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A digital epidemiological and citizen science methodology to capture prospective physical activity within social and physical contexts: A SMART platform study

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Title: A digital epidemiological and citizen science methodology to capture prospective physical activity within social and physical contexts: A SMART platform study

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ABSTRACT

Objectives The purpose of this study was to develop a novel and replicable methodology of mobile ecological momentary assessments (EMAs) to capture prospective physical activity (PA) within free-living social and physical contexts by leveraging citizen-owned smartphones running on both Android and iOS systems.

Design Data were obtained from the cross-sectional pilots of the SMART Platform, an innovative citizen science and mobile health initiative for active living surveillance.

Setting The study was conducted in the cities of Regina and Saskatoon, Canada.

Participants 538 citizen scientists (≥18 years) provided PA data during 8 consecutive days using a custom-built smartphone app. Citizen scientists who completed daily time-triggered EMAs (capturing prospective PA) and International Physical Activity Questionnaire (IPAQ) were included in the final analyses.

Outcome measures EMAs enabled reporting of light, moderate, and vigorous PA, as well as physical and social contexts of PA via complex looped linking of intensity and context questions. Retrospective PA was reported using IPAQ. For both measures, PA intensities were categorized into mean light and moderate-to-vigorous PA/day. Wilcoxon signed ranks tests and Spearman correlation procedures were conducted to compare PA intensities reported via EMAs and IPAQ.

Results The findings showed discrepancies between EMA and IPAQ measures of PA. Daily time-triggered EMAs were able to capture not only prospective light and moderate-to-vigorous PA, but also enabled PA reporting across varied physical and social contexts. Among physical contexts, citizen scientists reported accumulating PA predominantly at home. Among social contexts, citizen scientists reported accumulating PA predominantly by themselves.

Conclusions These findings suggest that time-triggered mobile EMAs are an effective method to record comprehensive prospective PA accumulated across multiple physical and social contexts. With over 3 billion smartphones users globally, these ubiquitous tools can be leveraged via citizen science to understand active living patterns of large populations in free-living conditions using EMAs.

Keywords: Physical activity, mHealth, Ecological Momentary Assessments, Measurement, Citizen Science, Digital Epidemiology

Strengths

- This study addresses current discrepancies in mobile ecological momentary assessment (EMA) methodologies (e.g., triggering processes, time to follow-up), as well as limitations in terms of usage of identical mobile devices need to be addressed to deploy EMA among large populations.
- This study shows that time-triggered mobile EMAs are an effective method to record comprehensive daily prospective physical activity.
- This study shows that EMAs can be used to capture both physical and social context of physical activity prospectively.

Limitations

- The main limitation is the small sample size after applying the inclusion criteria

INTRODUCTION

Advances in mobile technology over the past decade have facilitated the innovation of ecological momentary assessments (EMAs), which are digital epidemiological tools that aid in understanding environmental, social, and behavioural processes.[1,2] EMAs can capture real-time data that reflect the dynamics of participants' experiences in their natural environment and thus they are increasingly being used to monitor health behaviors among populations across the life course.[3-5] In active living research, evidence indicates that EMAs are a valid, reliable, and feasible method of data collection.[6,7]

EMAs are an advancement over traditional self-report methods as they enable data collection more proximal to the time and place that a behavior has occurred.[2,8] Moreover, EMAs overcome many of the limitations of traditional self-report surveys to provide information regarding specific activity types (e.g. watching TV vs video gaming) and capture important factors that influence health behaviors such as mood and environmental perceptions.[5,9,10] In measuring physical activity (PA) intensities, EMAs have been shown to minimize recall[6,11] and social desirability bias[12] of traditional self-report measures.

Several studies have examined the validity of smartphone-based EMAs compared to other objective devices (accelerometers, pedometers) and self-report measures of PA.[2,10-16] Overall, estimates from EMAs were found to be highly correlated with accelerometer estimates.[13,14] However, this evidence also indicates that PA was over-reported when International Physical Activity Questionnaire (IPAQ) was used[2] and that daily PA EMA reports were not significantly associated with their traditional recall measures.[12]

Currently there is little evidence of existing EMA methods that capture PA intensities across various physical (leisure-time PA, transit-related PA, occupation-related PA, and household/domestic-related PA)[18] and social contexts (with family, friends etc.).[15] Moreover, there are discrepancies in smartphone-based EMA methodologies, which range from inconsistent EMA triggering processes and varying times of prospective follow-up, to limitations of using identical mobile devices and operating systems.[19]

The objective of this study is to address current deficiencies in PA EMA approaches by developing a novel and replicable citizen science methodology of standardized time-triggered smartphone-based EMAs to capture prospective PA within free-living social and physical contexts by leveraging citizen-owned smartphones running on both Android and iOS systems. This study will also compare EMA measures with traditional self-report measures of PA within the same cohort.

METHODS

Design

This study is part of the SMART Platform, which is a mobile health (mHealth) and citizen science initiative for active living surveillance, integrated knowledge translation, and policy and real-time interventions.[8,16,17] Citizen science is a participatory approach where participants, termed citizen scientists, actively engage in the research process from data collection to knowledge translation, thus improving the probability of longitudinal participant compliance.[18] A detailed description of SMART Platform's methods, including recruitment and data collection strategies, are described in the Platform's methodology publication.[19]

The data for this study have been obtained from the 2017 (April 1 to May 31) and 2018 (January 4 to March 31) cohorts of the SMART Platform, [8] which is a prospective investigation designed to capture active living data from adults residing in the two largest urban centers in Saskatchewan, Canada (Regina and Saskatoon). All subjective (via traditional validated surveys and EMAs) and objective data (via smartphones sensors) related to PA, sedentary behaviour, and perception of environment, individual motivation, health outcomes, and eudaimonic well-being were obtained through citizen-owned smartphones on 8 consecutive days **(Figure 1).**

Patient and public involvement

Participants in the SMART Platform are "citizen scientists" as they can engage with the researchers at all stages of the research process. Thus, citizen scientists informed the design, research questions and outcome measures. As part of the social media campaign for recruitment, citizen scientists were encouraged to inform their friends about the study. Finally, as integrated knowledge translation is part of the SMART Platform, results are disseminated throughout the study period using the community voices webpage of the Platform's website: https://www.smartstudysask.com/community-voices

Recruitment and participants

Citizen scientists for SMART Adult cohorts were recruited online through social media, and in-person from the universities of Regina and Saskatchewan and community centres located in different neighbourhoods in each city to capture a socioeconomically representative sample. Citizen scientists were guided to download Ethica (Ethica Data Services Inc.), an epidemiological smartphone application (app), specifically adapted for the SMART Platform, which captures data through both Android and iOS platforms. All citizen scientists provided informed consent through the app and confirmed their age (≥18 years) before joining the study. Ethics approval was obtained from the universities of Regina and Saskatchewan through a synchronized review protocol (REB # 2017-29).

