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Connecting with fetus: The use of app-based fetal movement counting and experiences during pregnancy and birth

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ARTICLE INFO

Maternal-fetal attachment

Keywords: Fetal movement

Anxiety

Birth

ABSTRACT

Background: Pregnant people are often introduced to fetal movement counting to monitor the health of their fetus. This study aims to examine the impacts of app-based fetal movement counting on experiences during pregnancy and birth.

Method: This study used two types of secondary data including individual user's app use and their end of pregnancy survey data collected on the Count the Kicks (CTK) app. CTK is a free mobile app providing a virtual platform for pregnant people to conduct their daily kick counting. The study sample includes 1,147 pregnant people. Descriptive analyses were used to examine the number of kick counts using CTK and pregnant women's experiences with the app, their pregnancy, and childbirth. Bivariate analyses were used to examine the relationships between the frequency of kick counts and pregnant people's experience with their pregnancy and birth. Logistic regressions were used to model pregnant people's experiences: anxiety level related to their pregnancy and bonding with their baby.

Findings: The study found that there is inadequate compliance with daily fetal movement counting recommendations in third trimester among pregnant people. However, results showed that frequent use of fetal movement counting is associated with lower anxiety level related to their pregnancy, and more bonding with their baby. These positive pregnancy experiences are associated with healthy birth.

Conclusion: To benefit from the impacts of fetal movement counting on positive pregnancy and birth experience, the app developers and public health agencies need to develop strategies to increase daily use of fetal movement counting.

Statement of Significance

• Problem

A perceived decrease in fetal movement (DFM) is found to predict pregnancies at risk of adverse outcomes, including low birth weight, preterm birth, umbilical cord complications, placental insufficiency, emergency deliveries and stillbirth.

What is already known

As health-related mobile applications increased, several applications incorporated a kick "counter" that provides convenience of implementing fetal movement counting. However, there is no study on the effects of app-based fetal movement counting.

• What this paper adds

This study reported the benefits of app-based fetal movement counting, including lower anxiety level related to their pregnancy, and more bonding with their baby among pregnant people. These positive pregnancy experiences are associated with healthy birth.

Introduction

Background

A perceived decrease in fetal movement (DFM) is found to predict

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https://doi.org/10.1016/j.midw.2024.104214

Received 6 July 2023; Received in revised form 24 September 2024; Accepted 18 October 2024 Available online 19 October 2024 0266-6138/© 2024 Elsevier Ltd. All rights are reserved, including those for text and data mining, AI training, and similar technologies.







pregnancies at risk of adverse outcomes, including low birth weight, preterm birth, umbilical cord complications, placental insufficiency, emergency deliveries and stillbirth (Daly et al., 2019; Frøen, 2004; Heazell et al., 2018; Levy et al., 2020; Turner et al., 2021; Warrander et al., 2012; Winje et al., 2016; Winje et al., 2012). To prevent these adverse outcomes, clinicians such as obstetricians and gynecologists and midwives often provide pregnant people education on the importance of monitoring fetal movement. Many clinicians also provide women education on fetal movement counting, a daily systematic record of the mother's perception of her baby's movement (Daly et al., 2019; Lehman and Estok, 1987). The American College of Obstetricians and Gynecologists, 2021) provided suggestions for the timing and frequency of antenatal fetal surveillance, depending on the risk of stillbirth.

This study used data from Count the Kicks (CTK), a mobile app that offers a kick "counter". This study aims to examine the impacts of appbased fetal movement counting on experiences during pregnancy and birth.

Fetal movement counting

Most studies on fetal movement counting focused on education of fetal movement counting. These studies examined whether educating women about fetal movement counting can improve their birth outcomes. They reported mixed findings. For example, Winje et al. (2016) conducted a systematic review of studies evaluating interventions to enhance maternal awareness of decreased fetal movement. They reviewed 3 randomized controlled trials (RCTs) and 5 non-randomized studies (NRSs). They found mixed findings from RCTs: One large cluster RCT (n = 68,654) reported no stillbirth reduction, one RCT (n = 3111) reported significant stillbirth reduction, and one RCT (n = 1123) was small with no deaths. Similarly, they found mixed findings from NRSs: Three studies reported significant reductions in stillbirth or perinatal deaths.

