

Adolescent motherhood in rural Nepal: passive sensing data illuminates daily experiences in maternal lives

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Research Article

Keywords: Adolescent, Depression, Developing Countries, Mental Health, Postpartum Depression, Psychotherapy, Digital Health, Nepal, Child Health

Posted Date: September 22nd, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-82137/v1>

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Abstract

Background: Adolescent pregnancy, particularly in low-income settings, is associated with adverse health and social outcomes for both mother and child. Nepal has the second highest rate of adolescent pregnancy in South Asia alongside high rates of maternal depression and suicide. While the maternal morbidity risks of adolescent pregnancy are well researched, impacts on everyday lives, including behaviors and predictable patterns are less well-known. Passive sensing (geographic movement, physical activity, and proximity to infants using Bluetooth technology) is an emerging technology that can enhance the detection of behavior patterns. Given the risk of the postpartum period in LMIC settings, we sought to characterize normal behavioral patterns via passive sensing technology.

Methods: We collected passive data over a two-week period with 22 mothers using phone-based GPS, accelerometry, and Bluetooth technologies. Passive data was aggregated for each mother, collapsed into hourly readings, and descriptively summarized. We triangulated this information in a constant comparative approach with a range of qualitative data including multiple in-depth interviews, a daily diary, and systematic fieldnotes.

Results: Passive data illuminated a range of behaviors that varied across our participants. Women, during the average time window of 4am and 8pm, spent more than 80% of the day with their infants, were detected as 'active' 10-20% of the time in any given hour with peaks in the morning and mid-afternoon, and traveled fewer than 1675 meters from their homes. Household work, instrumental childcare, and household support, paired with the infant's age, appeared to drive activity patterns. Women with higher amounts of activity and GPS movement had more household support for chores and childcare. Women with young infants had smaller amounts of activity and GPS movement. Women that had nearly no time away from their infant expressed overwhelming responsibilities and increased stress, but also role fulfillment in that time with their infant was an indicator of good mothering.

Conclusion: We reveal typical behavioral patterns of rural adolescent mothers and highlight opportunities for integrating this information to improve health and well-being.

Introduction

Globally, low- and middle-income countries (LMIC) have the highest rates of adolescent marriage and pregnancy [1]. As of 2010, birth rates in the lowest income countries in the world averaged 106 births per 1,000 girls aged 15-19 [2], which is four times higher than the birth rate in high-income countries [3]. Adolescent pregnancy can lead to complications during delivery such as placental tear, prolonged labor, and preterm birth [4-6]. Additionally, adolescent motherhood is associated with poor social outcomes, including persistent poverty, increased risk of discrimination and violence, suboptimal psychosocial health, and poor physical health [5, 7, 8]. Special attention to this high-risk group during pregnancy and in the year following childbirth is especially critical.

Nepal has the second highest rate of adolescent pregnancy in South Asia [9], with approximately 40 percent of women becoming mothers before the age of 20 [10]. Childbirth is an important life event for Nepali women, fulfilling a seminal social role and providing upward social mobility [11-13]. Generally, Nepali culture follows a patrilocal tradition where, upon marriage, women leave their maternal household (*maiti*) and become a permanent member of her husband's parents household [14]. This major life transition is often accompanied with expectations of reproduction and assuming a majority of household responsibilities [15]. The woman's husband and in-laws typically have prominent decision making power related to her reproduction (pressure to produce male children still remains salient), healthcare, and social engagement [16]. These stressors may be compounded for women that marry at a young age, with pervasive effects limiting her educational, socioeconomic, and empowerment trajectories.

Literature on adolescent motherhood has predominantly focused on maternal health seeking behaviors and physical health outcomes of pregnancy and childbirth [17]. There is limited research focused on identifying the impacts of motherhood among adolescents on everyday behaviors in LMIC (such as physical activity, time in their home, geospatial movement, time spent with family and friends, etc) on their mental health and social lives. Understanding the cultural and social dimensions of a mother's typical life is a crucial step in determining the most effective ways to deliver appropriate health interventions to adolescent mothers. Given the importance of maternal mental health for both the mother and child's acute and long-term health outcomes [18, 19], the disparate burden of mental distress disadvantaged women and LMIC countries face [20, 21], and the relationship between mental health and prolonged social and economic success [22], adolescent maternal mental health is an pressing issue requiring increased resources and research.

Recent advancement in digital technologies provide a new avenue to better understand adolescent maternal behavior in context through passively collected digital behavioral data from a person's smartphone or a small wearable device. This allows behavioral data directly from the person's environment and everyday life, which can be harnessed to construct an individual digital phenotype [23]. Since digital passive sensing data are collected in real-time, digital phenotyping allows for the monitoring of changes in state. It can therefore become a powerful tool for the management of chronic disease [24] and mental health problems [25-27], for example in monitoring and supporting behavioral change for adolescent mothers receiving psychological interventions. Given the great complexity and volume of digital data that can be collected through this technique, digital phenotyping has the potential to elucidate the complex interactions that influence development [28], psychology [29, 30], and stress [31] in new ways. For example, features of movement extracted from passive sensing data have been associated with loneliness [30], worsening of depressive mood [32], and changes in state of patients with bipolar disorder [26].

Digital biomarkers of activity and movement have been extracted from actigraphy [33, 34], accelerometer [35-37], and GPS data [30, 38]. While actigraphy and accelerometer data can detect whether the individual is moving or not, GPS data can provide information including the distance travelled, locations visited, changes in cell towers, and time spent at locations [26]. The spatiotemporal information that can be

extracted from GPS data has been used to identify contextual exposures related to alcohol consumption in adolescents [39, 40]. In perinatal women, passive monitoring of movement is feasible and can provide information on sleep quality and physical activity [33]. Monitoring movement patterns may be useful in identifying women at risk for perinatal depression [38], but more research is needed to identify and validate associations between specific digital biomarkers and symptoms of perinatal psychosocial distress. Further opportunities remain to harness movement patterns of mothers as a tool for capturing their day-to-day experiences.

Social interactions have also been a target of inquiry with passive sensing technologies, measured using audio recordings [41], phone usage data [42, 43], and Bluetooth beacons [44-46]. Social features derived from audio data are associated with measures of social connectedness, which is a promising indication of their validity [47]. Bluetooth beacons have been used to measure proximity to other individuals to study social contact [44], and they are acceptable and feasible among women in rural South Africa [46]. Social environment has been examined as an important factor in overall well-being [47]²⁸, and opportunities exist to examine what measures of social interactions can tell us about the experiences of perinatal women.

Digital phenotyping collects large amounts of personal data, and previous work has made recommendations for establishing meaningful consent procedures and for adapting to the cultures and needs of the study population [46, 48, 49]. In postpartum women, proximity has been crudely measured by room sharing immediately postpartum and at night, or by if the mother lives with her infant or not (e.g., divorce) [50-52]. To date, studies have not systematically examined continuous infant proximity throughout the day nor how these patterns might be correlated with other aspects of maternal well being.

In the existing literature of passive sensing technologies, most studies focus on identifying digital markers of specific disease states and symptoms, but passively collected sensing data also holds enormous potential to capture the daily lives of individuals in an unobtrusive manner. The wealth of data on an individual's unique environment can help us understand lived experiences, identify needs, and tailor interventions. This study seeks to demonstrate the value of using passive sensing data to construct a holistic view of women's daily lives. In addition, there is a dearth of research focusing on women in LMIC – their digital phenotypes may be substantially different from those of women in HIC given the different daily tasks and social roles of women. This paper contributes to filling this gap in order to better understand the daily experiences of women in LMIC. Further, sensing data has the potential to measure proximity to children and to examine how this impacts parenting outcomes, such as attachment and well-being, but this potential has not yet been realized. This study aims to uncover what proximity to children can tell us about the day-to-day lives of mothers.

Methods

Data comes from the pilot study, Sensing Technologies for Maternal Depression Treatment in Low Resource Settings (StandStrong)[53]. The development, pilot protocol, and feasibility findings of

StandStrong are described in detail elsewhere [53, 54] and is registered with a International Registered Report Identifier (IRRID): DERR1-10.2196/14734. Below, we describe the elements specific to this analysis.

Setting

This study was conducted in Chitwan, Nepal an ethnically and culturally diverse southern region of Nepal bordering India. The region is predominantly agrarian, but also contains Nepal's fourth largest urban city. Chitwan's health and economic performance is slightly higher than average, and was selected due to longstanding relationships with the local government and health system. The health system was one of the first to pilot the integration of mental health services, providing decentralized community-linked care [55, 56]. This system includes a central hospital connected to several primary health centers, staffed by a medical doctor alongside other paramedical staff such as auxiliary nursing midwives (ANM). Health posts provide basic health services, including antenatal and postnatal care, and coordinate community health workers, including community psychosocial workers that provide decentralized mental health treatment and psychosocial education to communities. The average age of marriage is 17.9 and the average age for first childbirth is 20.4. The legal age of marriage is 18, however, 52% of women are married by this time [9]. This study is situated within a larger trial to develop and test the feasibility of enhancing depression treatment delivery with passively collected digital data. The full protocol description is published

Study Population and Sampling

This study was implemented between November 2018 through April 2019. Adolescent mothers were recruited at health posts during monthly infant vaccination days. Women were included if they were 15-25 years old and had an infant between 1-12 months old. All mothers were administered depression screening using the Nepali validated PHQ-9 [57]. Following consent into the study, a visit to her home was conducted to obtain family consent. If the participant was under 18 years of age, written informed consent was also obtained from an adult family member. For this analysis, only mothers that screened negative for depression were included (n=22) in order to establish an understanding of the daily lives of psychologically healthy adolescent mothers to use as a baseline for future comparison with depressed mothers. The study was approved by the Nepal Health Research Council (#327/2018) and George Washington University Institutional Review Board (#051845).

Data Collection

The study protocol is outlined in detail elsewhere, and we describe it briefly below; the procedures and results described here refer to Component 2 of the original study protocol [53], including only non-depressed mothers. Study enrollment lasted for 14 days. For passive data collection, mothers were given a low-cost android Samsung J2 Ace smartphone and a Bluetooth beacon. The beacon attaches to her infant's clothes. A study team member briefed each mother and her family on the technical use of the phone and beacon and made regular phone calls and household visits to ensure the technology was

working, answer questions, and conduct qualitative interviews. On average, mothers were visited by a study team member five times throughout the two week data collection period.

Passive data collection

The devices used in this study were selected following extensive ethnographic inquiry regarding acceptability and feasibility in the study site [48]. Two devices were considered culturally appropriate - a smartphone and a Bluetooth beacon. The Samsung J2 Ace smartphone is a lower cost smartphone that is commonly used in the study setting. The Bluetooth RadBeacon dot is developed by Radius Networks and attached to a belt around the infant's torso. Mothers were instructed to carry the smartphone with them throughout the day as much as possible and given a cell phone pouch in case no pockets were available. Devices were provided to the mother throughout the two-week data collection period and then returned to the study team. This analysis leverages three types of data obtained from the devices: beacon proximity, physical activity, and geographic location. A custom-built Electronic Behavior Monitoring app (EBM version 2.0) was developed to capture this data passively every 15 min between 4 am and 9 pm. To obtain proximity of mother and infant, the Bluetooth beacon was attached to infant clothing and the EBM app scanned for the presence of advertising packets from the assigned Bluetooth beacon and recorded whether the beacon was within detectable range (e.g., within the same room) or not. Physical activity data were collected through activity recognition based on the phone's accelerometer data. Finally, GPS coordinates were obtained from the mobile phone every time the phone underwent activity, such as unlocking the phone, and every time passive data was collected (a scan for the Bluetooth beacon).