Measures

The two primary measures used in this study are the International Physical Activity Questionnaire (IPAQ),[20] which collects retrospective PA in 4 physical domains (recreation, active transportation, work, and home), and the SMART Platform's modified EMA, which captures prospective daily PA in both social and physical contexts.

IPAQ

IPAQ was deployed at baseline as soon as citizen scientists downloaded the app to self-report physical activities over the past 7 days that were of at least 10 consecutive minutes in duration. These activities were categorized by 4 domains: 1) Recreation (e.g., weight training, sports (soccer, hockey, etc.), aerobics, running, jogging, swimming, cycling, etc.); 2) Household (e.g., carrying light loads, sweeping, washing windows, and raking, etc.); 3) Transportation (e.g., travelling in a train, bus, car, or other kind of motor vehicle, etc.); and 4) Work (e.g. heavy lifting, digging, heavy construction or climbing upstairs, etc.). The records included the number of times per week (within the last 7 days) and average minutes per day for each activity.

Adapted Daily EMAs

162 Using the SMART platform, time-triggered modified EMAs (Figure 1) were developed, tested, and piloted, before being pushed to citizen scientists' smartphones between 8pm and 8:30pm on each day for 8 consecutive days. These EMAs were designed to expire at 3am the next day. Citizen scientists were asked to report only those physical activities that were of at least 10 minutes in duration at a time. More importantly, each EMA was designed to not only measure intensity and volume (in minutes) of PA, but also to capture social (i.e., with whom they accumulated PA [Figure 1C]) and physical contexts (i.e., where they accumulated PA [Figure 1D]). This design was achieved by creating a looped linkage, where upon entering the volume of each activity, the EMA triggered the social and physical context questions.

171 **Derived variables – Intensities and Volume of PA**

172 ***IPAQ***

173 Thirty-seven questions related to PA were asked and 3 different categories of intensities were created (light, moderate, and vigorous PA) by combining PA across 4 domains: recreation, household, workplace, and active transportation. Moderate and vigorous PA intensities are combined to derive "moderate-to-vigorous PA." After conducting several aggregation techniques, 2 final intensity variables were derived for IPAQ retrospective PA: mean minutes per day of light and moderate-to-vigorous PA.

179

180

181 ***Adapted Daily EMAs***

A similar approach was employed to derive two final intensity variables for EMA prospective PA: mean minutes per day of light and moderate-to-vigorous PA. For example, the light PA included walking, light hiking, any light physical activity/sport (e.g. golf bowling etc.), yoga, and light intensity household chores (e.g. washing dishes sweeping laundry gardening). Moderate-to-vigorous PA included moderate to vigorous hiking, running, biking, any team sport (football hockey soccer etc.), any other sport or activity (swimming canoeing skiing etc.), weight training, dance/aerobic/cardio exercise, and moderate-to-vigorous intensity household chores (e.g. shovelling driveways, washing a car etc.).

Physical Context

PA information from the IPAQ and EMAs (based on the question "Where did you do this activity?") were grouped into domains. Domain 1: PA at workplace (IPAQ) and from work (EMAs). Domain 2: Transportation PA (IPAQ) and from street (EMAs). Domain 3: Housework, house maintenance, and caring from family (IPAQ) and from home (EMAs). Domain 4: Recreation, sport, and leisure-time PA (IPAQ) and from park, gym, and sport facility (EMAs).

Social Context

Social context information was collected via EMA question, “With whom did you do this activity?” for each physical activity that the participants reported. Categories for social context included “by myself, with my dog, with my friend(s), with my parent(s),” among others.

Statistical analyses

The inclusion criterion to determine the final sample was dependent on citizen scientists completing the IPAQ, and answering the daily EMA on at least 3 days. Continuous estimates were reported as means with standard deviations (SD) and medians with 25th and 75th percentiles, depending on normality. Where estimates were non-normal and positively skewed, median and interquartile ranges were used. Wilcoxon signed ranks tests and Spearman correlation procedures were conducted to compare PA intensities and domain-based PA reported via IPAQ and EMAs. Correlation coefficient values of <0.20, 0.21-0.40, 0.41-0.60, 0.61-0.80 and 0.81-1.0 were considered as weak, fair, moderate, strong and very strong correlation, respectively.[21]. Analyses were conducted in SPSS version 24.0 (SPSS Inc., Chicago IL, USA) with significance set at alpha < 0.05.

RESULTS

After applying the decision rule of including only those citizen scientists who completed IPAQ, and answered the daily EMA on at least 3 days, out of 538 participants, only 89 were included in this study, among whom 47 identified as female (52.80%). The final sample had the mean age of 36.7 years (SD=15.74), and a mean body mass index of 28.34 (SD=7.82). The median (25th, 75th percentiles) and the mean (SD) duration of time (minutes per day) spent in each of the activity intensities (light, moderate and vigorous), as well as overall PA were derived from both IPAQ and EMA measures.

Using EMAs, citizen scientists reported 140.91, 87.16, and 70.38 mean minutes/day of overall PA, light PA, and moderate-to-vigorous PA. The same citizen scientists reported 194.39, 116.99, and 98.42 mean minutes/day of overall PA, light PA, and moderate-to-vigorous PA using the IPAQ (**Tables 1 and 2**). These findings show that although there are no significant differences between activity intensities reported via EMAs and IPAQ, citizen scientists consistently overestimated their PA using IPAQ. **Table 3** demonstrates the correlation between EMA and IPAQ measures to show that overall PA (ρ=0.414, p<0.001), and light (ρ =0.261, p=0.012) and moderate-to-vigorous PA (ρ =0.316, p=0.009) were fairly correlated. **Figure 2** shows the visual representation of these correlations.