In another review, Bellussi et al. (2020) pooled results from five studies using randomized controlled trials to compare perinatal mortality in those women randomized to receive instructions for fetal movement counting and a control group of women without such instruction. The authors reported that instructing pregnant people on fetal movement counting compared with no instruction is not associated with a clear improvement in pregnancy outcomes, including perinatal deaths, stillbirths, neonatal deaths, birth weight less than 10th percentile, reported decreased fetal movement, 5-minute Apgar score less than 7, neonatal intensive care unit admission or perinatal morbidity. There are weak associations with some secondary outcomes such as preterm delivery, induction of labor, and cesarean delivery. In Japan, Koshida et al. (2021) found that informing pregnant people about the daily fetal movement counting was associated with a reduction in delayed maternal reaction after the perception of DFM. They also showed that the stillbirth rate reduced after their study region implemented mass education on fetal movement counting. However, the change was not statistically significant. Another study examined the intervention including two components: 1) written information to women about fetal activity and DFM, including an invitation to monitor fetal movements, and 2) guidelines for management of DFM for health-care professionals. (Tveit et al., 2009) The authors found that the stillbirth rate showed a statistically significant decrease from pre-intervention to post-intervention.

As compared with studies on education of fetal movement counting, fewer studies focused on the behavior of fetal movement counting. These are different concepts, since being educated in fetal movement counting does not always translate into actual use of fetal movement counting. People who are aware of the importance of fetal movement counting may not implement fetal movement counting persistently and accurately (Clark and Britton, 1985). Kamalifard et al. (Kamalifard et al.

(2013) confirmed the diagnostic value of fetal movement counting. The authors had a sample of 291 mothers who used two common fetal movements counting methods: The method "ten fetal movements counting in two hours" and the method "three fetal movements counting in one hour." They reported the results of both two methods of fetal movement counting are statistically significant associated with the results from the biophysical profile test of the fetus. That is, active fetuses identified by both methods are more likely to be detected active in the biophysical profile test. However, Mangesi et al. (2015) in their Cochrane systematic review on fetal movement counting for reducing perinatal mortality as compared with no fetal movement counting.

Using mobile applications to monitor fetal movement

Pregnant people's use of mobile applications has increased dramatically in the last decade. Mobile apps directed at pregnancy constitute a major genre among health & fitness and medical apps as identified by Daly et al. (2019) They identified 24 mobiles apps intended for use during pregnancy. The authors reported that all 24 apps mentioned decreased fetal movement (DFM), however, only 5 apps link DFM to stillbirth. Fewer apps link DFM to other specific adverse outcomes. The authors also reported that two-thirds (N = 16) of the apps recommend "kick counting" and one third (N = 8) incorporate a kick "counter" to use within the app.

Existing studies on apps focus on their contents and recommendations. There are no studies about the effect of these apps on maternal behavior or perinatal health outcomes (Daly et al., 2019; Flenady et al., 2019). Moreover, there is no study on the effects of app-based fetal movement counting. This study aims to address both gaps.

Research questions

This study answers five research questions:

- 1. How frequent do CTK users conduct fetal movement counting (i.e., kick counting) on the app?
- 2. Is the frequency of app-based fetal movement counting associated with the anxiety level among pregnant people? We hypothesize that frequent app-based fetal movement counting is associated with lower anxiety level among pregnant people.
- 3. Is the frequency of app-based fetal movement counting associated with the bonding with their baby among pregnant people? We hypothesize that frequent app-based fetal movement counting is positively associated with pregnant people's bonding with their baby.
- 4. Is pregnant people's anxiety level associated with their birth outcome? We hypothesize that lower anxiety level is associated with better birth outcome (i.e., healthy birth) among pregnant people.
- 5. Is the pregnant people's bonding with their baby associated with their birth outcome? We hypothesize that the experience of bonding with their baby is associated with better birth outcome (i.e., healthy birth) among pregnant people.