Qualitative data

Three types of qualitative data were collected: in-depth interviews, daily diaries, and field notes written by the research assistants following participant encounters. Two in-depth interviews were conducted with mothers. The first was on the second or third day following the acquisition of technology. This interview elicited details about her experiences related to motherhood, child rearing, her daily activities, her relationships, and psychosocial wellbeing. This interview lasted approximately 40 minutes. The second interview was conducted on the last day of data collection (Day 14) and elicited her and her family's experiences with the technology package and data collection process. Although this interview focused on feasibility and acceptability, mothers shared additional information about her everyday life. On the penultimate day of data collection, mothers completed a structured daily diary that asked about her activities on the previous day. This included her main activities every hour between 5am and 9pm, where she was located, where her child was located, and who else was with her. It also elicited information on her waking time, nap times, bedtime, and breastfeeding. Finally, field notes were written systematically following every participant encounter and documented the mother's environment and information that may not be captured by the transcript. This included histories provided by the mother in conversations before and after the interviews, interruptions, emotions, and what happened during silent periods. It also included information gleaned during phone call check ins. An advantage of the intensive and frequent data collection procedures was that study team members established close rapport with both the mother

and her family due to multiple encounters. This increased participant comfort, additional opportunities for her to share her experiences, and allowed for detailed field notes. The Consolidate Criteria for Reporting Qualitative Studies (COREQ) checklist provides more details on the qualitative data collection procedures and is included in Supplementary material.

Data Analysis

Passive sensing data analysis:

Sensor data aggregated by the EBM v2.0 app was downloaded from the smartphone, exported in a csv file, and pre-processed and cleaned on import into a SQL database. These data were then loaded into a JupyterLab Notebook. The proximity data collected from mother's phone and child's proximity beacon were collapsed for hour intervals such that, any 15 minute scan that detected a beacon within an hour was coded as 'with the child' and if all four readings did not detect a beacon, the reading was recorded as 'away'. The result of the query is either present or not present for each hour interval between 4 AM and 9 PM. Similarly, the activity data were processed in the same way so that any 'movement' (vehicle or bicycle or on foot) captured by the phone within an hour was categorized as moving'. Using scikit-mobility, GPS data were loaded into a trajectory DataFrame. Data were pre-processed to remove noisy points (if the speed required to move from point to point was greater than 500km/h), and compress lat/lon pairs with 100m of each other while retaining the trajectory structure of the data. Several mobility measures were then applied to these data including max distance from home (great-circle distance between two points), and radius of gyration (characteristic movement range each day) [58]. GPS heatmaps were created using the heatmap function in scikit-mobility to plot visited points on a Folium map. Graphic representation of the dichotomized proximity and activity data by hour (aggregated from all days of data collection) were produced for each woman. Women that had fewer than 100 data points for each passive sensor were not included in a given domain because the significant amount of missing data made comparison with observed qualitative trends impractical.

Qualitative data analysis:

All in-depth interviews were conducted by bilingual (Nepali and English) female research assistants and transcribed verbatim. One translator then translated Nepali transcripts into English, ensuring culturally meaningful terms were preserved in their original language. These terms were given an English term derived from a standardized Nepali mental health glossary specific to emotional and psychological terms [59]. All fieldnotes were combined with the transcript text and uploaded into Nvivo 12.0. Daily diaries were also uploaded into Nvivo and tagged with the appropriate participant so data could easily be triangulated with transcripts and field notes. The mother's demographic data (age, parity, and household members) were uploaded into Nvivo as attributes. Analysis took a systematic thematic approach [60]. First, a codebook was developed combining both deductive themes expected to explain passive sensing data (transportation, isolation, leaving home, childcare support, household activities, etc.). Open coding was used to develop inductive themes from the data (e.g., cultural practices) that also appeared to explain passive data patterns. Once the initial coding scheme was finalized, a subset of transcripts were coded

by three members of the study team to determine inter-rater reliability. Disagreements were discussed, the codebook adjusted, and another batch of transcripts were coded until a kappa of 0.7 or higher was achieved. Following high agreement, all transcripts were coded and thick descriptions were developed to summarize the depth, breadth, and nuance of each domain as they related to each piece of passive data (activity, proximity, and geospatial movement) [61]. Daily diaries were triangulated with the passive data patterns and incorporated into thick descriptions. We describe the results below, first highlighting the dimensions of women's lives that may explain passive data patterns and then providing case examples of how passive data profiles might illuminate important aspects of young mothers' psychosocial experiences.

Results

Our sample consisted of 22 adolescent mothers ranging from 16 to 25 years of age with infants averaging 5.7 months old (median of 4, IQR 3-9). For 81% of women, this was their first child. The majority (59%) were from indigenous ethnic groups (Janajati/others). Most of the women were Hindu (77%). Nearly 82% of the sample had a secondary education (about grade 10) or less. The majority of women were housewives, and about 23% had formal employment outside the home. For activity, five women (P22, P53, P52, P49 and P43) were excluded for having less than 100 readings. For proximity, three women were excluded for having less than 100 readings (P49, P43 and P52). For GPS, eight women were excluded for having less than 100 hours of GPS data (P6, P22, P24, P28, P49, P52, P53, P26). Daily diaries were not collected for two participants (P1 and P20). For passive sensing data, 48.1% of activity data was collected (3,304 readings for the total sample); 43.9% of proximity data (3,087 readings); and 36.7% of GPS data (2,527 readings) were available for analysis (for a full description on data collection rates and reasons for incomplete data, see Maharjan et al 2020[54]).

Table 1: Demographic characteristics of study sample

Total participants (n=22)	N (%) or mean (range)
Mother age	19.6 (16-25)
16-18	6 (27.27)
19-21	11 (50.00)
22-25	5 (22.73)
Caste	N (%)
Brahmin/Chhetri	5 (22.73)
Janajati/Other	13 (59.09)
Dalit	4 (18.18)
Religion	N (%)
Hindu	17 (77.27)
Buddhist	3 (13.64)
Christian	2 (9.09)
Education	N (%)
Primary	3 (13.64)
Secondary	17 (77.27)
Higher	2 (9.09)
Child gender	N (%)
Female	11 (50.00)
Child age	5.77 (2-12)
1 to 7 months	17 (77.27)
8 to 12 months	5 (22.73)
Number of children	1.18 (1-2)
First child	18 (81.81)
Participant Occupation	N (%)
Housewife	17 (77.27)
Agriculture	3 (13.64)
Business	1 (4.55)
Day wage laborer	1 (4.55)

Livestock	N (%)
Yes	8 (36.36)
No	14 (63.64)

Activity

Generally, mothers were active around 10-20 percent of the time in any given hour. Average detected activity spiked from 5 percent during the 7 a.m. hour to nearly 20 percent during the 8 a.m. hour when most mothers are up and completing their daily tasks. Detected activity remained at this level during the 9 a.m. hour and then slowly decreased from 10 a.m. to 1 p.m. when mothers were usually sitting down for a meal or taking a midday rest. Average detected activity rose back up to nearly 20 percent from 2-4 p.m. when mothers usually resumed their daily tasks and began to drop off once again from 5 p.m. and onward as mothers sat down for their last meal of the day and prepared for bed. See Figure 1 for the average activity of mothers throughout the day.

Mothers were grouped into three clusters dependent on their level of movement. Mothers who were “very active” experienced peaks in movement that considerably exceeded 20 percent (n= 4). Mothers who were considered “moderately active” were active around 20 percent of the time during peak activity hours (n=5). Mothers considered to be “largely inactive” had very low or no activity peaks throughout the day (n=7). During hours when they were active, peak movement was only around 10 percent.

Very active

Four women (P51, P33, P20, and P1) had much higher activity detection than average throughout the day, with multiple peaks that significantly exceed 20%. See their activity graphs in Figure 2. Some are continuously active, while others are active episodically.

Very active mothers experienced activity peaks throughout the entire day, beginning around 7-8 a.m. until around 6 p.m. Housework largely drives their increased detected activity. All four mothers shared they do extensive housework in the morning (cooking, sweeping, etc), explaining the heightened activity witnessed around 7-8 a.m. Another factor driving detected activity is childcare. Certain childcare activities, like playing with or carrying the baby, may heighten a mother’s activity levels. Playing with a child can be a source of increased physical activity especially if the mother spends time carrying around her child or if her child is old enough to walk and move around on its own. The amount of house/childcare work a mother is responsible is largely influenced by the amount of daily support she receives from her family.

Both participants 20 and 51 shared they were responsible for a large amount of housework in addition to being the main caretaker of their baby. Common household chores included cleaning their home, sweeping, cleaning utensils, preparing food, and washing clothes. All these tasks require moderate levels of activity from mothers, however, washing clothes is especially labor intensive for women in rural Nepal given the lack of running water and the amount of dirty clothes infants produce. These mothers are the

main caretaker for their babies and are usually responsible for most, if not all, of the childcare activities. These activities include bathing, changing soiled clothes, massaging with oil, carrying, and playing with the baby.

Both mothers expressed some dissatisfaction with the amount of work they had. Participant 51 (17yo, 3mo, 7 household members) stated, *“Previously before being a mother, I used to complete my work rapidly. But now I can’t work fast, I used to be able to take more time to finish all my work”*. She also shared her challenges around caring for her child saying, *“We have to check whether they pass urine or not, change their clothes at night, we have to regularly breastfeed, we have to help them sleep at night. These types of difficulties mothers have to face.”* Despite being the only mother in this category to come from a larger household, participant 51 does not report having any substantial childcare or household support.

The childcare activities described above drive a large portion of mothers’ detected activity. Mothers with substantial childcare responsibilities who are the main caretakers of their baby are still largely active even if they do not have large amounts of housework to complete. This is observed especially among women who do not receive much or any childcare support. For example, Participant 1 (19yo, 5mo, 3 household members) shared she does not let anyone care for her baby other than her, saying, *“Because I can’t trust other people easily. I think they might drop my baby while walking or doing some work. I think other people don’t provide care as I do. So, I take this baby all the time with me. I don’t leave her with other people.”* Mothers that don’t receive childcare support have to do all the work themselves, thus increasing their detectable activity. The exceptions to this are mothers who are employed. Mothers who work paid jobs usually have childcare support while they are working, but still may have high activity levels. Participant 33, for example, does labor working during the day such as carrying bricks, cement, and sand. Her work requires a lot of physical activity and movement, which explains her heightened detected activity.

Given these mothers’ experiences, a combination of childcare/play, housework, and labor work are the likely drivers behind increased detected activity in rural Nepalese mothers.

Moderate activity:

Five mothers were considered “moderately active” (P6, P21, P23, P24, P26). They are usually active in the middle part of the day, and in the hours of peak activity they are active around 20% of the time. See Figure 3 for the activity graphs of these women.

Similar to “very active” mothers, mothers with moderate activity levels still have a considerable amount of household work to complete throughout the day. However, a common theme among these women is that many of them reported having childcare support throughout the day, absolving them of some of the more movement driven childcare activities, such as playing with/carrying the baby, changing the baby’s clothes, or giving the baby an oil massage.

Participant 23 (18yo, 4mo, 4 household members) received childcare support from her husband and mother-in-law and shared that she found it difficult to complete her housework and watch her baby when she did not have that support. For example, this mother told her interviewer that she felt difficult one day when her husband and mother-in-law were not home because, "On that day, I have to do household work also. So, I feel it is difficult to look after my baby and to do household work." This childcare support allows the mother to take more time to rest throughout the day leading to more periods of inactivity. This mother shared she rests three times a day and sometimes engages in entertainment saying, "Like when I get a chance, I used to watch good and entertaining programs on television otherwise I used to watch videos on YouTube."