Figure 3 and 4 demonstrate the distribution of overall PA accumulated across different physical and social contexts, as reported by citizen scientists using EMAs. Among physical contexts, citizen scientists reported accumulating overall PA predominantly at home (26.4%), on the streets ([20.4%] i.e., active transportation), at the gym (13.7%), at work (13.1%), and in parks (12.3%). When it comes to social context, citizen scientists overwhelmingly reported accumulating overall PA by themselves (64.2%), with some reporting being active with friends (14.7%) and relatives (6.3%).

As IPAQ captures PA in 4 physical domains (workplace, active transportation, household, and recreation, sport and leisure-time) to compare estimates between EMA and IPAQ, EMA estimates of overall PA accumulated across various physical contexts were categorized to match the physical domains of IPAQ. Using EMAs, citizen scientists reported 20.50, 16.41, 25.33, and 20.88 mean minutes/day of overall PA across workplace, active transportation, household, and recreation, sport and leisure-time domains, respectively. Using IPAQ, the same citizen scientists reported 32.14, 43.97, 38.27, and 145.90 mean minutes/day of overall PA across workplace, active transportation, household, and recreation, sport and leisure-time domains, respectively.

These findings show that there is a consistent pattern of over-reporting of overall PA across all physical domains when citizen scientists used IPAQ, with statistically significant differences observed in active transportation (p=0.002) and recreation, sport and leisure-time domains (p=0.003) (**Table 4**). Corroborating these findings, **Table 5** demonstrates correlation between EMA and IPAQ physical domain measures, with moderate correlation being depicted with overall PA accumulated in household domain light (ρ =0.607, p=0.036).

DISCUSSION

The objective of this study was to address current deficiencies in PA EMA approaches by developing a novel and replicable methodology of standardized time-triggered smartphone-based EMAs to capture prospective PA within free-living social and physical contexts by leveraging citizen-owned smartphones running on both Android and iOS systems.

We were able to not only develop a novel EMA that can be time-triggered by both iOS and Android devices to capture prospective PA across physical and social contexts to address current gaps in EMA methodologies[22,23], but also compared this EMA measure with IPAQ to highlight potential discrepancies between prospective and retrospective measures in capturing active living in free-living conditions.

Although not statistically significant, irrespective of the intensity of PA (overall PA, light, and moderate-to-vigorous PA), citizen scientists consistently over-reported activity using IPAQ. However, when PA intensities were compared across the 4 physical domains (workplace; active transportation; household; and recreation, sport, and leisure), PA reported via IPAQ in active transportation; and recreation, sport, and leisure domains was significantly greater than PA reported via EMAs.

These findings corroborated a longitudinal validation study by Swendeman et al., (2018), who concluded that the inter-method reliability between smartphone-based EMAs and their corresponding recall reports was low and no significant associations were observed.[24] Another validation study that compared PA EMAs with IPAQ and accelerometer measures concluded that EMA measures correlated better with accelerometers.[4] Several studies have been conducted to compare self-report estimates of PA with objective measures (an accelerometer),[4,25,26] with evidence suggesting that an ideal approach potentially lies between self-reports and accelerometry,[24] especially because accelerometry is unable to capture context.

This is indicative of EMAs being the potential solution for comprehensively capturing PA by minimizing recall bias. However, a key gap in current methodologies is that EMAs are used in more controlled experiments, where identical mobile devices running on same operating systems are being provided to participants (Refs). Moreover, EMA methodologies lack standardization and sufficient rigour. Another important gap is the inability of existing EMAs to capture critical physical and social contexts within which PA is accumulated.

In our study we addressed these gaps by adopting a citizen science approach[27], where participants used their own smartphones, which operated on either iOS and Android systems, thus expanding the scope of leveraging these ubiquitous tools[28] to conduct ethical surveillance[8,29] of PA among large populations. Citizen science approaches are increasingly being considered in active living research[30], and it is important that methodological advancements are in step with conceptual and technological innovations. Another key advancement of this study is including only those participants who completed EMAs on at least 3 days, an inclusion criterion which provides the necessary rigour to arrive at valid data.

However, perhaps the most important addition to the methodology was introducing a looped linking EMA that not only captured the intensity and volume of PA, but also the physical and social contexts of PA (**Figures 3 and 4**). The findings showed that citizen scientists reported accumulating most PA while at home, through active transportation, at the gym, at their work places, and in parks.[15,31] The distribution of accumulation of overall PA across these physical contexts provides important evidence to develop interventions modifying physical spaces to address physical inactivity.[32-35] Perhaps even more interesting were the results of social context, where the findings showed that most citizen scientists accumulated PA by themselves[31], which points towards informing individual-level interventions that facilitate intrinsic motivation.[36-38]

Current evidence clearly indicates that there is no gold standard in assessing prospective PA using mobile EMAs, and this study advances a methodology that introduces conceptual and technological advancement (citizen science approach utilizing citizen-owned devices functioning on both iOS and Android systems), scientific rigour (stringent inclusion criteria for valid data), and comprehensiveness of data collection (volume, intensity, and context). In working towards a standardized EMA methodology future studies need to address the balance between burden and compliance. Moreover, future studies could combine EMAs with objective measurement to measure PA,[39,40] to concretely capture PA prospectively. Nevertheless, EMAs have the potential to reliably record active living and could substitute accelerometers when needed.[2]

Strengths and Limitations

The primary strength of the study is the development of novel and replicable methodology to capture prospective PA comprehensively from large populations using citizen-owned devices.

