leveraged a mixed methods approach across Daasanach communities, contextualizing pregnancy experiences through both focus group discussions and PA monitoring. Because this study took place during a period of prolonged drought, we expect our results represent a more negative pregnancy experience for this population due to widespread food and water insecurity (Rosinger et al. 2024).

Reported dietary changes during pregnancy included decreased energy intake due to lack of appetite. In other subsistence-based populations, reducing energy intake has been reported as a perceived mechanism to reduce birth weight and prevent obstructed labor and maternal and infant mortality (Maggiulli et al. 2022). It is possible that reduced birth weight and easier delivery were unvoiced considerations for Daasanach mothers in our focus groups as well. During discussions with women in the summer of 2024, however, women did indicate a preference for smaller babies as a way to ease labor. Additional discussion with the community, as well

TABLE 3 | Descriptive statistics for PA monitoring participants.

Variable	Central	Peripheral	*p*	Communities combined
Number of participants (*n*)	9	12		21
Maternal age (years)	36.8 (5.4)	27.1 (5.8)	0.003	31.2 (7.4)
Gestational age (months)	5.6 (1.9)	5.1 (2.4)	0.64	5.3 (2.2)
Nulliparity	0 (0%)	2 (16.7%)	0.18	2 (9.5%)
Number of living children	5.0 (1.8)	3.8 (3.0)	0.33	4.3 (2.6)
Height (cm)	162.2 (5.4)	164 (5.7)	0.43	163.2 (5.5)
Weight (kg)	53.8 (7.7)	50.8 (4.8)	0.37	52.1 (6.2)
Body fat %	24.0 (6.6)	22.0 (5.3)	0.43	22.8 (5.8)
Body water %	51.9 (3.8)	54.0 (3.8)	0.21	53.1 (3.9)
BMI (kg/m^2)	20.4 (2.5)	18.9 (2.1)	0.17	19.6 (2.3)
Mean daily steps per day	4964 (2569)	8436 (5971)	0.34	6948 (5034)
Mean daily distance (km) per day	3.4 (1.7)	5.8 (4.0)	0.34	4.7 (3.4)

Note: Data are reported in mean (SD) or count (%).

TABLE 4 | Results from multiple linear regression models, combining all communities and stratifying by community.

	Mean daily steps ~ gestational age + community + maternal age	Mean daily steps ~ gestational age + maternal age	
Variables	**Communities combined**	**Central**	**Peripheral**
Intercept	11410.9** (2803.5)	7801.3* (2796.0)	15770.9** (3517.1)
Gestational age (months)	−1160.4* (436.5)	−510.7 (479.5)	−1442.9* (629.2)
Community (central vs. peripheral)	2924.2 (1869.2)	NA	NA
Adjusted R^2	0.30	0.02	0.28
N	21	9	12

Note: Data are reported in β-coefficient estimate (SE).
*$p < 0.05$.
**$p < 0.01$.

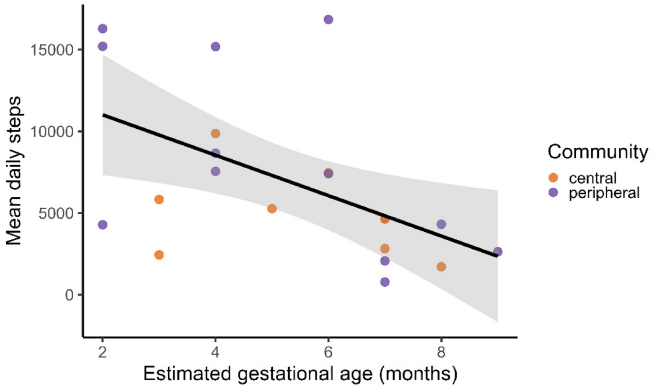

FIGURE 3 | Regression plot (with 95% confidence interval) of estimated gestational age (months), on the *x*-axis, and mean daily steps, on the *y*-axis, among pregnant Daasanach women ($n = 21$). Gestational age significantly predicts mean daily steps, with a decrease of 1160 steps per day with each consecutive pregnancy month.

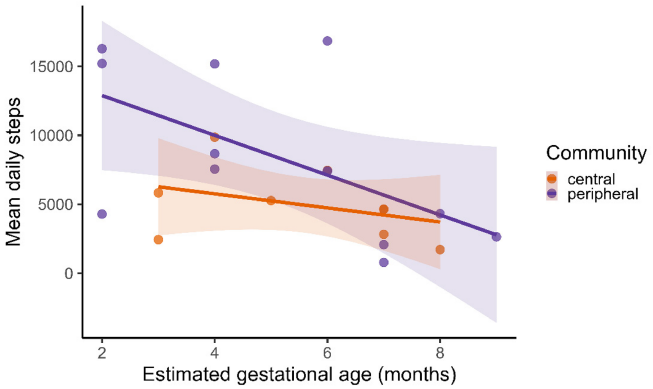

FIGURE 4 | Regression plots (with 95% confidence interval) of estimated gestational age (months), on the *x*-axis, and mean daily steps, on the *y*-axis, stratified by community type among pregnant Daasanach women ($n = 21$). Participants living in central communities are shown in orange, and participants living in peripheral communities are shown in purple. Gestational age only predicts mean daily steps in peripheral communities, with a decrease of 1443 steps per day with each consecutive pregnancy month.

as quantitative assessments of realized calorie intake during late pregnancy, may clarify these issues.