Another possible reason why these mothers have less detected activity than the four mothers above is because they spend more time breastfeeding. Breastfeeding is a childcare activity most mothers do at least once a day that requires them to be mostly sedentary. While all the "very active" mothers mention breastfeeding in their interviews, some mothers in the "moderate activity" category speak about it having to breastfeed multiple times a day. Participant 24 (17yo, 3mo, 3 household members) shared she breastfed her baby several times a day, saying, "*Whole day I used to breastfeed, play with her, sometimes when she gets sleep, I used to keep her in the cradle, move here and there with her etc.*" Similarly, Participant 23 (18yo, 4mo, 4 household members) shared she had to stop attending her college because she needed to breastfeed her baby so often, saying, "*Because I have to breastfeed [many times], he used to cry if I leave him for long time.*" Participant 26 (16yo, 4mo, 5 household members) also shared she breastfeeds her baby when the baby cries as a way to pacify her child, which likely happens multiple times a day. All of these mothers have very young babies (under 4 months old) that likely need to breastfeed often.

Largely inactive:

Seven mothers were considered "largely inactive" (P3, P7, P25, P27, P44, P47, P55). Their activity graphs are in Figure 4.

Of these seven mothers, almost all of them came from larger, non-nuclear households meaning they were more likely to share the housework with other family members. Two of these mothers (P44, P55) even expressed that they experienced a decrease in household chores after they became mothers. Participant 44 (25yo, 7mo, 6 household members) shared, "*Before being mother I remained busy with other works, but after I have to give time for my baby. I have to look after him, wash his clothes, provide food for him, breastfeed him etc.*" Similarly, Participant 55 (20yo, 3mo, 6 household members) said, "*Before giving birth to my baby I used to prepare meal but now I don't. I used to wash my husband's clothes, but now I don't. Now, I only wash my baby's and my clothes. I used to clean whole house, but now I clean just clean my room.*" When she is not completing her old housework, she is looking after her baby, indicating no time for herself.

Another similarity within this group is nearly all the mothers had young babies under seven 7 months. Younger babies demand less physical movement from their mother, and more sedentary caretaking (e.g., breastfeeding, providing warmth, oil massage, etc.). Some mothers also expressed having to stay home all the time because they needed to be near their baby to provide more care and breastfeeding when needed. In Nepal, families perform rice feeding ceremonies (for male children around 7 months old and for female children around 5 months old) to mark the introduction of solid food to their diet and mark the end of exclusive breastfeeding. Six out of the seven “largely inactive” mothers had babies under 7 months old or younger, with a majority under 5 months old, likely indicating that these women were exclusively breastfeeding and had to do so several times throughout the day.

For example, participant 7 (19yo, 4mo, 2nd, 8HH) shared, “*Before being mother I could stay freely, but after being mother I have to look after my babies and look after her... Before I was free but now, I am not free.*” These mothers must always remain in or near their homes and put their babies' needs ahead of their own. This means they aren't able to roam around as they please because they need to be on hand to breastfeed and care for their babies. This limitation likely plays a role in decreased detected activity (and geospatial movement, discussed below). This, in combination with decreases in housework and increased instances of breastfeeding likely drive the inactivity being observed in the passive data.

Infant proximity:

Mothers were near their infants, on average, 81% of the day (4a to 8p). Nine mothers were detected to be with their infant over 90% of the period, while two were with their infants for less than 60% of the period. The average daily pattern indicates that mothers are most likely to be apart from their infant early in the morning (around 6am) and late in the evening. See Figure 5 for the average daily proximity pattern across our sample. Women broadly fit within three categories of child proximity patterns, those together nearly all day, those apart more than average, and those episodically apart at the extremes of the day. We describe these patterns, triangulated with women's descriptions of their everyday lives to provide various explanations of these findings.

Average proximity patterns of mothers

Every mother described her role of caretaking and being physically with the infant as her primary responsibility, one that fundamentally brought happiness and joy. Nearly all the women described the largest change they experienced after becoming a mother was having to put their baby before their own needs and desires. Women reported that they must remain with their infants ‘all day’ to provide important care. Often, this proximity was cited as a proxy indication for ‘good mothering’. Mothers described two main drivers bringing them close to their child (1) instrumental care, including breastfeeding, bathing, giving an oil massage, etc.; and (2) emotional care (playing, consoling, teaching, etc.). Mothers placed an emphasis on maintaining her infant's hygiene (n=16) and, as such, bathing her child, changing diapers, and cleaning her infant's clothes took up substantial portions of her day. Instrumental cleaning activities

might take the mother farther from her infant (water taps or water containers are kept outside the home), and women did this while their child was sleeping (which may indicate why levels vary slightly throughout the day. Similarly, women that were exclusively breastfeeding, especially those with children under 7 months, indicated that they were doing so several times throughout the day and was described as a reason why mothers had to be close to their infants throughout the day, preventing them from going 'anywhere she wants.' The need to be physically close to her infant was one of the most commonly noted transformations following new motherhood – some women indicated this as a lack of freedom, others as a 'responsibility.' Indeed, one mother mentioned ending her educational pursuits because she had to breastfeed her baby (P23). Another woman (P51, P7) stated that she struggles to get rest during the day because she has to look after her child without support. These instrumental tasks can be overwhelming given the amount of effort and time (changing clothes after every pass of urine).

Emotional care was the second most reported theme that brought mothers close to her child and occurred throughout the day. This usually took the form of playing with the baby, talking with the baby, carrying the baby, and/or consoling the baby when they cried. In certain cases, participants simply described the activity as "taking care of my baby" or "looking after my baby" without any details. Mothers placed an emphasis on demonstrating love and affection for their child in addition to providing them with instrumental care. In several cases, mothers announced that engaging in emotional care activities with their baby made them happy. Additionally, in more than one instance, mothers reported that they played with their babies as a way of taking care of themselves. Mothers may enjoy providing emotional care to their child because it provides them with an opportunity to get to know their baby more, unlike when they provide instrumental care, which focuses more on fulfilling the baby's physiological needs.

Household responsibilities outside direct childcare also may take the mother out of range from her infant, but only if she had access to other help. Some mothers replace their household [HA2] work with childcare responsibilities (P51 used to take care of goats but does not anymore b/c she has to take care of her baby; P55 does not prepare meals anymore). Others must find time to do everything (and bring their baby with them). Interestingly, some participants cited a decrease in their household responsibilities so they could focus more on taking care of their baby, while others were still expected to complete the same amount of household work as they did before becoming a mother. This difference may be related to the amount of support a mother has in her household. This difference in level of responsibilities among mothers in different households may cause some mothers to experience more stress and negative emotions than others. Several mothers shared that they completed their chores early in the morning, while their baby was still asleep, or later in the day when the baby was napping. This shows that mothers only have the time to do household work when they don't have to worry about taking care of the baby. It also means that a mother's daily schedule revolves around the baby's sleep schedule.

Together all day:

Eleven women (P7, P24, P22, P53, P20, P27, P55, P47, P25, P28) are together with their infant nearly the entire day, with only episodic and limited likelihood of being apart from their child. See Figure 6 for the

proximity graphs of these women.

Nearly all the mothers in this group were first time mothers with younger children (2-4 months). Younger children require more frequent and intense instrumental care (e.g., breastfeeding, changing, soothing, etc). Mother's noted several emotions connected to her physical proximity with her infant, including both positive attachment, fear, and stress. Participant 47 smiled as she described the time she spends with her daughter. She says, "*She sleeps well and I give oil massage and sekne [warmth]...babies don't cry if we perform these types of activities and play. Playing and laughing is good for their health.*" She goes on to describe that her family helps. For example, her husband holds the baby while they eat dinner together. "*In this way, he cares for me.*" On the other hand, the demands and uncertainties of new motherhood brought negative feelings. For example, participant 28 (17yo, 2mo, 1st, 9 household members) described that she has to let her baby cry alongside her so she can do her work, "*After I finish all my household work, I stay in my room with my baby. I have to look after her. I don't have time to think about me, she doesn't let me wash my own clothes – at that time, I feel difficult (garro lagchha).*" Other women echo the stress of completing their household chores with their child alongside them, wherein managing the demanding emotional care on top of cooking and cleaning the home was overwhelming.

These women also describe limited household help. For some, this is because they live in a nuclear home, such as participant 20 who was 15 years when she had her first child and lives in a nuclear household, where her husband works all day outside the home. For others, they may live in a multigenerational household, but do not easily receive help. Without childcare assistance, these women must be with their child throughout the entire day, bringing them with them as they do their other daily tasks. Participant 27 describes her day, "*I just stay with him and hold him....i feel shy and scared [to ask my mother-in law for help]...I am scared [my mother-in-law] might scold me (gali garnee).*" Women's relationship with household members, particularly in-laws, seems to contribute to her spending time physically distant from her baby. Notably, when women are apart from their child in this group, it is to do another household chore leaving little time for 'themselves'.

Apart more than average all day:

Six women are apart from their children much more than average throughout the day. Some women are continuously apart, and some are apart during certain periods of the day. Proximity graphs of P26, P23, P6, P44, P33, and P48 can be found in Figure 7.

Three women in this group are in the formal workforce and they do not bring their children with them (P33, P48, P44). This maps onto their beacon data. For example, P33's beacon is not detected often between nine am and five pm, her typical workday. She is a daily waged labor worker and leaves her 12-month daughter with her mother and brother during the day. She elucidates, "I leave her from morning to evening. In the daytime, my brother brings her to me for breastfeeding...sometimes twice a day, sometimes when she eats other food at home, he'll bring her to me only once." (P33, 17yo, 12m, 1st, 4

household members). Her husband works abroad, and, because of her love marriage, she remains in her maternal home and is happy to have the support of her own family. For mothers that must be away from their children for work, finding familial support is essential. Some mothers are unable to pull on their household members for help. For example, participant 6 lives with 11 other family members in her husband's home but is uncomfortable asking for help and must leave her baby to do required tasks (laundry, cooking, cleaning). She explains her overwhelming responsibilities, "Still she is small, at this time I have to look after her when she starts crying. When I am free, I can look after her but when I remain busy it would be better if someone else could. I can't force other people to look after her. If other people didn't give attention towards my baby at that time, I myself have to manage all these things...They [in-laws] don't even talk to me..." (6, 19yo, 5mo, 1st, 12 household members). Formal work and household support are integrally related to a mother's proximity to her child throughout the day. Two women in this group qualitatively reported usually being together with their infants (P23 and P26), indicating disagreement with the beacon data.

Apart more than average in morning and evening times

Five women are apart from their children more than average in the mornings and/or evenings. Most of these women are usually with their child in the middle of the day, though P21 is also apart from her child often for a period of the afternoon. The graphs of P21, P4, P1, P3, and P51 were included in Figure 8.

Women in this group often did chores first thing in the morning, while their child was sleeping. This may explain why women were often not with their child in the early morning. Cooking and cleaning typically happen outside the home in the open air. In her daily diary, P51 describes her morning routine beginning at 6am. She sweeps the yard around the house and prepares the morning meal. Her three-month-old daughter stays with her husband in the bedroom until 9am when she serves them food and they eat together in the kitchen. Similarly, P3 reports that her responsibilities have increased dramatically since the birth of her second child. She must cook a separate meal for her daughter (*jaulo*) and wash all of their clothes. This often happens while she is outside, and her daughter is in the bedroom with her husband. In her daily diary, she is busy with a household chore every hour until the early afternoon, then starts cooking and cleaning again towards the evening. She exclaims, "A mother has to face many difficulties. And we must face all these difficulties." These women are typically able to leave their children with another family members so that they can perform their household responsibilities, on top of caring for their children.