Participants, ethics and methods

Data sources and participants

This study used two deidentified data files provided by Healthy Birth Day Inc., the provider of the CTK app. The first data file contains records of kick count sessions. Each session is comprised of 10 kick counts. The records show the start and end times of each session as well as the exact time of each count. The second data file contains data from the end of pregnancy survey which CTK users receive 14 days after their due date. Pregnancy ID was used as the link ID between these two files. The data was collected from pregnant people in Iowa and Florida. Iowa was the first state to promote the use of CTK in the US since 2008, while Florida started promoting the use of CTK more recently in 2020. This anonymized data was approved for analysis by the IRB of the researchers' institution.

The process of sample selection was presented in Fig. 1. From Healthy Birth Day Inc., we obtained 446,949 records of kick count sessions. Among all the records, 84 % (N = 373,753) lasted for at least 60 s. The remaining 16 % of records that lasted less than 60 s were removed from data analysis. The cutoff of 60 s was used because realistically, it takes at least 60 s to record 10 counts of kicks (Dr. Ruth C. Fretts, personal communication, September 22, 2021). Among remaining records, 0.1 % (N = 426) do not have pregnancy ID, which is needed for data link, and therefore were removed from analysis. This results in 373,327 remaining records. Among them, 0.5 % (N = 1938) do not have pregnancy due date, which is needed for constructing variables on frequency of CTK use during the third trimester, and therefore were moved from analysis. This results in 371,389 remaining records.

We selected the records on the kick count sessions during the third trimester: 91 % (N = 338,348) were recorded between 90 days prior to due date to 3 weeks after due date. The decision to use a cutoff of 3 weeks after due date was made to include as many complete sessions as possible, since the estimated due date could have been reported incorrectly or the user did not deliver the baby until the 42nd week of



Fig. 1. Process of sample selection.

pregnancy. These 338,348 records of count sessions were from 18,768 pregnancy ID. In other words, 18,768 pregnancies have 338,348 kick count sessions. We selected 99.7 % (N = 18,707) of pregnancies with due dates between July 15, 2021, and March 31, 2022, which was the time frame needed for data merge.

We merged the data on kick count sessions with the data from the end of pregnancy survey. Among the 18,707 pregnancies, only 6 % (N = 1147) can be linked with the end of pregnancy survey. In other words, only women of 6 % of the pregnancies completed the end of pregnancy survey, after their childbirth. Therefore, the final sample size is 1147. Table 1 shows demographics, pregnancy, and childbirth information of the final sample.

Measurement and variables

Frequency of kick counts by month during the third trimester

Using the data file on kick count sessions, we computed each pregnancy's frequency of kick counts by month, as indicated by the number of days of kick counts. In the first month of the third trimester, the number of days of kick counts ranged from 0 to 30. In the second month, the number of days of kick counts also ranged from 0 to 30. In the third month, the number of days of kick counts ranged from 0 to 42. The maximum days for the third month use is greater than 30, since some women gave birth after their expected due date.

End of pregnancy survey

CTK sends the end of pregnancy survey to their users 14 days after their due date. The survey contains questions on pregnant people's experience with their pregnancy and childbirth, and their behaviors related to COVID-19. This study used participants' responses on their anxiety level, bonding, and birth outcome as dependent variables.

The question on anxiety level asks, "How did the Count the Kicks app make you feel during your pregnancy?" The three responses options include "I felt less anxious," "I felt more anxious," and "No difference." We used the original variable of three options for ANOVA. We transformed the variable to a dichotomous variable for logistic regression

Table 1

Demographics, Pregnancy, and Childbirth Information of the Final Sample (N = 1147).