Reducing energy intake may also coincide with increased fatigue, which was reported in both central and peripheral communities. Participants described chronic fatigue, dietary change, continued workload, and fear of harming the fetus during their pregnancies. The similar experiences of fatigue across communities may reflect how many tasks that often fall to women in Daasanach culture (water gathering, firewood collecting, etc.) are required regardless of community type. The perceived danger to the fetus with certain tasks, which was pervasive across both central and peripheral communities, points to behavioral modifications of subsistence labor tasks unrelated to the metabolic demands of pregnancy.

Notably, we find significant PA decreases across pregnancy, especially for women in peripheral communities who begin their pregnancies at a high PA level. PA also differs significantly by level of market integration, as indexed by central or peripheral community location, but this pattern only holds in early pregnancy until about 6 months gestational age, when PA differences between central and peripheral communities attenuate (Figures 2 and 3). Also striking was the similarity in sedentary lifestyles between Daasanach participants living in the central communities and pregnant people living in industrialized populations. Pregnant people from across diverse regions, socioeconomic standings, and ethnicities in industrialized nations achieve approximately 5000–7000 steps per day in pregnancy, which does not change with lifestyle interventions (Barone Gibbs et al. 2021; Hesketh et al. 2018; Renault et al. 2010; Sharp et al. 2022).

Previous studies have reported that changes to female PA patterns occurred before changes to male PA patterns in populations beginning their integration into market economies; this initial change is also associated with increased female fertility (Bocquet-Appel 2011; Kraft et al. 2021; Page et al. 2016; Shephard and Rode 1996; Snodgrass et al. 2006). In analyses across Daasanach communities, mean daily steps for men is higher than for nonpregnant women and pregnant women (this sample), and sex-specific mean daily steps are not statistically significantly different across central and peripheral

communities (McGrosky et al. 2024). Building upon the current study, we hypothesize that pregnant female PA may change before other reproductive stages, genders, and age groups in the Daasanach. As lifestyle changes continue, it is likely that PA will change in nonpregnant women, followed by men. This hypothesis warrants future research.

Degree of market integration may also influence PA patterns for pregnant Daasanach women through introduction of labor-saving technologies and commodification of food and goods, as found in previous research with Mayan and Ethiopian populations (Gibson and Mace 2002, 2006; Kramer and McMillan 1998). We collected PA data using accelerometry and GPS tracking during the same field season as the current analysis and found no PA differences between levels of market integration in nonpregnant Daasanach women (McGrosky et al. 2023). In a population of Shuar forager-horticulturalists in Ecuador who are rapidly experiencing market integration, Madimenos et al. (2011) did not observe differences in PA between pregnant, lactating, and nonpregnant, nonlactating individuals, though this study did not include a measure of market integration. With market integration, sedentary behaviors are carried forward into pregnancy and PA does not change, yielding no effect of gestational age on daily PA in central Daasanach communities. Interestingly, Daasanach participants did not perceive their labor investment differently between community types.

This study also highlights the importance of family and community networks during pregnancy. Existing human ecology literature considers the role of family members, such as male and older female relatives, supplementing the pregnant mother with food and helping with subsistence tasks to support her energy needs (Hawkes et al. 1998; Kramer and Ellison 2010; Marlowe 2003). Similarly, our results show Daasanach family and community members take on extra labor-intensive tasks to allow mothers to reduce PA and support pregnancy. Women living in peripheral communities were able to reduce their high PA to sedentary levels at later stages of pregnancy (> 6 months gestational age) with assistance from others.

Assistance with labor-intensive tasks, and the ensuing negative relationship between gestational age and PA, might serve to alleviate increasing metabolic costs in the later months of pregnancy (Butte and King 2005; Forsum and Löf 2007; Löf and Forsum 2006; Savard et al. 2021). In industrialized populations, high occupational PA predicts adverse pregnancy outcomes, such as inadequate gestational weight gain, inadequate maternal fat mass, preterm birth, small-for-gestational-age infants, fetal loss, and hypertensive conditions (Cai et al. 2020; Lee et al. 2017; Mozurkewich et al. 2000; Prentice et al. 1981; Ruchat et al. 2018; Schlüssel et al. 2008; Singh et al. 1989). Certain tasks, such as bending over, lifting heavy objects, and standing for long periods of time, are directly correlated with adverse outcomes (Cai et al. 2020; Mozurkewich et al. 2000; Schlüssel et al. 2008). Less understood is the role of energy allocation in producing such pregnancy outcomes, especially when metabolic demands of pregnancy increase in the second and third trimesters. When faced with a metabolic limit in pregnancy, it is likely that behavioral strategies, such as reducing PA, help allocate energy toward pregnancy.