Geospatial movement:

We analyze the GPS data of 14 women. The mothers were sorted into tertiles based on their radius of gyration, defined as the average radius that a person travels from their center over the course of a day. The average radius of gyration among our sample was 1675 meters, and the median was 798 meters. The ranges of mothers in the first, second, and third tertiles are 47-618, 654-1455, and 2047-5100 meters, respectively. The mothers commonly left their homes to visit the following places: health

facilities/hospitals, market/shops, and their maternal homes. Formal work, college, temples, new places, and other errands were mentioned less frequently. Most women only reported leaving their child at home for a few minutes to an hour and a half, but participant 21 shared that she went to the market and was gone for seven hours. Many mothers expressed that they only left the house for essential reasons, though participant 1 shared that she likes to visit new places for entertainment.

By Age: <=7mo, >7mo		1st tertile (46.6-618.2m)	2nd tertile (654.4-1454.6m)	3rd tertile (2047.8-5099.5m)
Radius of gyration- Average radius that a person travels from their center over the course of a day	Subject IDs	SS1069 SS1029	SS2104	SS3004
		SS3027	SS2016	SS1009
		SS2037 SS3080	SS2006	SS2011
			SS3005	SS3012
				SS2024

At home, all of the mothers spent time taking care of their baby and doing household chores (described in detail in the activity section above). A few women mentioned other factors besides household chores and childcare responsibilities that keep them at home – for example, Participant 7 shared that concerns for her own health kept her at home. To illuminate the daily lives of women in the lowest and highest tertile, we synthesize qualitative data from interviews, field notes, and daily diaries to understand what brought these women out of their homes and what kept them in their homes.

Maximum geospatial movement (third tertile)

The mothers in the highest tertile (43, 1, 21, 47, 25) also spent large portions of the day around their home doing housework and taking care of their baby. For some women, their workload of household chores decreased after giving birth so that they could devote more time to childcare and activities that brought them outside of their home. For instance, participant 21 reported that her workload decreased after birth, and she also shared that she left her baby with the child’s grandparents to go to the market and was gone for 7 hours[HA5] . Notably, many women across the tertiles reported a decreased workload, so this was not always associated with increased geospatial movement of the mothers.

As mentioned above, women were often kept at home unless they had someone to help them complete their household responsibilities. All of these mothers shared that they had family members who they could ask for help, and none expressed difficulty asking for help[HA6] . Four of them shared that their mother-in-law helped with the baby or with chores (43, 1, 21, 47). Four mothers also mentioned that their husband or other family members pitched in (47, 21, 1, 25). Participant 47 shared of her husband that *“he understands my feelings and fulfills my wishes... He returns fast from his work, hold this baby when I was eating food. He used to bring snacks for me.”* Women in other tertiles also mentioned having help from

family members, but few women outside the third tertile reported family members offering significant help on a routine basis. For instance, Participant 25 shared that her sister generally does the meal preparation, so she only has to prepare meals if her sister is too busy with other works.[HA7] Having supportive family members who were willing to help with childcare or housework may contribute to the mothers' ability to leave the house.

All of the women in this tertile reported leaving the house without their child at least once. Completing essential errands was one of the main reasons that women left their homes. Three of these women reported leaving their baby with family members to go to the market (1, 21, 47), and Participant 25 shared that she occasionally left her baby to run an errand at the roundabout. Women in the third tertile ran these errands more frequently than women in other tertiles, who usually reported running errands only on rare occasions.

Family visitation was another reason that women left their homes. Two mothers in this tertile reported visiting their maternal home (47, 1). Adolescent mothers often lived with their in-laws, so visiting their maternal home may be a source of comfort for them. One mother in the second tertile (23) also reported visiting her maternal home, suggesting that women across the tertiles view this as important. Some women also visited other family members – Participant 47 often visited the house of her sister-in-law, and Participant 25 visited her grandmother and her sister. Women with large geospatial movement shared that visiting family members brought them out of their homes.

Women also left their homes to go to a medical facility or hospital (43, 47), but women across all tertiles reported this. Most women reported only leaving the house for a few minutes for essential reasons, but there are a few exceptions. Participant 1 shared that she went to visit new places for fun. Participant 21 spent 7 hours at the market.

Some of these mothers were accustomed to having more social interactions outside the house before giving birth. Participant 47 shared that she used to go to her sister-in-law's house before having her baby. Participant 21 used to work in the fields before giving birth. Even in this group of mothers who have large radii of gyration, these mothers shared that they did not travel far because they needed to be near their babies (1, 21, 47, 25). Participant 21 shared that "*doing oil massage, washing clothes, taking care of my baby, breastfeeding, I can't just go anywhere I want.*" Regardless of their volume of geospatial movement, women expressed that the need to be close to their child kept them from travelling very far.

Limited geospatial movement (first tertile)

The mothers in the lowest tertile (7, 3, 51, 27, 55) usually remained very close to home, travelling an average of 47 to 618 meters away from home per day. All of these women reported spending their days at home completing household chores and taking care of the baby. The age of the baby may contribute to keeping women at home because women must exclusively breastfeed younger babies. The mean child age in this tertile is 4.4 months, compared to 8.8 and 7.0 months in the second and third tertiles, respectively. With their household responsibilities, mothers were often kept at home unless they had

someone who could watch the baby and/or help with chores. Women with limited geospatial movement did not always have great relationships with family members, so they may not have had the help from others that would have enabled them to leave the house. All of the mothers in this cohort shared that they had family members or neighbors who they could ask for help, but only women in this tertile (7 and 27) reported that they felt difficult to ask for help. Lacking supportive family members to help with housework or childcare may have kept women from leaving the home.

Most women with limited geospatial movement ventured outside of their homes infrequently. Participant 3 reported going to buy soap and taking her child to the hospital. Participants 51 left her baby with family members once, and participant 27 took her child to the immunization center. However, two women (55 and 7) did not mention one instance in which they left their child at home and went somewhere. For women in the first tertile, leaving the home was a rare occurrence.

Isolation

Besides a few essential trips outside of the home, four mothers explicitly stated that they usually remained at home all day (55, 3, 7, 27). This isolation was connected to becoming a mother for women like participant 3080, who shared that she could not leave the house like she did before giving birth. She said:

“Now, I don’t go for walks. I always remain in my home, but previously during pregnancy I used to walk here and there. I didn’t stay in my home. I used to go in my neighbor’s house after completing my household activities. Sometimes I went to my aunt’s house, sometimes to my maternal home and then come back here to prepare breakfast. Then, after preparing breakfast again I used to go to my maternal uncles’ home...Now, I have my baby so, I don’t go anywhere.”

Motherhood restricted geospatial movement and might also restrict her social engagement. Restricting her ability to visit her maternal home may be very significant for her well-being, as we will discuss in the following section.

This is not unique to the first tertile; participant 33, from the second tertile, shared that she also could not wander outside the home like she could before having her baby. Participant 21, from the third tertile, expressed that she did not leave home as much as she did before giving birth because she no longer had to work in the fields.

Case studies illuminating passive data profiles

We share case studies of two women to synthesize their passively monitored behaviors with their day-to-day experiences. We combine the activity, proximity, and GPS data of these women to provide a more complete picture of their daily lives and to help understand and interpret the passive data.

P33: Second tertile for radius of gyration

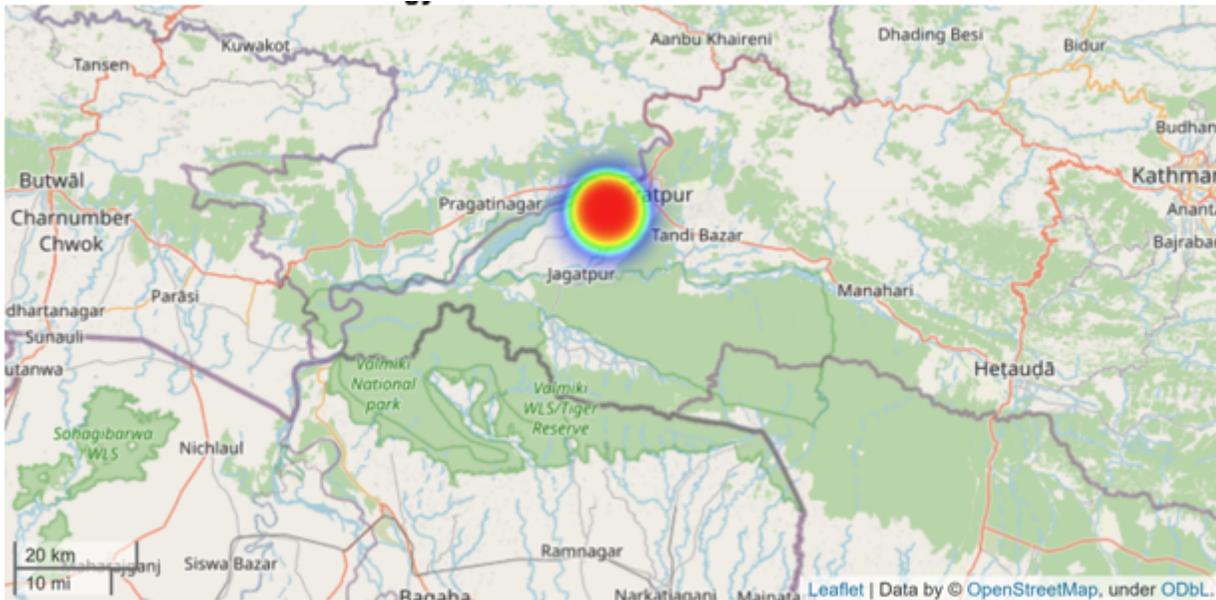


Participant 33 is 17 years old and has one child, a 12-month-old girl. Despite getting married and giving birth at such a young age, this mother did not report any difficulties because she wanted to have a child. She had a love marriage, so she lives at her maternal home with her mother, brother, and child. Her husband is working abroad. After she wakes up around 5:30 am, she takes a bath and then brings water from the tap. At 6:00 am, she begins preparing food in the kitchen. Once her baby wakes around 7:00 am, she breastfeeds her baby in the bedroom, and then eats a meal in the kitchen. Her qualitative data is reflected in her proximity to her child during this time. She leaves her daughter with her mother and brother to go to work, which is reflected in her being apart from her child in the middle of the day. She describes the impact of her mother's help with childcare on her day to day life, *"Now I don't have any difficulty. I have my mother with me so I don't have any difficulty."* This is important given that her husband is a migrant laborer and not home with her in the household.

Her activity in the morning reflects her walking to work, and it corresponds to the time that her proximity data shifts from together to apart. She does not work far from home because she needs to be close to her child in order to breastfeed. Every day, around 2:00 pm, her brother brings her daughter to her work for breastfeeding. This is reflected in the spike in proximity around this time. She shared that, after having her baby, she could no longer go places like she used to: *"After giving birth to my baby, I couldn't go very far... I can't leave her for long time, I have to do breastfeeding."* She also shared that, because she works, she does not usually have time for entertainment, but at work she is in the company of her friends: *"I meet and talk with my friends in the workplace."*

Her activity in the afternoon reflects how she leaves work around 5:00 pm, and when she gets home, she takes a bath, takes care of the baby, and washes her and her daughter's clothes. She spends time with her daughter until she goes to bed, which is reflected in her proximity data showing her with her child in the evening. Since she leaves the house regularly but does not go far for work, she falls into the second tertile for radius of gyration.

P55: First tertile for radius of gyration



Participant 55 is 20 years old, and she has one child, a 3-month-old boy. She lives with her husband, father-in-law, mother-in-law, sister-in-law, and child. She wakes up around 6 a.m. and immediately begins cleaning her baby. The mother used to have to wake up at 5 a.m. to serve her father-in-law breakfast and complete many household chores, but now, after becoming a mother, she can sleep in later, clean herself, and look after her baby. She shared:

“At first, I clean my baby when I wake up in the morning like wash his face and change his clothes. Then I take rest for some time [with her baby]. Then, I go to the ground floor and do regular activities like brushing my teeth, washing my face, going to the bathroom, etc. Then, again I come back to my baby to clean his face and breastfeed him. Then, I have my breakfast and wash clothes.”