The main limitation is the small sample size after applying the inclusion criteria, however, smaller sample sizes are not uncommon in smartphone-based EMA studies.[41] Nevertheless, to capitalize on the citizen science approach, it is important consider innovative solutions such as crowdsourcing[42,43] to engage large populations for the ethical active living surveillance.[8]

CONCLUSION

With growth of smartphones projected to only magnify in the future[16], these ubiquitous tools can be leveraged via citizen science to capture accurate active living patterns of large populations in free-living conditions through innovative EMAs. This citizen science methodology adapted mobile EMAs to minimize recall bias and capture not only prospective PA, but also important physical and social contexts within which individuals accumulate PA.

LIST OF ABBREVIATIONS

EMAs: Ecological momentary assessments

PA: Physical activity

IPAQ: International physical activity questionnaire

DECLARATIONS

Ethics approval and consent to participate: All citizen scientists provided informed consent through the app and confirmed their age (≥18 years) before being recruited. Ethics approval was obtained from the universities of Regina and Saskatchewan through a synchronized review protocol (REB # 2017-29).

Consent for publication: Not applicable

Availability of data and materials: The corresponding author will make the data available upon reasonable request.

Competing interests: Authors declare no conflict of interest.

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454 **Table 1. Overall physical activity measurement: IPAQ vs. EMA**

	Mean (minutes/day)	Standard Deviation	Percentiles (minutes/day)			p-value*
			25th	50th	75th	
IPAQ	194.39	266.10	63.80	122.14	175.72	0.331

EMA	140.91	98.31	73.07	123.75	183.48	

Note: Based on Wilcoxon Signed Ranks Test; IPAQ: international physical activity questionnaire; EMA: ecological momentary assessment

Table 2. Light and moderate-to-vigorous physical activity measurement: IPAQ vs. EMA

Intensity		Mean (minutes/day)	Standard Deviation	Percentiles (minutes/day) 25th	50th	75th	p-value*
Light	IPAQ	116.99	171.24	36.00	67.86	110.00	0.322
	EMA	87.16	64.44	41.25	68.33	103.67	
Moderate to vigorous	IPAQ	98.42	175.18	17.14	49.44	92.86	0.995
	EMA	70.38	63.48	40.00	52.50	87.50	

Note: Based on Wilcoxon Signed Ranks Test; IPAQ: international physical activity questionnaire; EMA: ecological momentary assessment

Table 3. Overall physical activity measurement across physical domains: IPAQ vs. EMA

Domain		Mean (minutes/day)	SD	Percentiles (minutes/day) 25th	50th	75th	p-value *
Workplace	Survey	32.14	34.97	7.86	12.86	66.07	0.345
	EMA	20.50	17.87	5.63	15.00	38.13	
Active Transportation PA	Survey	43.97	24.32	25.36	40.00	66.43	0.002
	EMA	16.41	11.51	7.56	10.00	25.69	
Household	Survey	38.27	35.01	9.04	28.50	74.46	0.117
	EMA	25.33	46.29	5.16	10.31	19.84	
Recreation Sport and Leisure-time PA	Survey	145.90	306.95	15.00	34.29	72.86	0.003
	EMA	20.88	16.19	7.50	17.50	37.50	

466 Note: Based on related-samples Wilcoxon Signed Rank Tests; IPAQ: international physical activity questionnaire; EMA: ecological momentary assessment

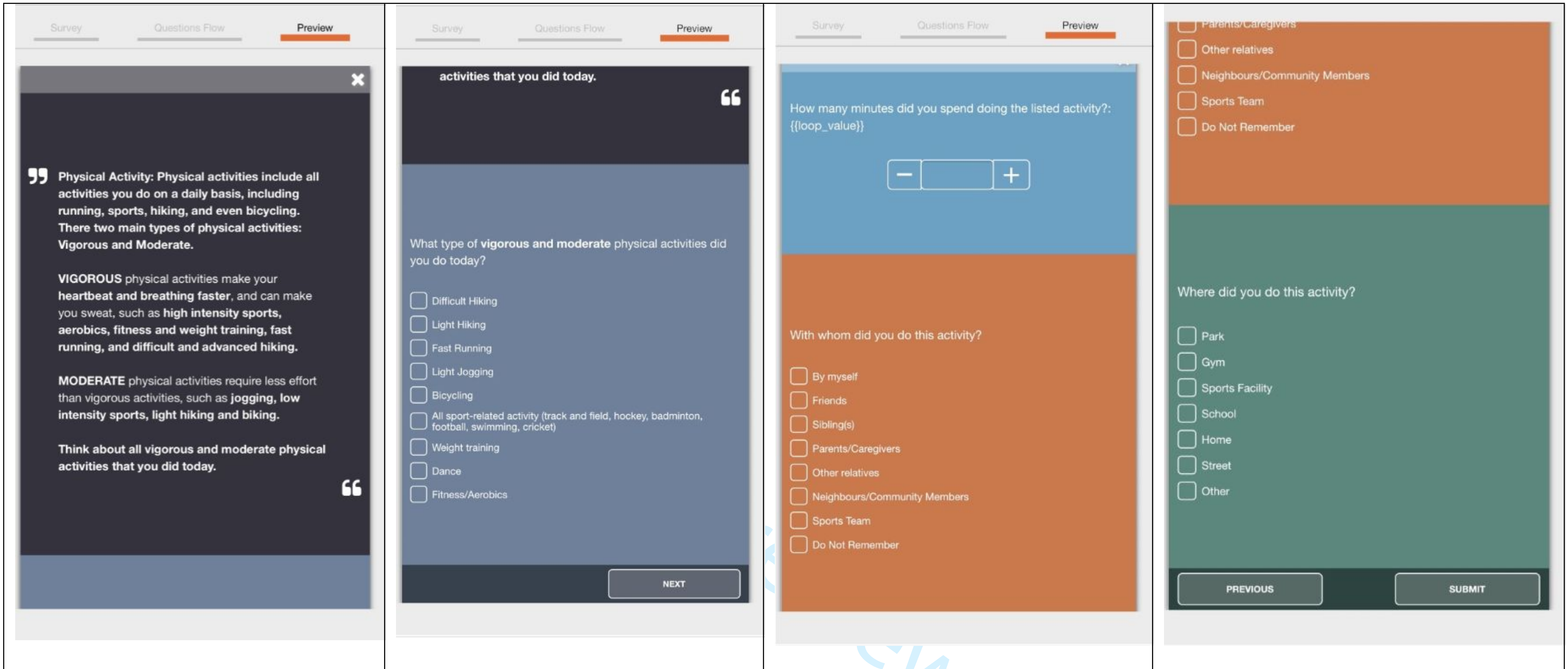
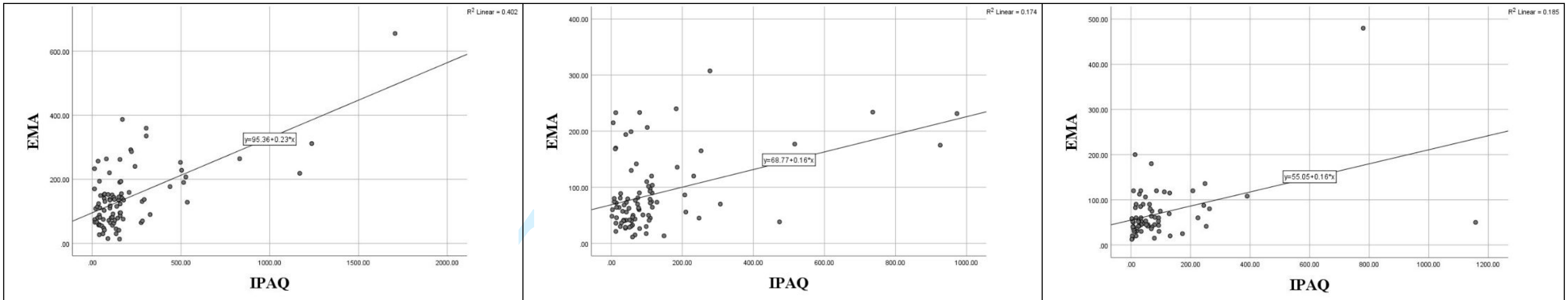