	Frequency	Percent
Ethnicity/race		
Black/African American	90	8.1 %
White/Caucasian	702	61.2 %
Hispanic/Latino	117	10.2~%
Asian	93	8.1 %
Other	97	8.5 %
Missing	48	4.2 %
Did your doctor consider your pregnancy high risk?		
Yes	379	33.0 %
No	704	61.4 %
I don't know.	64	5.6 %
Expecting twins	11	1 %
Anxiety level		
I felt less anxious	897	78.2 %
I felt more anxious	71	6.2 %
No difference	179	15.6 %
Bonding with baby		
Yes	829	72.3 %
No	102	8.9 %
I don't know	216	18.8~%
Birth outcome		
My baby was born healthy, within two weeks of due	842	73.4 %
date		
My baby was born premature but is now home	71	6.2 %
My baby was born premature and is still in the NICU	28	2.4 %
My baby died shortly after birth	0	0 %
My baby was born still	5	0.4 %
I prefer not to answer	201	17.5 %

with 1 indicating "I felt less anxious" and 0 indicating "I felt more anxious" or "No difference."

The question on bonding asks, "Did the Count the Kicks app help you bond with your baby?" The three response options include "Yes," "No," and "I don't know." We used the original variable of three options for ANOVA. We transformed this variable to a dichotomous variable for logistic regression with 1 indicating "help you bond with your baby" and 0 indicating "not help you bond with your baby" or "I don't know."

The question on birth outcome asks, "Please tell us your birth story." The six response options include "My baby was born healthy, within two weeks of due date," "My baby was born premature but is now home," "My baby was born premature and is still in the NICU," "My baby died shortly after birth," "My baby was born still," and "I prefer not to answer."

Analytic strategies

Descriptive analyses

Descriptive analyses including frequency, percentage, mean, and standard deviation were used to examine the number of kick counts using CTK and pregnant women's experiences with the app, their pregnancy, and childbirth.

Bivariate analyses

Bivariate analyses including ANOVA and chi-square were used. Specifically, ANOVA was used to examine the association between the frequency of kick counts and pregnant women's experience with their pregnancy: anxiety level related to their pregnancy, and bonding with their baby (research questions 1 and 2). Chi-square was used to examine the association between pregnant women's experience with their pregnancy and their birth outcome (research questions 3 and 4).

Logistic regression

Logistic regression was used to model women's experiences with their pregnancy, including anxiety level related to their pregnancy, and bonding with their baby (research questions 1 and 2). The rational to conduct logistic regression in addition to ANOVA is to control for the confounding variables including demographic variables, high risk pregnancy status, and multiple pregnancy status.

Results

Frequency of CTK use

We used data from all the 18,707 pregnancies to examine the frequency of fetal movement counting. The descriptive analyses (Table 2) showed that only small percentages of women used CTK for at least 21 days each month. Specifically, in the first month of their third trimester, 31.3 % of pregnant people used CTK for 0 days, 35.1 % used for 1–6 days, 16.4 % used for 7–13 days, 11.2 % used for 14–20 days, 6.1 % used for 21 days or more. In the second month of their third trimester, 50.5 % of pregnant people used CTK for 0 day, 23.8 % used for 1–6 days, 10.1 % used for 7–13 days, 6.2 % used for 14–20 days, 9.4 % used for 21 days or more. In the third month of their third trimester, 69.4 % of pregnant people used CTK for 0 day, 17.3 % used for 1–6 days, 5.9 % used for 7–13 days, 3.7 % used for 14–20 days, 3.8 % used for 21 days or more.

We also compared the frequency of fetal movement counting between women who completed the end of pregnancy survey (N = 1147, Final Sample) and women who did not (N = 17,560). The results showed that women who completed the end pregnancy are more likely to be frequent CTK users in each of the three months. For example, in the first month of their third trimester, only 5.2 % of the survey non-completers used CTK for 21+ days, while 19.4 % of the survey completers used CTK for 21+ days. Therefore, individuals in the final sample are relatively active users of CTK.