These tasks do not require much movement, which is reflected in her activity data. The proximity data shows that she is always near her baby, which reflects how she devotes her time to caring for her baby.

She used to leave the house to visit neighbors’ homes, her aunt’s house, and her maternal home before giving birth, but now, as the proximity data shows, she does not leave her baby: *“Now, I have my baby, so I don’t go anywhere.”* Although becoming a mother has restricted her ability to leave the house, she does not get bored of spending time with her son. She shared that *“I like to watch when he plays, and sometimes I feel happy when he tries to speak. At that time, I think I am watching some drama and I enjoy those activities.”* She enjoys devoting her time to caring for her child.

Because she does not leave her baby, she is in the lowest tertile for radius of gyration. She shared that when she is feeling lonely or irritated, *“I listen songs, watch television. Sometimes I talk with my sister-in-law.”* Because these activities do not require movement or leaving the house, she has very little activity and a very low radius of gyration.

Discussion

This is the first study to capture various passively collected sensing indicators among adolescent mothers. We triangulated these digital phenotypes with qualitative data to gain insights regarding the activity levels of typical adolescent Nepali mothers. Specifically, we highlight that these women have fairly restricted movements, largely influenced by accessible household and childcare support, the age of their infants, and traditional gender and cultural roles. Previous research conducted on maternal movement focuses primarily on demographic, lifestyle, and clinical factors associated with lessened to heightened activity levels [62, 63]. Our research provides novel insights into adolescent maternal activity patterns in the postpartum period and what actions drive various movements (GPS, child proximity, and activity).

We found most mothers enrolled in this study upheld traditional gender roles and were responsible for most of the instrumental and emotional child rearing tasks as well as most of the housework. This was not unexpected, given what we know about the cultural expectations for women in Nepal [12, 13, 15]. We found that mothers detected activity levels were influenced by their child's age and the amount of childcare and household support they receive from family and friends. Mothers who have considerable support tended to have lower activity levels and spent more time sedentary. Mothers with higher levels of detected activity were less likely to have familial support throughout the day to help them either care for their baby or help them complete their housework. As a consequence of this, these mothers are usually moving around and working all day, providing them with little time to lay down, take naps, or engage in entertainment.

This constant work schedule coupled with lack of rest time may impact mothers' health. Many mothers expressed frustrations with their heavy workload and may experience feelings of stress. Some researchers theorize stress can make one more susceptible to both physical and mental health problems [64]. This finding, coupled with proximity and geospatial findings, shine a light on how passive sensing data can be used as part of an intervention supporting maternal mental health.

Mother-infant proximity studies largely focus on household presence or absence of mothers and do not explore more fine-grained distance measures. Previous health studies have primarily focused on the use of interpersonal proximity measurement to assess infectious disease risk [65]. Moreover, relatively few measure proximity to infants specifically. Ozella [66], Kiti [67], and Campbell [68] used infant proximity as a way to understand their social lives (and human exposures) to inform infectious disease transmission and risk. Ozella and Kiti pilot the use of digital sensors, while Campbell uses self-reported paper diaries. All studies identify that the infant spends the majority of time with its mother and focus on the location and specific number of contacts made. None of the studies explore effects of infant proximity on maternal behaviors or psychosocial well-being. To this end, researching mother-infant interpersonal activity through sensing technologies remains novel. Our findings highlight that objective measures of infant proximity give important insights into a mother's life, including both the benefits and challenges of being near or far from her baby throughout the day. Specifically, adolescent Nepali mothers are near to

their infants for the majority of the waking day, fulfilling an important social role, offering a rewarding identity (motherhood), and providing positive emotional attachments. This research also highlights the enormous workload particularly for mothers with limited household support. These concepts have been identified among low-income women with adverse childhood experiences in western contexts, but limited work is conducted cross-culturally in LMIC [69, 70]. Future investigations can provide more insights into how the transition to motherhood, particularly for vulnerable younger mothers in low income contexts, affects their daily activities, social world, and subsequent identity. This information can inform behavioral interventions, specifically those focused on psychological well-being. For example, infant proximity patterns can be used to identify need and opportunities for self-care and support, necessary components for maternal well-being.

The geospatial movement data that was collected allowed us to identify groups of women with different geospatial movement patterns, similar to how previous studies have used GPS data to distinguish different walking patterns of an elderly population [71] and of a population of postpartum women [38]. Unlike Faherty's study of postpartum women, we were not comparing geospatial movement patterns based on depressive status. Instead, we were using GPS data to illuminate the daily lives of nondepressed mothers. Our finding that women with lower radii of gyration often lacked support at home may reveal contributing factors to the association between worsened mood and contracted radius of gyration that Faherty identified. Strained familial relationships and lack of support may contribute to worsened mood and contracted radius of gyration, though more inquiry is needed to determine the direction of causality in these associations. Our future analyses will compare the passive sensing data profiles of the non-depressed women described in this study with depressed women in the same region.

The above studies measured geospatial movement in high-income countries, but there are few studies about postpartum women in LMIC that utilize GPS data beyond the purpose of feasibility studies. However, the relatively small distance that the mothers in this study travel (the average radius of gyration is less than 2 kilometers) is consistent with the findings of a study in India that found that, while GPS data indicated that older men travelled less than younger men, older women actually traveled more than younger women because young women with children are largely confined to the household [72].

This limited ability to travel outside the home may have implications on women's mental health. Interventions that provide child-care or household assistance may enable women to leave their house more frequently, which may have a positive impact on their well-being. Further, changes in movement patterns may serve as an indicator of worsening depressive symptoms in women with postpartum depression [38]. Using GPS data to monitor for signs of worsening depressive symptoms can be delivered through a mobile application that triggers contact with healthcare providers when it detects troubling signs [73]. Passively sensed GPS data that triggers provider contact has enormous potential to deliver individualized treatment for postpartum depression.

Strengths and limitations

This study is the first to deploy a suite of passive sensing data collection approaches in an adolescent maternal population in LMIC. We used an ethnographic and community-based participatory approach to data capture and interpretation by triangulating passive data with qualitative accounts in order to better understand how young mothers describe and explain their everyday experiences vis-a-vis technology based captures of their activities. Multiple encounters between the research team, female informants, and their families, created important trust and several opportunities for data capture across several weeks. Additional remote check-ins by telephone and in-person visits helped to avoid technological barriers and further develop trust with mothers and their families. However, there are important limitations to consider given the novel approach and emerging technology. We describe the feasibility and technical limitations in detail elsewhere [54], but provide particularly salient limitations for this analysis here. First, the phone-based data capture did not detect all activity as the cell phone may have been put down while conducting various household activities, particularly those involving water or threats to the phone's safety. Data capture only occurred in 15 minute increments throughout the day, limiting the granularity. Second, the proximity beacon has a large range (5 to 50 meters), thus not allowing for precise inference on physical closeness between the mother and child. Some women's qualitative reports did not match their passive sensing data. More validation work is needed to identify whether this is a self-report issue or a technology issue. Third, we only capture passive data during waking hours, limiting information on activities and behaviors that may happen overnight. Finally, our sample of women likely exhibits some selection bias given that women from more restrictive families may not allow the participants to freely participate and interact with the research team.

Conclusion

We present novel passive data patterns of adolescent mothers' daily lives, including activity, infant proximity, and geospatial movement throughout the day. In the rural Nepali context, we find that mothers are rarely apart from their infants, remain close to their homes, and have limited activity. The patterns vary within our sample and are largely driven by available household support, her infant's age and instrumental care requirements, and a mother's ability to acquire help. Acquiring passive sensing data has exciting opportunity to inform, enhance, and improve behavioral health interventions by providing social, behavioral, and environmental information within an individual's larger social context that does not require self report. It is important to triangulate this information with qualitative inquiry that generates person-centered accounts of patterns to best interpret its meaning. More research is needed to further refine the technology and adapt approaches to best fit the health needs, culture, and context of the targeted population.

Declarations

Ethics approval and consent to participate

Ethical approval was received from the Nepal Health Research Council (#327/2018) and George Washington University Institutional Review Board (#051845). Written informed consent was garnered

from participants over 18 years. For participants under 18 years, written assent and parental permission from participants under 18 years was obtained. Verbal informed consent from adult members of their household was also obtained.

Availability of data and materials

Passive data will be made publicly available upon publication of the final study results.

Competing interests

The authors declare that they have no competing interests.

Funding

Funding for this study was provided by the Bill and Melinda Gates Foundation (Grant #. OPP1189927, PI: B.A. Kohrt)

Authors' contributions

AH, AP, AvH, SMM, PB, and BAK contributed to the design of the study. AvH developed the EBM app and conducted passive data analysis. AvH and PB developed the StandStrong app. Qualitative data collection was overseen by SMM, AP, and AH. AH led the analysis and interpretation of the data, with participation from DLM, CB, and AP. CB and AvH created the passive data figures. The manuscript was written by AH with significant contributions and revisions from all authors. All authors approved the final version of the manuscript.

Acknowledgements

We would like to thank mothers and their families who participated in this study. We also like to thank the field-based research team (Aasha Mahato, Bhagwati Sapkota, Sabita Lohani, Bindu Aryal, Kendra Chaudhary, Bibek KC, Sirjana Panday) and colleagues at Transcultural Psychosocial Organization Nepal.