Figure 1A. Instructions of Physical activity intensity	Figure 1B. Questions of Physical activity intensity	Figure 1C. Social context question	Figure 1D. Physical context question

Figure 1. Time-triggered ecological momentary assessment capturing prospective physical activity



Overall Physical Activity	**Light physical activity**	**Moderate to vigorous physical activity**

Figure 2. Correlation between IPAQ and EMA measurements of physical activity

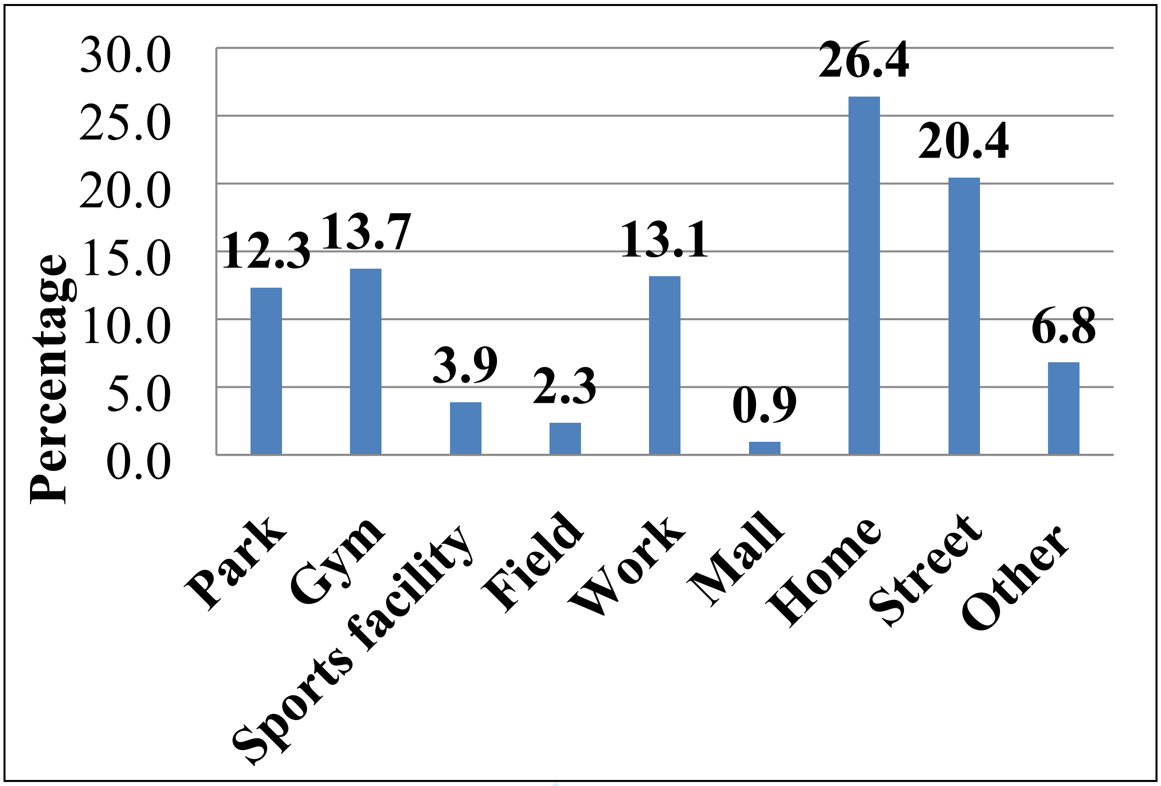


Figure 3. Distribution of Daily EMA Physical activity within physical contexts

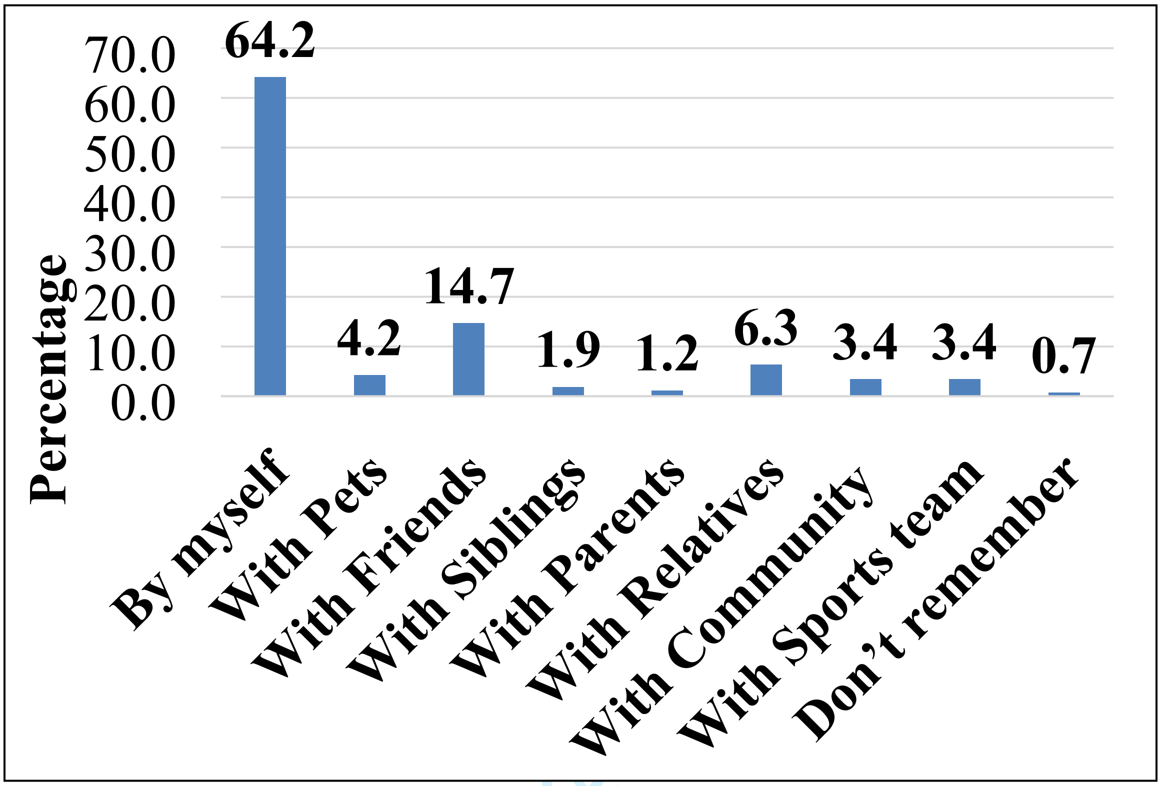


Figure 4. Distribution of Daily EMA Physical activity within social contexts

STROBE Statement

Checklist of items that should be included in reports of observational studies

Section/Topic	Item No	Recommendation	Reported on Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	6
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6,7,8,9
Data sources/measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6,7
Bias	9	Describe any efforts to address potential sources of bias	9
Study size	10	Explain how the study size was arrived at	9
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6,7,8,9
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	9
		(*b*) Describe any methods used to examine subgroups and interactions	
		(*c*) Explain how missing data were addressed	9
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	9
		(*e*) Describe any sensitivity analyses	

Section/Topic	Item No	Recommendation	Reported on Page No
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	10
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	10
		(b) Indicate number of participants with missing data for each variable of interest	
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	10, 11
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	10,11
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	
Discussion			
Key results	18	Summarise key results with reference to study objectives	12
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	14
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	12.13
Generalisability	21	Discuss the generalisability (external validity) of the study results	14
Other Information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	17

**Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.*

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

A digital epidemiological and citizen science methodology to capture prospective physical activity in free-living conditions: A SMART platform study

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Title: A digital epidemiological and citizen science methodology to capture prospective physical activity in free-living conditions: A SMART platform study

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ABSTRACT