Bivariate analyses on the relationship between fetal movement counting and pregnancy experiences

As shown in Table 3, the results from ANOVA tests showed that the frequency of kick count is associated with pregnant people's anxiety level related to their pregnancy. Women who reported less anxious about their pregnancy showed higher frequency of kick count. On average, women who felt less anxious about their pregnancy did kick counts 11 days in the first month of their third trimester, 15 days in their second month, 11 days in their third month; women who felt more anxious about their pregnancy did kick counts 10 days in the first month of their third trimester, 7 days in their third month; women who felt no difference did kick counts 8 days in the first month of their third trimester, 9 days in their second month, 6 days in their third month.

Similarly, the results from ANOVA tests showed that the frequency of kick counts is associated with pregnant people's bonding with their

Table 2

Descriptive Analysis of Kick Use.

	All Pregnancies (<i>N</i> = 18,707)		Survey Non-completers(<i>N</i> = 17,560)		Survey Completers ($N = 1147$)		Chi square (df)
	Frequency	Percent	Frequency	Percent	Frequency	Percent	
Days of CTK use in the first month of the third trimester							642.397 (4)***
0 day	5846	31.3	5522	31.4 %	324	28.2 %	
1–6 days	6559	35.1	6391	36.4 %	168	14.6 %	
7–13 days	3069	16.4	2892	16.5 %	177	15.4 %	
14–20 days	2099	11.2	1844	10.5 %	255	22.2 %	
21 days or more	1134	6.1	911	5.2 %	223	19.4 %	
Days of CTK use in the second month of the third trimester							1482.127 (4)***
0 day	9441	50.5	9184	52.3 %	257	22.4 %	
1–6 days	4443	23.8	4307	24.5 %	136	11.9 %	
7–13 days	1890	10.1	1744	9.9 %	146	12.7 %	
14–20 days	1167	6.2	996	5.7 %	171	14.9 %	
21 days or more	1766	9.4	1329	7.6 %	437	38.1 %	
Days of CTK use in the third month of the third trimester							1852.733 (4)***
0 day	12,981	69.4	12,707	72.4 %	274	23.9 %	
1–6 days	3230	17.3	2948	16.8 %	282	24.6 %	
7–13 days	1102	5.9	896	5.1 %	206	18.0 %	
14–20 days	686	3.7	521	3.0 %	165	14.4 %	
21 days or more	708	3.8	488	2.8 %	220	19.2 %	

* *p*<.05, ** *p*<.01, *** *p*<.001.

Table 3

ANOVA of Days of CTK Use in Each Month of the Third Trimester (N = 1147).

	Days of CTK use in the first month		Days of CTK use in the second month			Days of CTK use in the third month			
	Mean	S.D.	F (df1, df2)	Mean	S.D.	F (df1, df2)	Mean	S.D.	F (df1, df2)
Anxiety Level									
I felt less anxious	11	10	12.058 (2, 1144) ***	15	11	28.468 (2, 1144) ***	11	10	22.678 (2, 1144) ***
I felt more anxious	10	10		12	11		7	9	
No difference	8	9		9	11		6	9	
Bonding with baby									
Yes	12	10	18.489 (2, 1144) ***	15	11	19.774 (2, 1144) ***	11	10	9.500 (2, 1144) ***
No	9	9		12	10		8	9	
I don't know	8	8		10	11		8	10	

* *p*<.05, ** *p*<.01, *** *p*<.001.

baby. Women who counted kicks more often are more likely to report that the CTK app helped them bond with their baby. On average, women who felt bonded with their baby through the app did kick counts 12 days in the first month of their third trimester, 15 days in their second month, 11 days in their third month; women who did not feel bonded with their baby through the app did kick counts 9 days in the first month of their third trimester, 12 days in their second month, 9 days in their third month; women who reported not knowing the CTK effects on bonding did kick counts 8 days in the first month of their third trimester, 10 days in their second month, 8 days in their third month.