Abbreviations

ANM: Auxiliary nursing midwives

COREQ: Consolidated Criteria for Reporting Qualitative Studies

EBM: Electronic Behavior Monitoring

GPS: Global Positioning System

HIC: High income countries

LMIC: Low- and middle-income countries

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Figures

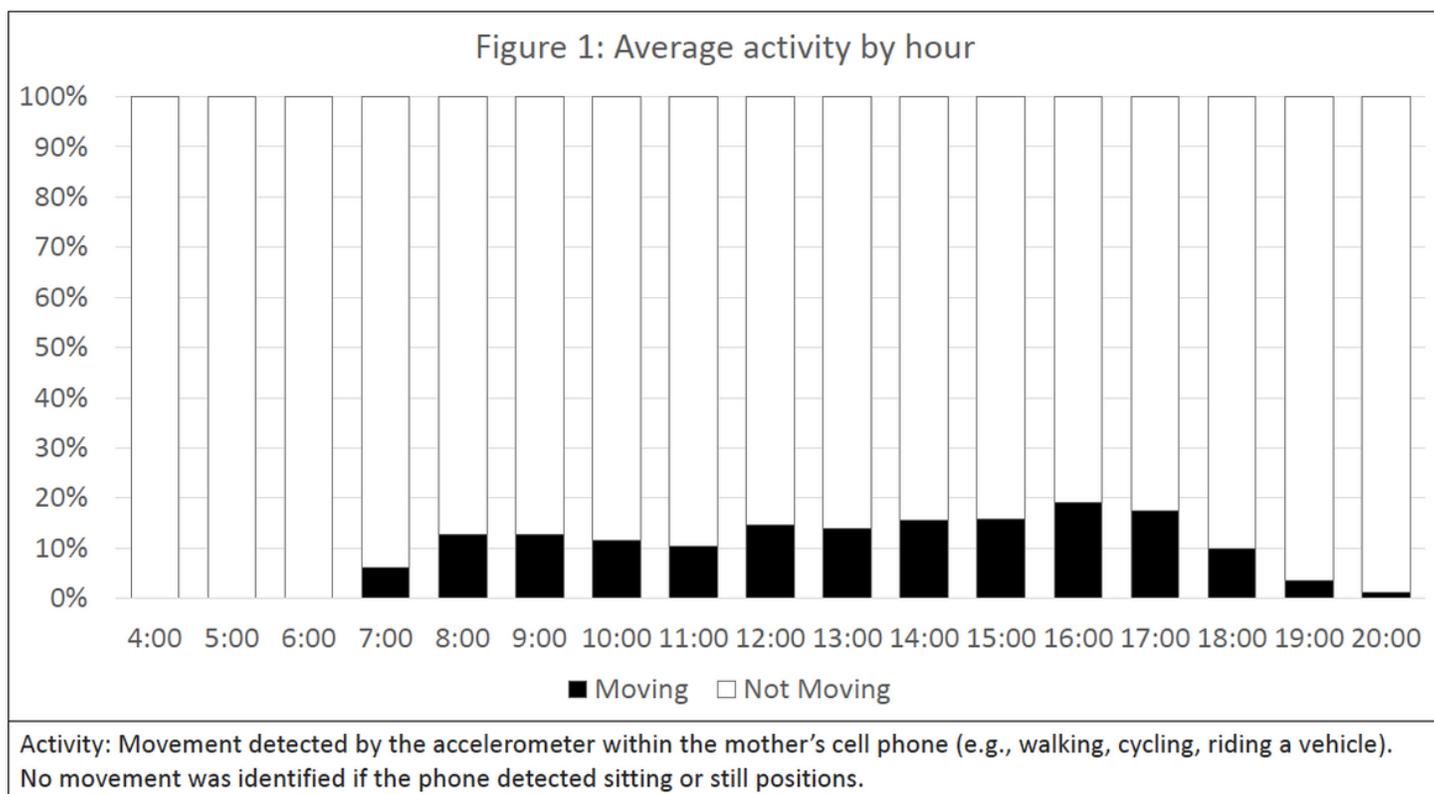


Figure 1

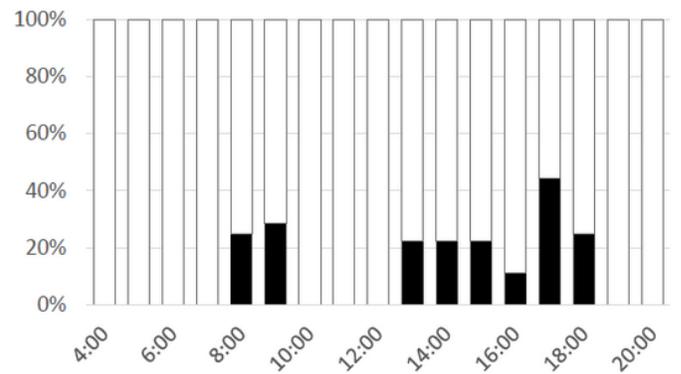
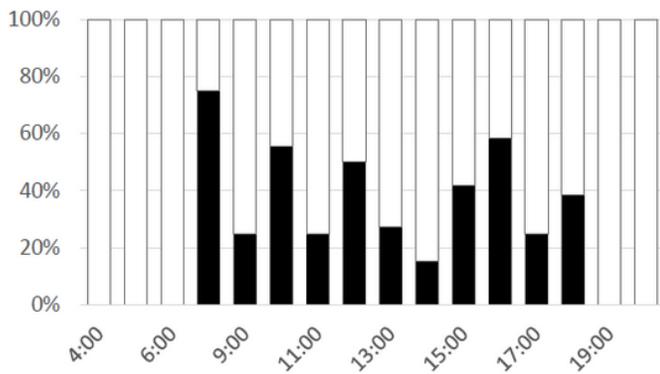
Average activity by hour

Figure 2. Activity by hour: very active mothers

■ Moving □ Not Moving

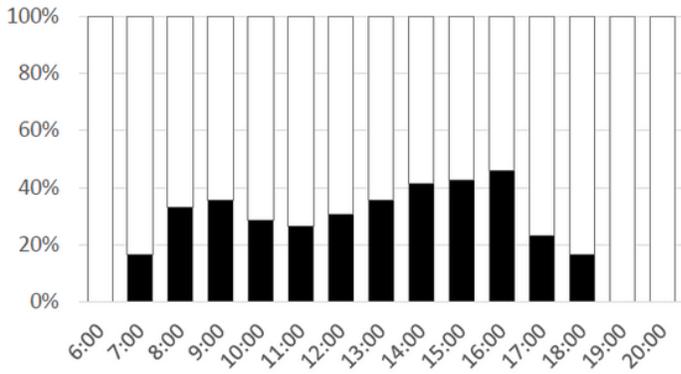
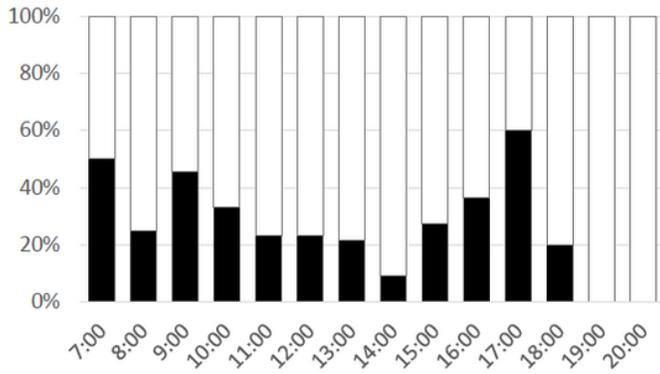
Participant #51 (n = 131) 17yo, 3mo, 1st, 7 household members

Participant #33 (n = 124) 17yo, 12mo, 1st, 4 household members



Participant #20 (n = 126) 19yo, 12mo, 2nd, 4 household members

Participant #1 (n = 159) 19yo, 5mo, 1st, 3 household members



Activity: Movement detected by the accelerometer within the mother's cell phone (e.g., walking, cycling, riding a vehicle). No movement was identified if the phone detected sitting or still positions.

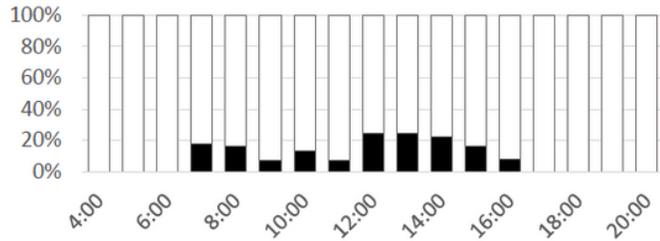
Figure 2

Activity by hour: very active mothers

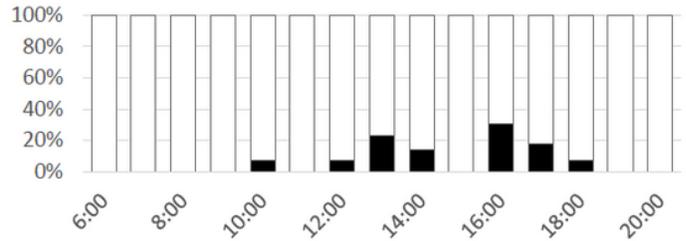
Figure 3. Activity by hour: moderately active mothers

■ Moving □ Not Moving

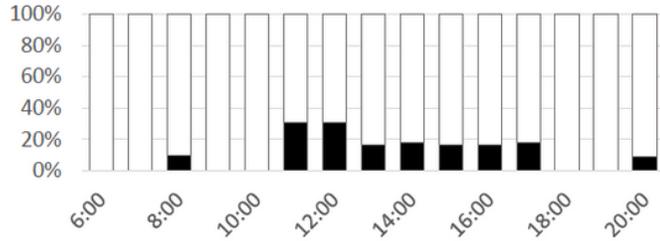
Participant #6 (n = 193) 19yo, 5mo, 1st, 12 household members



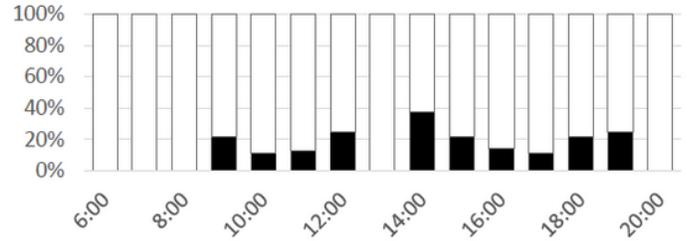
Participant #21 (n = 186) 22yo, 12mo, 1st, 4 household members



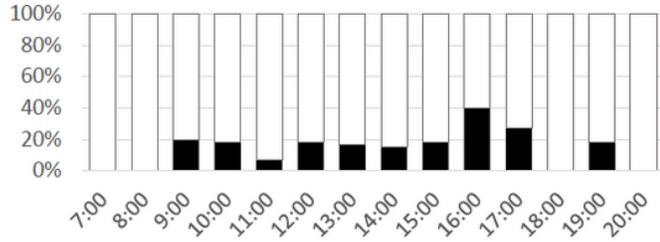
Participant #24 (n = 160) 17yo, 3mo, 1st, 3 household members



Participant #26 (n = 115) 16yo, 4mo, 1st, 5 household members



Participant #23 (n = 145) 18yo, 4mo, 1st, 4 household members



Activity: Movement detected by the accelerometer within the mother's cell phone (e.g., walking, cycling, riding a vehicle). No movement was identified if the phone detected sitting or still positions.