Objectives The purpose of this study was to develop a replicable methodology of mobile ecological momentary assessments (EMAs) to capture prospective physical activity (PA) within free-living social and physical contexts by leveraging citizen-owned smartphones running on both Android and iOS systems.

Design Data were obtained from the cross-sectional pilots of the SMART Platform, a citizen science and mobile health initiative.

Setting The cities of Regina and Saskatoon, Canada.

Participants 538 citizen scientists (≥18 years) provided PA data during 8 consecutive days using a custom-built smartphone app, and after applying a rigid inclusion criteria, 89 were included in the final analysis.

Outcome measures EMAs enabled reporting of light, moderate, and vigorous PA, as well as physical and social contexts of PA. Retrospective PA was reported using International Physical Activity Questionnaire (IPAQ). For both measures, PA intensities were categorized into mean minutes of light and moderate-to-vigorous PA per day. Wilcoxon signed ranks tests and Spearman correlation procedures were conducted to compare PA intensities reported via EMAs and IPAQ.

Results Using EMAs, citizen scientists reported 140.91, 87.16, and 70.38 mean minutes/day of overall, light, and moderate-to-vigorous PA, respectively, whereas using IPAQ they reported 194.39, 116.99, and 98.42 mean minutes/day of overall, light, and moderate-to-vigorous PA, respectively. Overall (ρ=0.414, p<0.001), light (ρ =0.261, p=0.012) and moderate-to-vigorous PA (ρ =0.316, p=0.009) were fairly correlated between EMA and IPAQ. In comparison with

EMAs, using IPAQ citizen scientists reported significantly greater overall PA in active transportation (p=0.002) and recreation, sport and leisure-time domains (p=0.003).

Conclusions This digital epidemiological and citizen science methodology adapted mobile EMAs to capture not only prospective PA, but also important physical and social contexts within which individuals accumulate PA. Ubiquitous tools can be leveraged via citizen science to capture accurate active living patterns of large populations in free-living conditions through innovative EMAs.

Keywords: Physical activity, mHealth, Ecological Momentary Assessments, Measurement, Citizen Science, Digital Epidemiology

Strengths

- The methodology addresses current discrepancies in mobile ecological momentary assessments (EMAs) (e.g., triggering processes, time to follow-up).
- The methodology of time-triggered mobile EMAs is effective in recording comprehensive daily prospective physical activity.
- The methodology facilitates capture of both physical and social contexts of physical activity prospectively.
-

Limitations

- The main limitation is the small sample size after applying the inclusion criteria
- All observations are self-reported by citizen scientists.