Multivariate analyses on the relationship between fetal movement counting and pregnancy experiences

As shown in Table 4, Logistic regression was conducted to model the odds of reporting being less anxious. The model includes the frequency of kick counts in each month, and covariates include ethnicity/race, high- risk pregnancy status and the number of expected children. The results showed that after controlling for covariates, the frequency of kick counts in the second and the third month is positively associated with the odds of reporting being less anxious. That is, women who counted kicks more often in the second and third months are more likely to report being less anxious about their pregnancy. Among the covariates, women who do not know about high-risk status of their pregnancy are less likely to report being less anxious about their pregnancy.

As shown in Table 5, logistic regression was also conducted to model the odds of reporting bonding with their baby. The model includes the frequency of kick counts in each month, and covariates include ethnicity/race, high risk pregnancy status and the number of expected children. The results showed that after controlling for covariates, the frequency of kick counts in the first month of the third trimester is positively associated with the odds of reporting bonding with their baby.

Table 4

Logistic Regression on the Odds of Reporting Being Less Anxious (N = 1147).

	В	S.E.	Exp (B)
Ethnicity/race (ref: Asian)			
Black/African American	-0.265	.371	.767
White/Caucasian	.014	.293	1.014
Hispanic/Latino	-0.279	.354	.757
Other	-0.489	.361	.614
Missing	.438	.522	1.550
Did your doctor consider your pregnancy high risk?			
(ref: No)			
Yes	.325	.172	1.384
I don't know.	-1.201***	.282	.301
Expecting twins (ref: expecting one)	-0.440	.713	.644
Days of CTK use in the first month	-0.002	.011	.998
Days of CTK use in the second month	.027*	.011	1.027
Days of CTK use in the third month	.031**	.010	1.031
Constant	1.198	.767	3.315

* *p*<.05, ** *p*<.01, *** *p*<.001.

Table 5

Logistic Regression on the Odds of Reporting Bonding with their Baby (N = 1147).

	В	S.E.	Exp (B)
Ethnicity/race (ref: Asian)			
Black/African American	.160	.342	1.174
White/Caucasian	-0.058	.256	.944
Hispanic/Latino	.518	.338	1.678
Other	.014	.335	1.014
Missing	.244	.434	1.276
Did your doctor consider your pregnancy high risk?			
(ref: No)			
Yes	.148	.154	1.160
I don't know.	-1.189***	.280	.304
Expecting twins (ref: expecting one)	.022	.700	1.022
Days of CTK use in the first month	.027**	.010	1.028
Days of CTK use in the second month	.014	.010	1.014
Days of CTK use in the third month	.011	.009	1.011
Constant	.385	.743	1.470

* *p*<.05, ** *p*<.01, *** *p*<.001.

That is, women who counted kicks more often in the first month are more likely to report bonding with their baby. Among the covariates, women who do not know about high-risk status of their pregnancy are less likely to report bonding with their baby.

Bivariate analyses on the relationship between pregnancy experiences and birth outcome

As shown in Table 6, the results from chi-square tests showed that women's anxiety level related to their pregnancy is associated with birth outcome. Women who reported feeling less anxious about their pregnancy are more likely to report a healthy birth. Seventy seven percent of women who reported feeling less anxious about their pregnancy reported healthy birth. In comparison, 66 % of women who reported feeling more anxious and 58 % of women who reported no difference reported a healthy birth.

The results from chi-square tests also showed that women's bonding with their baby is associated with their birth outcome. Women who felt bonded with their baby by using the app are more likely to report healthy birth. Seventy six percent of women who reported bonding with their baby reported healthy birth. In comparison, 69 % of women who did not feel bonded with their baby through the app and 64 % of women who reported not knowing the CTK effects on bonding reported healthy birth.