Figure 3

Activity by hour: moderately active mothers

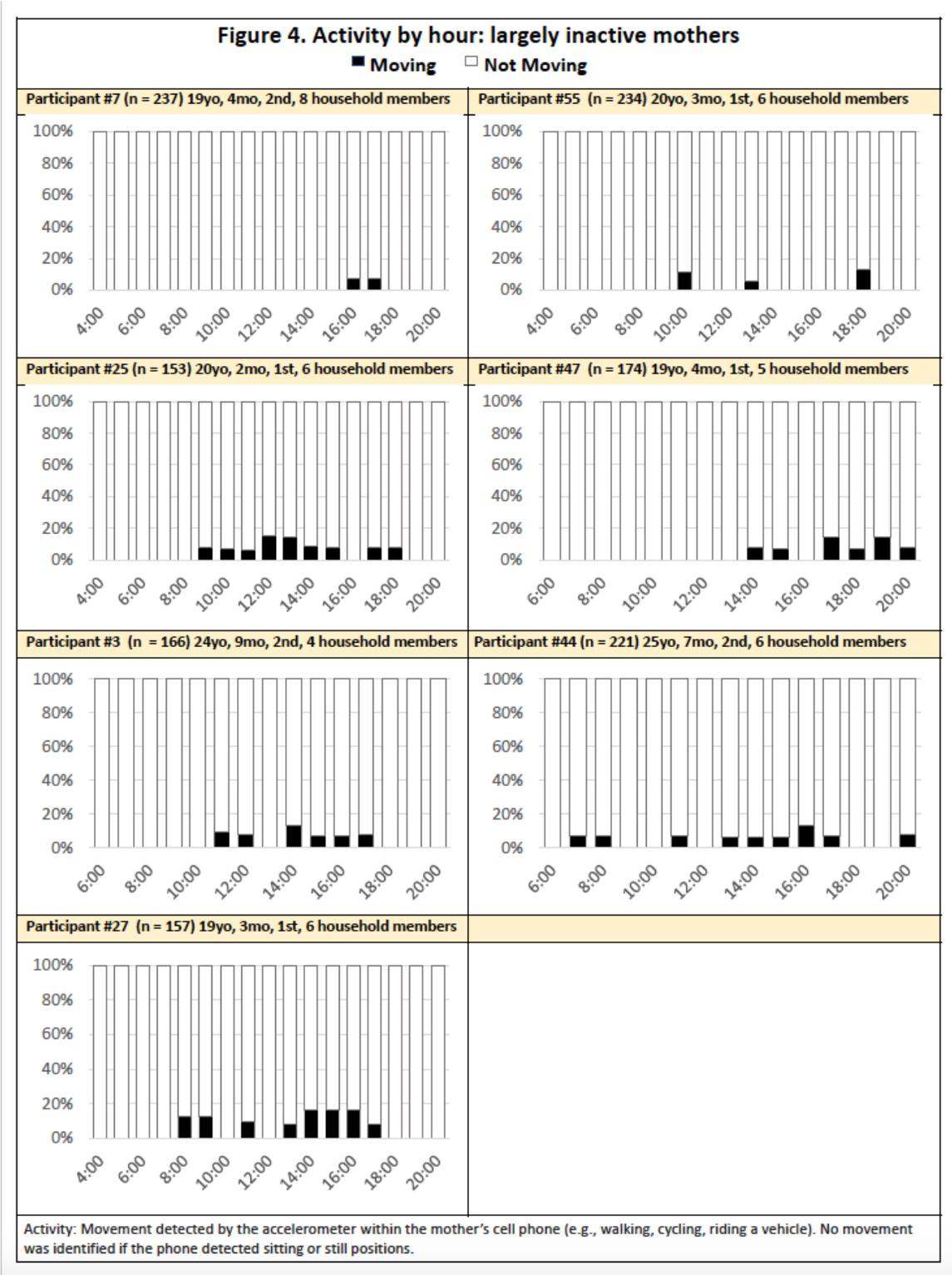


Figure 4

Activity by hour: largely inactive mothers

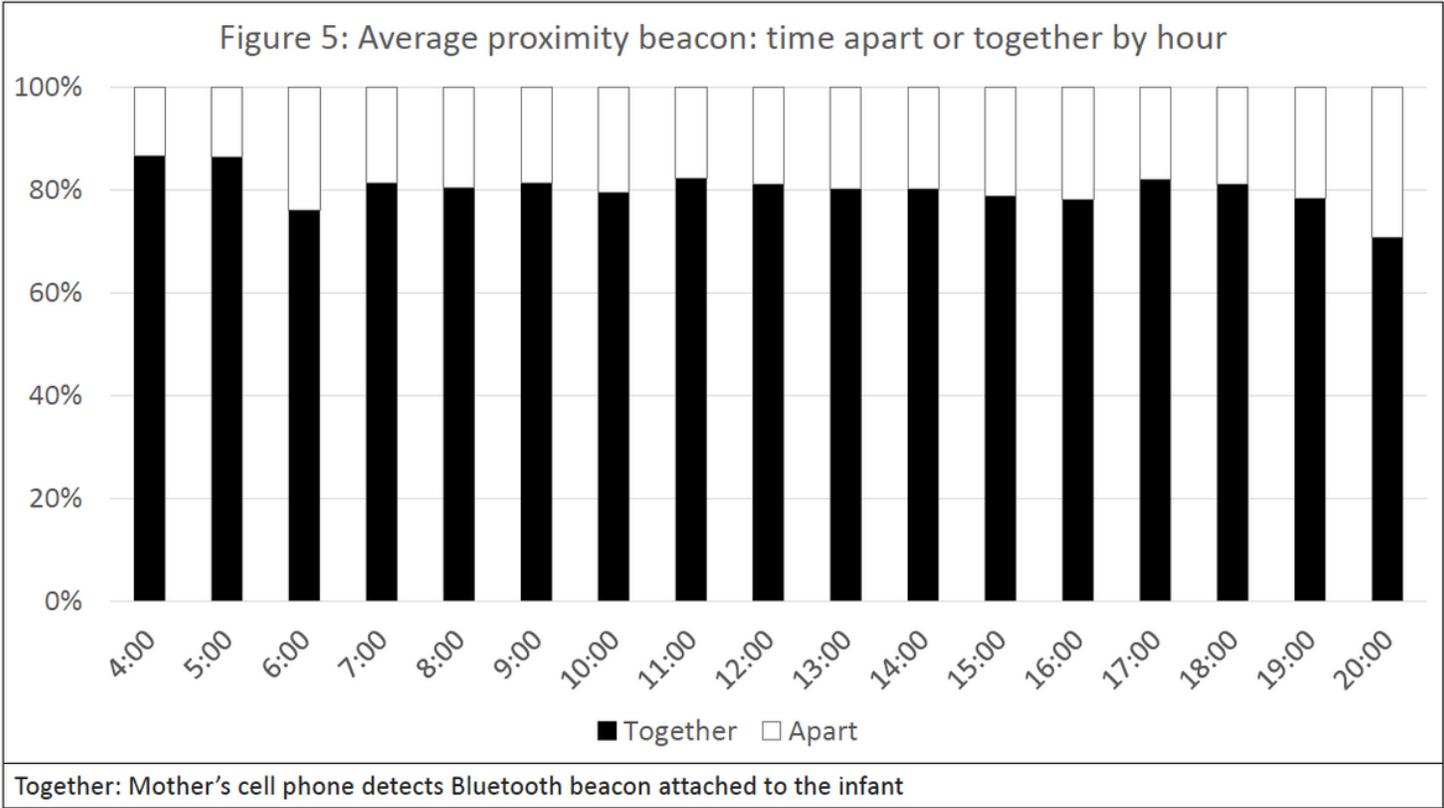


Figure 5

Average proximity beacon: time apart or together by hour

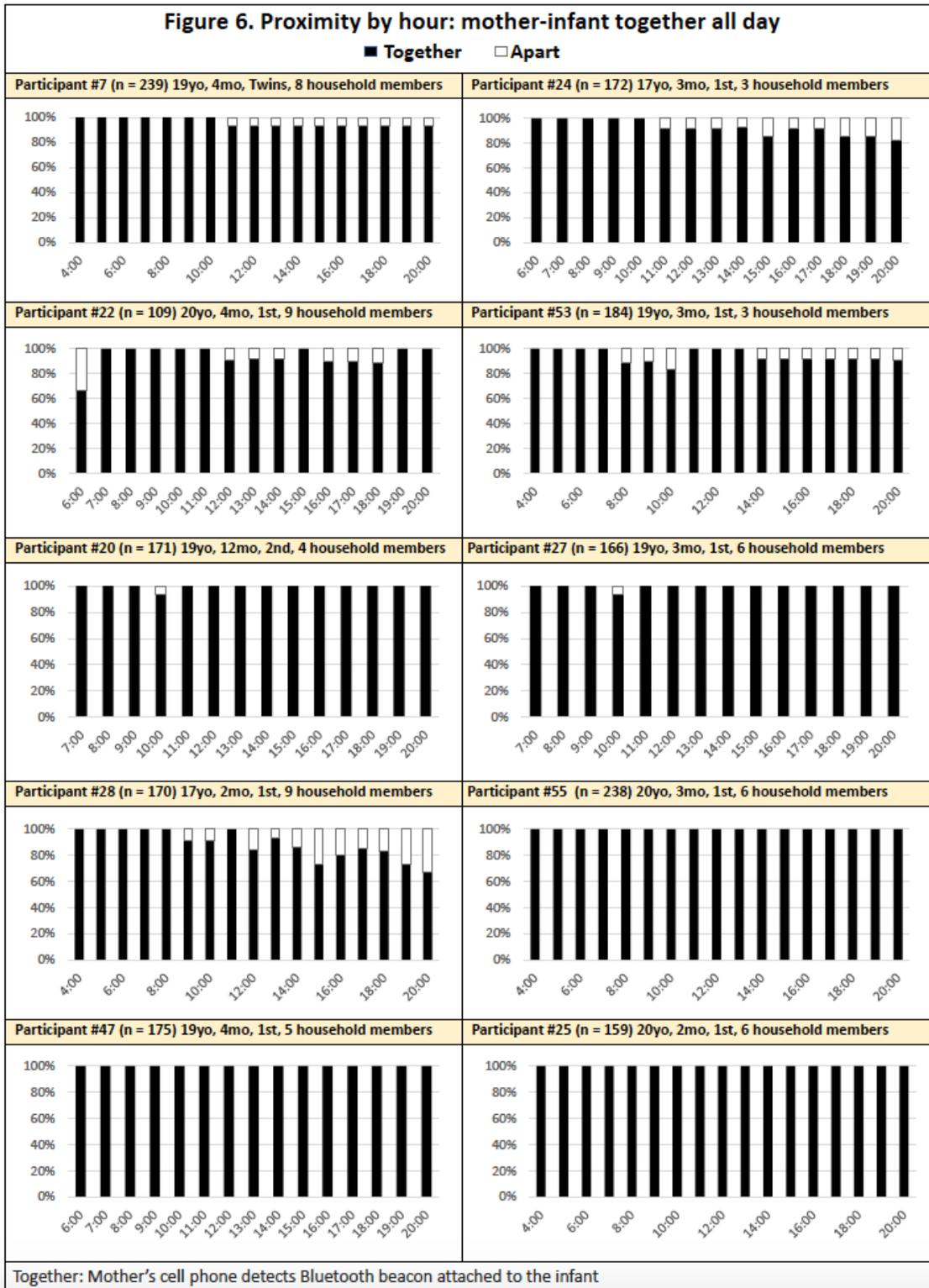


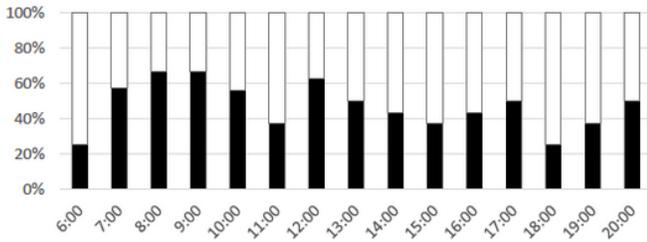
Figure 6

Proximity by hour: mother-infant together all day

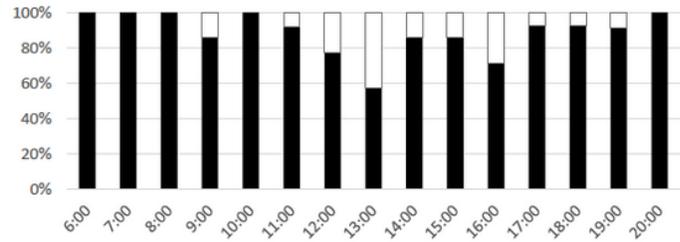
Figure 7. Proximity by hour: mother-infant apart more than average all day

■ Together □ Apart

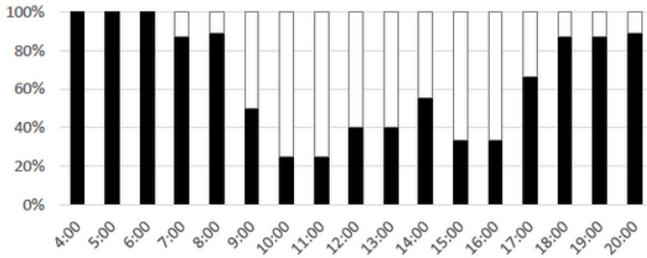
Participant #26 (n = 114) 16yo, 4mo, 1st, 5 household members



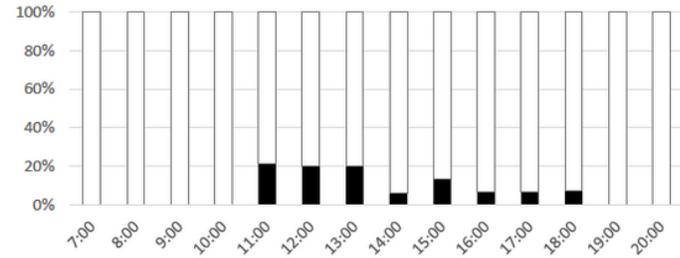
Participant #48 (n = 160) 23yo, 10mo, 1st, 7 household members



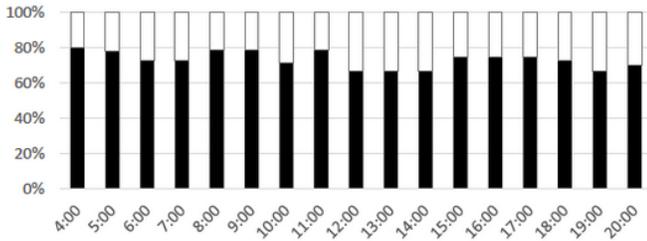
Participant #33 (n = 133) 17yo, 12mo, 1st, 4 household members