INTRODUCTION

Advances in mobile technology over the past decade have facilitated the innovation of ecological momentary assessments (EMAs), which are digital epidemiological tools that aid in understanding environmental, social, and behavioural processes.[1,2] EMAs can capture real-time data that reflect the dynamics of participants' experiences in their natural environment and thus they are increasingly being used to monitor health behaviors among populations across the life course.[3-5] In active living research, evidence indicates that EMAs are a valid, reliable, and feasible method of data collection.[6,7]

EMAs are an advancement over traditional self-report methods as they enable data collection more proximal to the time and place that a behavior has occurred.[2,8] Moreover, EMAs overcome many of the limitations of traditional self-report surveys to provide information regarding specific activity types (e.g. watching TV vs video gaming) and capture important factors that influence health behaviors such as mood and environmental perceptions.[5,9,10] In measuring physical activity (PA) intensities, EMAs have been shown to minimize recall[6,11] and social desirability bias[12] of traditional self-report measures.

Several studies have examined the validity of smartphone-based EMAs compared to other objective devices (accelerometers, pedometers) and self-report measures of PA.[2,10-16] Overall, estimates from EMAs were found to be highly correlated with accelerometer estimates.[13,14] However, this evidence also indicates that PA was over-reported when International Physical Activity Questionnaire (IPAQ) was used[2] and that daily PA EMA reports were not significantly associated with their traditional recall measures.[12]

Currently there is little evidence of existing EMA methods that capture PA intensities across various physical (leisure-time PA, transit-related PA, occupation-related PA, and household/domestic-related PA)[15] and social contexts (with family, friends etc.).[16] Moreover, there are discrepancies in smartphone-based EMA methodologies, which range from inconsistent EMA triggering processes and varying times of prospective follow-up, to limitations of using identical mobile devices and operating systems.[8]

The objective of this study is to address current deficiencies in active living EMA approaches by developing a replicable digital epidemiological and citizen science methodology to capture prospective PA within free-living social and physical contexts. This objective will be achieved by leveraging citizen-owned smartphones running on both Android and iOS systems, and by comparing EMA measures with traditional self-report measures of PA within the same cohort.

METHODS

Design

This study is part of the SMART Platform, which is a mobile health (mHealth) and citizen science initiative for active living surveillance, integrated knowledge translation, and policy and real-time interventions.[8,17,18] Citizen science is a participatory approach where participants, termed citizen scientists, actively engage in the research process from data collection to knowledge translation, thus improving the probability of longitudinal participant compliance.[15] A detailed description of SMART Platform's methods, including recruitment and data collection strategies, are described in the Platform's methodology publication.[8]

The data for this study have been obtained from the 2017 (April 1 to May 31) and 2018 (January 4 to March 31) cohorts of the SMART Platform,[8] which is a prospective investigation designed to capture active living data from adults residing in the two largest urban centers in Saskatchewan, Canada (Regina and Saskatoon). All subjective (via traditional validated surveys and EMAs) and objective data (via smartphones sensors) related to PA, sedentary behaviour, and perception of environment, individual motivation, health outcomes, and eudaimonic well-being were obtained through citizen-owned smartphones on 8 consecutive days **(Figure 1).**

Patient and public involvement

Participants in the SMART Platform are "citizen scientists" as they can engage with the researchers at all stages of the research process. Thus, citizen scientists informed the design, research questions and outcome measures. As part of the social media campaign for recruitment, citizen scientists were encouraged to inform their friends about the study. Finally, as integrated knowledge translation is part of the SMART Platform, results are disseminated throughout the study period using the community voices webpage of the Platform's website: https://www.smartstudysask.com/community-voices

Recruitment and participants

Citizen scientists for SMART Adult cohorts were recruited online through social media, and in-person from the universities of Regina and Saskatchewan and community centres located in different neighbourhoods in each city to capture a socioeconomically representative sample. Citizen scientists were guided to download Ethica (Ethica Data Services Inc.), an epidemiological smartphone application (app), specifically adapted for the SMART Platform, which captures data through both Android and iOS platforms. All citizen scientists provided informed consent through the app and confirmed their age (≥18 years) before joining the study. Ethics approval was obtained from the universities of Regina and Saskatchewan through a synchronized review protocol (REB # 2017-29).

Measures

The two primary measures used in this study are the International Physical Activity Questionnaire (IPAQ),[19] which collects retrospective PA in 4 physical domains (recreation, active transportation, work, and home), and the SMART Platform's modified EMA, which captures prospective daily PA in both social and physical contexts.

IPAQ

IPAQ was deployed at baseline as soon as citizen scientists downloaded the app to self-report physical activities over the past 7 days that were of at least 10 consecutive minutes in duration. These activities were categorized by 4 domains: 1) Recreation (e.g., weight training, sports (soccer, hockey, etc.), aerobics, running, jogging, swimming, cycling, etc.); 2) Household (e.g., carrying light loads, sweeping, washing windows, and raking, etc.); 3) Transportation (e.g., travelling in a train, bus, car, or other kind of motor vehicle, etc.); and 4) Work (e.g. heavy lifting, digging, heavy construction or climbing upstairs, etc.). The records included the number of times per week (within the last 7 days) and average minutes per day for each activity.

Adapted Daily EMAs

Using the SMART platform, time-triggered modified EMAs (**Figure 1A-D**) were developed, tested, and piloted, before being pushed to citizen scientists' smartphones between 8pm and 8:30pm on each day for 8 consecutive days. These EMAs were designed to expire at 3am the next day. Citizen scientists were asked to report only those physical activities that were of at least 10 minutes in duration at a time. More importantly, each EMA was designed to not only measure intensity and volume (in minutes) of PA, but also to capture social (i.e., with whom they accumulated PA [**Figure 1C**]) and physical contexts (i.e., where they accumulated PA [**Figure 1D**]). This design was achieved by creating a looped linkage, where upon entering the type and volume of each activity, the EMA triggered the social and physical context questions.