4.1 | Limitations and Future Directions

In this study, we did not explicitly measure energy expenditure in pregnant Daasanach women, and we are unable to evaluate how energy allocation changes throughout pregnancy. Ongoing research projects assessing energy expenditure and PA in highly active pregnancies will help address open questions about the maternal metabolic demands.

We were limited by a small sample size for PA monitoring and a lack of reliability estimate for gestational age calculation. The effect of gestational age on PA may also differ between central and peripheral communities in the Daasanach population, but we did not have the power to test for an interaction due to a small sample size. The use of daily steps and distance in our models do not encompass all possible physically intensive activities. These metrics are confined to acceleration-based movement, which is biased against activities that might be stationary or weight-bearing (e.g., carrying water or firewood on one's head). Future directions include expanding the sample size of PA monitoring to test for an interaction effect, as well as including longitudinal PA monitoring across pregnancies that also takes heart rate changes into account.

This study did not investigate the impact of other salient nutritional, social, and environmental factors on pregnancy, such as micronutrient intake, climate, social status, and food and water availability. It is unclear how actualized the widely reported diet restriction during pregnancy is. If future studies indeed identify energy intake restriction, then there are important implications for maintaining positive energy balance in pregnancy, such as PA reduction, suppression of basal metabolic rate in early pregnancy, and lipolysis of maternal fat stores in late pregnancy as energy buffering mechanisms to maintain a viable pregnancy (Lawrence et al. 1984; Poppitt et al. 1993; Sadhir and Pontzer 2023). In other cases, the abovementioned factors may interact or be independent of PA and energy metabolism.

Previous work with the Daasanach population has identified substantial heat stress and food and water insecurity (Bethancourt et al. 2021, 2023; Ford et al. 2023; Rosinger et al. 2021a, 2021b). Plausibly, reducing PA could also be a behavioral response to heat stress. The effects of chronic heat stress on pregnancy is understudied, but there is some epidemiological evidence to suggest an association between heat stress and fetal strain (Bonell et al. 2022), leading to adverse outcomes such as low birth weight, shorter gestational length, preterm birth, and stillbirth (Barreca and Schaller 2020; Schifano et al. 2013; Wells 2002; Wells and Cole 2002; Zhang, Yu, and Wang 2017). In the Daasanach focus group discussions, reports of increased water borrowing during pregnancy might counteract widespread heat stress and water insecurity. Future work is needed to examine this aspect of water-gathering behavior.

4.2 | Conclusion

This study demonstrates that Daasanach women can modify their PA during pregnancy by relying on family and community members to assist with labor tasks. This is especially the case for

women living in peripheral communities, where PA is high to begin with in pre-pregnancy and early pregnancy. While women in central communities still fetch water and firewood, they may not bear as many traditional labor-intensive tasks as in peripheral communities. These women no longer need to greatly modify PA, and they maintain a relatively sedentary lifestyle through pregnancy. Regardless of location, women across all communities identified barriers they face for maintaining a healthy pregnancy, including the need for better healthcare access, and undertaking necessary labor tasks that might be harmful to the fetus. Reducing PA may be a strategy to alleviate a highly active mother's energy demands when pregnancy becomes metabolically costly at later gestational months. Future directions include measuring daily energy expenditure and PA in high-activity populations such as pregnant athletes and additional subsistence-based populations.

Author Contributions

Srishti Sadhir: conceptualization, data curation, formal analysis, investigation, methodology, project administration, validation, visualization, writing – original draft, writing – review and editing. **Amanda McGrosky:** conceptualization, data curation, investigation, project administration, supervision, writing – review and editing. **Leslie B. Ford:** conceptualization, investigation, methodology, project administration, writing – review and editing. **Rosemary Nzunza:** project administration, resources, supervision, writing – review and editing. **Sylvia N. Wemanya:** data curation, investigation, writing – review and editing. **Husna Mashaka:** data curation, investigation, writing – review and editing. **Rahab N. Kinyanjui:** data curation, investigation, project administration, writing – review and editing. **Emmanuel Ndiema:** project administration, supervision, writing – review and editing. **David R. Braun:** project administration, supervision, writing – review and editing. **Asher Y. Rosinger:** conceptualization, funding acquisition, investigation, methodology, project administration, resources, supervision, writing – review and editing. **Herman Pontzer:** conceptualization, funding acquisition, investigation, methodology, project administration, resources, supervision, writing – review and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The de-identified data that support the findings of this study are available from the authors upon reasonable request. The data are not publicly available due to privacy and ethical restrictions.

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