Discussion

Low compliance with daily fetal movement counting

This study showed low compliance with daily fetal movement counting among the CTK users. Most users did not count their fetal

Table 6

Chi-square Tests of the Associations between Pregnancy Experiences and Birth Outcome (N = 1147).

	Birth outcome					
	I prefer not to answer	My baby was born healthy, within two weeks of due date	My baby was born premature and is still in the NICU	My baby was born premature, but is now home	My baby was born still	
Anxiety Level						
I felt less anxious	126 (14 %)	692 (77 %)	21 (2 %)	56 (6 %)	2 (0.2 %)	60.493 (8)***
I felt more anxious	13 (18 %)	47 (66 %)	5 (7 %)	6 (9 %)	0 (0 %)	
No difference	62 (35 %)	103 (58 %)	2 (1 %)	9 (5 %)	3 (2 %)	
Total <i>Bonding</i>	201 (18 %)	842 (73 %)	28 (2 %)	71 (6 %)	5 (0.4 %)	
Yes	125 (15 %)	633 (76 %)	23 (3 %)	46 (6 %)	2 (0.2 %)	25.286 (8)***
No	18 (18 %)	70 (69 %)	3 (3 %)	10 (10 %)	1 (1 %)	
I don't know	58 (27 %)	139 (64 %)	2 (1 %)	15 (7 %)	2 (1 %)	

movement daily. Most users counted their fetal movement less than 21 days in each of the three months during their third trimester. The frequency of CTK use is especially low in the first and third months of their third trimester, when more than half of the users did the counting less than 13 days each month.

This result is consistent with previous studies that reported inadequate compliance with daily fetal movement counting among pregnant people (Clark and Britton, 1985; Grant et al., 1989; Moore and Piacquadio, 1989; Saastad et al., 2011; Winje et al., 2016). Previous studies measured compliance with daily use of paper-based counting charts, while this study measured compliance with daily use of app-based fetal movement counting.

It is unexpected to find such low compliance among the CTK users, since CTK uses the count-to-ten method. Previous studies reported that compliance with the count-to-ten method (once a day) is higher than other fetal movement counting methods (more than once a day) (Mangesi et al., 2015; Winje et al., 2016). Moreover, CTK is a free and easy app to record the time it takes for users to feel 10 movements. Given the large number of smartphone owners in the US (O'Dea, 2022), building a fetal movement counter on an app is a way to facilitate fetal movement counting among pregnant people. However, its impact on increasing compliance of daily fetal movement counting seems limited.

The association between fetal movement counting and pregnancy experiences

This study showed that the frequency of kick counts is associated with better experiences among pregnant people: lower anxiety level related to their pregnancy, and more bonding with their baby. Our finding on lower anxiety level is consistent with literature. Some studies reported that fetal movement counting did not cause concerns for delivery among pregnant people (Gibby, 1988; Liston et al., 1994). Some studies reported that pregnant people found fetal movement counting acceptable and reassuring (Eggertsen and Benedetti, 1987; Smith et al., 1992). Moreover, in their randomized controlled trial, Saastad et al. (Saastad et al., 2012) found that women who performed fetal movement counting in the third trimester reported less concern than those in the control group who receiving standard antenatal care. Our finding did not support the criticism that fetal movement counting may induce increased maternal concern. The reason why the frequency of kicks count is associated with lower anxiety level might be because pregnant women gained more confidence in their own assessment about the fetal activity pattern (Saastad et al., 2012).

Our finding on the bonding is also consistent with a group of literature that found fetal movement counting is associated with higher maternal attachment to fetus (Güney and Uçar, 2019; Mikhail et al., 1991; Salehi et al., 2017). Although a recent meta-analysis of two RCTs showed that fetal movement counting is not effective in increasing maternal attachment to fetus by itself, the authors acknowledged that fetal movement counting alongside other attachment behaviors such as touching the belly and talking to fetus can enhance maternal attachment to fetus (Abasi et al., 2021). Increasing maternal attachment to the fetus is important, since it can have a long-lasting effect for increasing postnatal bonding (Cuijlits et al., 2019) and more optimal early childhood development (Alhusen et al., 2013; Branjerdporn et al., 2017).