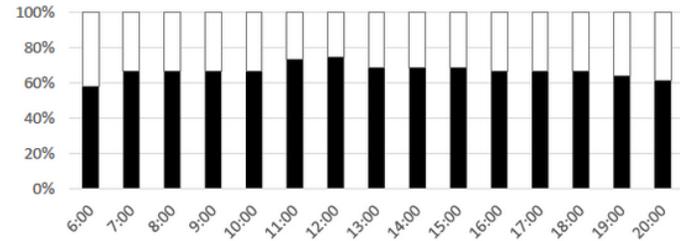
Participant #23 (n = 180) 18yo, 4mo, 1st, 4 household members



Participant #6 (n = 197) 19yo, 5mo, 1st, 12 household members



Participant #44 (n = 223) 25yo, 7mo, 2nd, 6 household members



Together: Mother's cell phone detects Bluetooth beacon attached to the infant

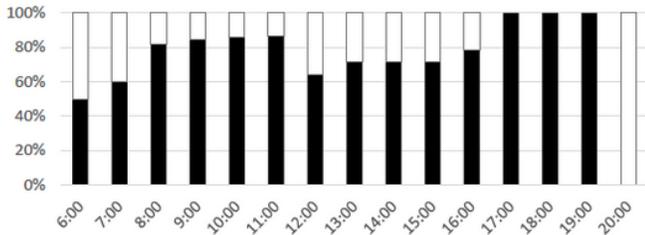
Figure 7

Proximity by hour: mother-infant apart more than average all day

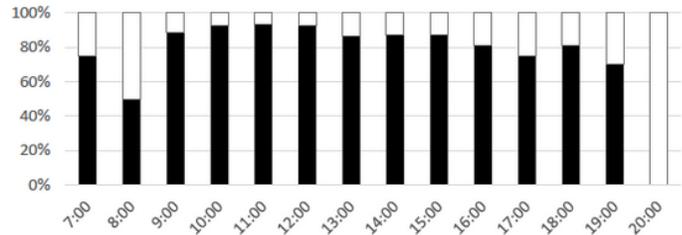
Figure 8. Proximity by hour: mother-infant apart more than average in morning and evening times

■ Together □ Apart

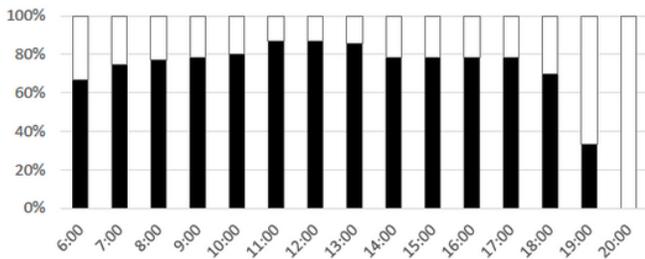
Participant #21 (n = 201) 22yo, 12mo, 1st, 4 household members



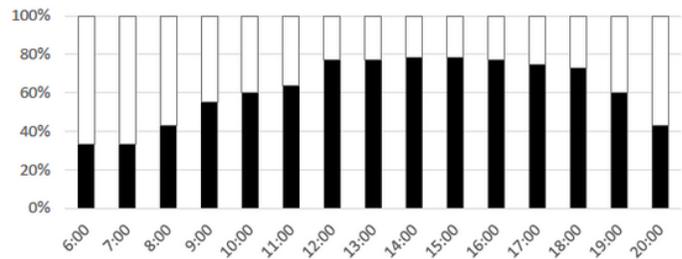
Participant #4 (n = 170) 21yo, 4mo, 1st, 7 household members



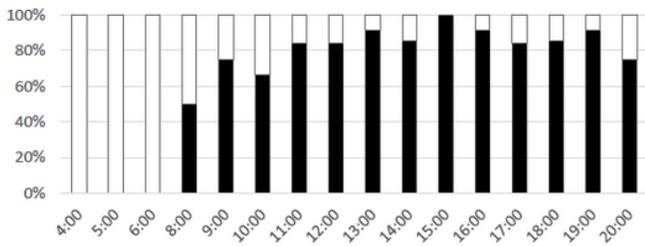
Participant #1 (n = 171) 19yo, 5mo, 1st, 3 household members



Participant #3 (n = 156) 24yo, 9mo, 2nd, 4 household members



Participant #51 (n = 143) 17yo, 3mo, 1st, 7 household members



Together: Mother's cell phone detects Bluetooth beacon attached to the infant

Figure 8

Proximity by hour: mother-infant apart more than average in morning and evening times

Figure 9. Case study: Participant #33

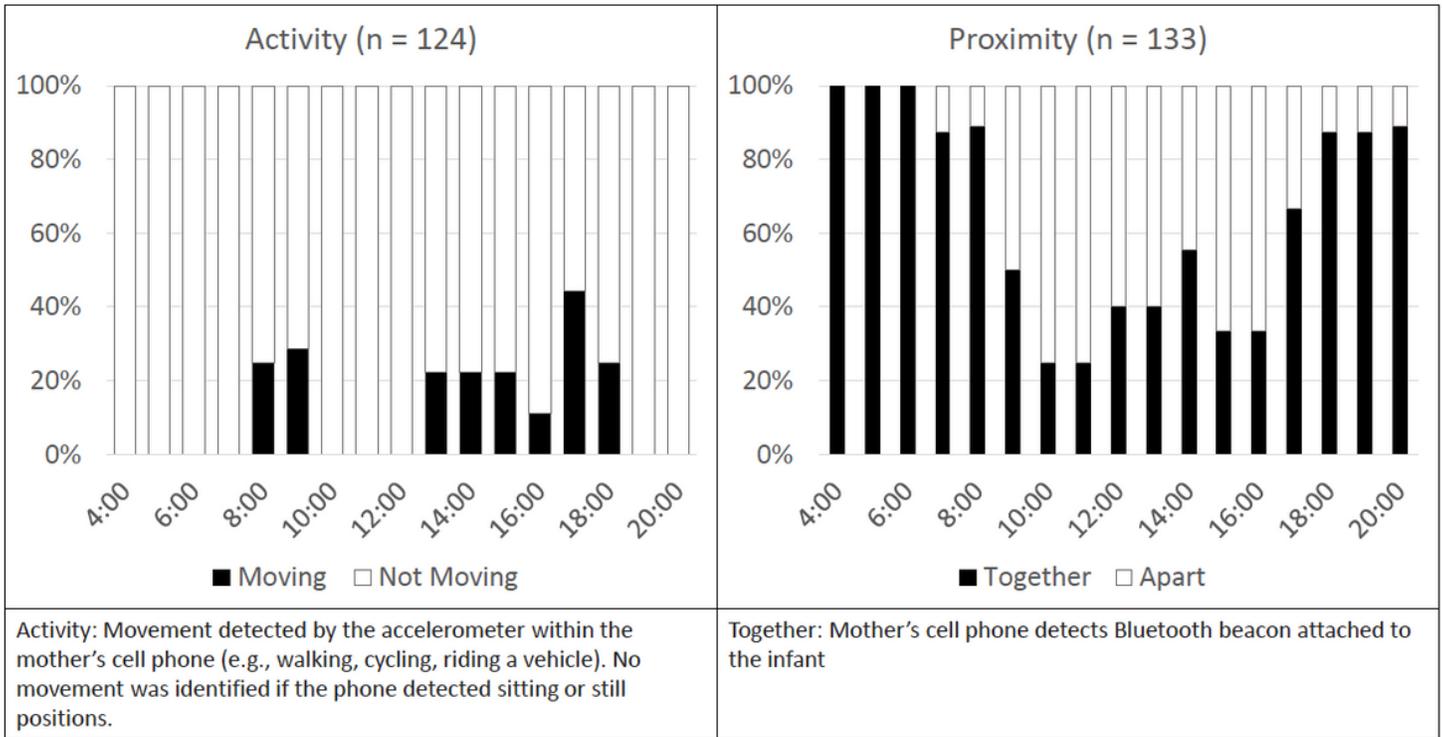


Figure 9

Case study: Participant 33

Figure 10. Case study: Participant #55

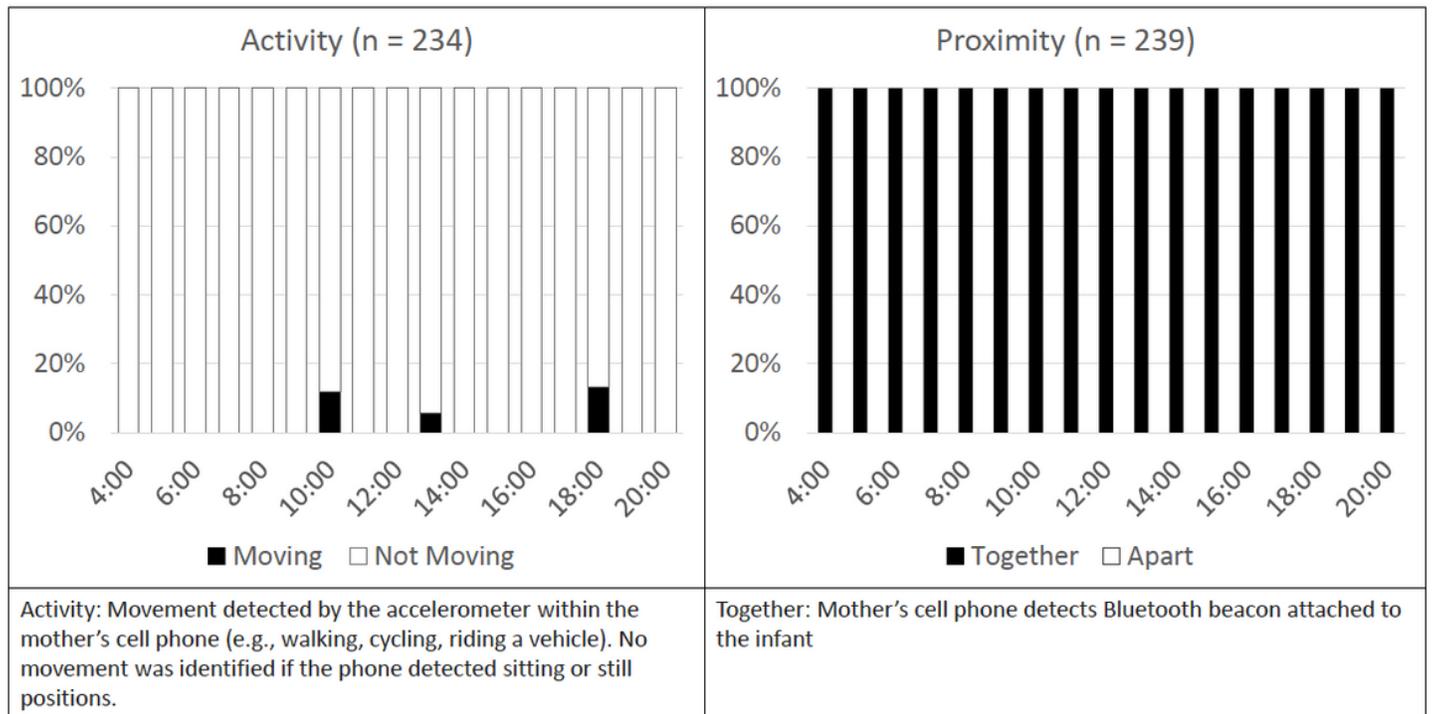


Figure 10

Case study: Participant 55

Supplementary Files

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- [DailyDiary.pdf](#)