The association between pregnancy experiences and birth outcomes

This study showed that lower anxiety about their pregnancy and stronger bonding with their fetus are associated with greater odds of healthy birth. Our finding on lower anxiety level is consistent with the literature. A systematic review reported strong evidence that antenatal distress during pregnancy, including pregnancy-specific distress, increases the likelihood of preterm birth (Staneva et al., 2015). One study (Catov et al., 2010) reported a significant association between anxiety and preterm birth among African American women. Given the higher rates of preterm births among African Americans as compared with other races (Staneva et al., 2015), it is especially important to help them manage anxiety during pregnancy, which can be preventative of preterm births.

Our study contributed to a knowledge gap on the relationship between maternal-fetal attachment (MFA)/bonding and birth outcome. No previous studies examined this relationship. Previous studies on MFA focused on its positive impacts on early childhood development (Alhusen et al., 2013; Branjerdporn et al., 2017). Our finding on its positive impacts on healthy birth is expected. Since mothers with strong MFA experience lower level of prenatal anxiety, which is a protective factor of preterm birth (Göbel et al., 2018; Staneva et al., 2015), mothers with strong MFA are less likely to experience preterm birth.

Limitations

It is important to acknowledge this study has two limitations. First, the study sample is comprised of 1147 CTK users who completed the end of pregnancy survey, making up only 6 % of CTK users who used CTK during the study frame in the two study states (i.e. Iowa and Florida in US). We limited our sample to the survey completers, since we needed to extract outcome variables (i.e. experiences with their pregnancy and birth) from the survey. However, limiting to the survey completers limits the generalizability of our study. It is possible that the survey completers are more smartphone savvy and more receptive of using technology to improve their quality of life. Second, the data on outcome variables were from participants' self-report. Participants self-reported their experiences with their pregnancy (i.e. anxiety level related to their pregnancy, bonding with their baby) and birth outcome in the end of pregnancy survey. Although research has shown validity of using self-report data

from pregnant women (Matthey et al., 2013), self-reports can be influenced by social desirability (Van de Mortel, 2008). For example, participants influenced by social desirability might be more likely to report more bonding with their baby.

Conclusion

App-based fetal movement counting has become more widely available in recent years. Pregnant people can easily use apps like CTK to implement the count-to-ten method for fetal movement counting. However, even with apps, there is still inadequate compliance with daily fetal movement counting among pregnant people. Frequent use of fetal movement counting is associated with lower anxiety level related to their pregnancy, and more bonding with their baby. These positive pregnancy experiences are associated with healthy birth. App developers and public health agencies need to develop strategies to increase daily use of fetal movement counting, which can generate impacts on positive pregnancy and birth experiences.

CRediT authorship contribution statement

Hui Huang: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. **Olivia Ceavers:** Writing – original draft, Writing – review & editing. **María C Pinzón-Iregui:** Data curation, Project administration, Writing – original draft, Writing – review & editing. **Melissa M. Howard:** Conceptualization, Data curation, Funding acquisition, Project administration, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We acknowledge that the authors' time/efforts to work on this manuscript was supported in part by the Maternal and Child Health Public Health Catalyst Program funded by Maternal and Child Health Bureau (MCH) Catalyst mechanism of Health Resources and Services Administration (HRSA) in the United States of America (Award No: 1 T1CMC353550100) and in part by the National Institute On Minority Health and Health Disparities of the National Institutes of Health Under Award Number NIMHD (U54MD012393), Florida International University Research Center in Minority Institutions.. The content is solely the responsibility of the authors and does not necessarily represent the official views of the Health Resources and Services Administration (HRSA) and the National Institutes of Health in the United States of America.

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