Derived variables – Intensities and Volume of PA

IPAQ

Thirty-seven questions related to PA were asked and 3 different categories of intensities were created (light, moderate, and vigorous PA) by combining PA across 4 domains: recreation, household, workplace, and active transportation. Moderate and vigorous PA intensities are combined to derive "moderate-to-vigorous PA." After conducting several aggregation techniques, 2 final intensity variables were derived for IPAQ retrospective PA: mean minutes per day of light and moderate-to-vigorous PA.

Adapted Daily EMAs

A similar approach was employed to derive two final intensity variables for EMA prospective PA: mean minutes per day of light and moderate-to-vigorous PA. For example, the light PA included walking, light hiking, any light physical activity/sport (e.g. golf bowling etc.), yoga, and light intensity household chores (e.g. washing dishes sweeping laundry gardening). Moderate-to-vigorous PA included moderate to vigorous hiking, running, biking, any team sport (football hockey soccer etc.), any other sport or activity (swimming canoeing skiing etc.), weight training, dance/aerobic/cardio exercise, and moderate-to-vigorous intensity household chores (e.g. shovelling driveways, washing a car etc.).

Physical Context

PA information from the IPAQ and EMAs (based on the question "Where did you do this activity?") were grouped into domains. Domain 1: PA at workplace (IPAQ) and from work (EMAs). Domain 2: Transportation PA (IPAQ) and from street (EMAs). Domain 3: Housework, house maintenance, and caring from family (IPAQ) and from home (EMAs). Domain 4: Recreation, sport, and leisure-time PA (IPAQ) and from park, gym, and sport facility (EMAs).

Social Context

Social context information was collected via EMA question, “With whom did you do this activity?” for each physical activity that the participants reported. Categories for social context included “by myself, with my dog, with my friend(s), with my parent(s),” among others.

Statistical analyses

The inclusion criterion to determine the final sample was dependent on citizen scientists completing the IPAQ, and answering the daily EMA on at least 3 days. Continuous estimates were reported as means with standard deviations (SD) and medians with 25^{th} and 75^{th} percentiles, depending on normality. Where estimates were non-normal and positively skewed, median and interquartile ranges were used. Wilcoxon signed ranks tests and Spearman correlation procedures were conducted to compare PA intensities and domain-based PA reported via IPAQ and EMAs. Correlation coefficient values of <0.20, 0.21-0.40, 0.41-0.60, 0.61-0.80 and 0.81-1.0 were considered as weak, fair, moderate, strong and very strong correlation, respectively.[20]. Analyses were conducted in SPSS version 24.0 (SPSS Inc., Chicago IL, USA) with significance set at alpha < 0.05.

RESULTS

After applying the decision rule of including only those citizen scientists who completed IPAQ, and answered the daily EMA on at least 3 days, out of 538 participants, only 89 were included in this study (Table 1), among whom 47 identified as female (51.68%), and 26 identified as male (29.21%), and 19.11% (n=17) did not reveal their identity. The final sample had the mean age of 37.15 years (SD=15.92), and a mean body mass index of 28.46 (SD=7.78). The median (25th, 75th percentiles) and the mean (SD) duration of time (minutes per day) spent in each of the activity intensities (light, moderate and vigorous), as well as overall PA were derived from both IPAQ and EMA measures.

Using EMAs, citizen scientists reported 140.91, 87.16, and 70.38 mean minutes/day of overall PA, light PA, and moderate-to-vigorous PA. The same citizen scientists reported 194.39, 116.99, and 98.42 mean minutes/day of overall PA, light PA, and moderate-to-vigorous PA using the IPAQ (Table 2). These findings show that although there are no significant differences between activity intensities reported via EMAs and IPAQ, citizen scientists consistently overestimated their PA using IPAQ in comparison with EMAs. Table 3 demonstrates the correlation between EMA and IPAQ measures to show that overall (ρ=0.414, p<0.001), light (ρ =0.261, p=0.012) and moderate-to-vigorous PA (ρ =0.316, p=0.009) were fairly correlated across both measures. Figure 2 shows the visual representation of these correlations.

Figures 3 and 4 demonstrate the distribution of overall PA accumulated across different physical and social contexts, as reported by citizen scientists using EMAs. Among physical contexts, citizen scientists reported accumulating overall PA predominantly at home (26.4%), on the streets ([20.4%] i.e., active transportation), at the gym (13.7%), at work (13.1%), and in parks (12.3%). When it comes to social context, citizen scientists overwhelmingly reported accumulating overall PA by themselves (64.2%), with some reporting being active with friends (14.7%) and relatives (6.3%).

As IPAQ captures PA in 4 physical domains (workplace, active transportation, household, and recreation, sport and leisure-time) to compare estimates between EMA and IPAQ, EMA estimates of overall PA accumulated across various physical contexts were categorized to match the physical domains of IPAQ. Using EMAs, citizen scientists reported 20.50, 16.41, 25.33, and 20.88 mean minutes/day of overall PA across workplace, active transportation, household, and recreation, sport and leisure-time domains, respectively. Using IPAQ, the same citizen scientists reported 32.14, 43.97, 38.27, and 145.90 mean minutes/day of overall PA across workplace, active transportation, household, and recreation, sport and leisure-time domains, respectively.

These findings show that in comparison with EMAs, there is a consistent pattern of over-reporting of overall PA across all physical domains when citizen scientists used IPAQ, with statistically significant differences observed in active transportation ($p=0.002$) and recreation, sport and leisure-time domains ($p=0.003$) (Table 4). Table 5 demonstrates correlation between EMA and IPAQ measures for overall physical activity across four physical domains, with moderate correlation being depicted in household ($\rho=0.607$, $p=0.036$), and recreation, sport, and leisure-time domains ($\rho=0.587$, $p=0.021$) domains.

DISCUSSION

The objective of this study was to address current deficiencies in PA EMA approaches by developing a novel and replicable methodology of standardized time-triggered smartphone-based EMAs to capture prospective PA within free-living social and physical contexts by leveraging citizen-owned smartphones running on both Android and iOS systems.

We were able to not only develop a novel EMA that can be time-triggered by both iOS and Android devices to capture prospective PA across physical and social contexts to address current gaps in EMA methodologies[21,22], but also compared this EMA measure with IPAQ to highlight potential discrepancies between prospective and retrospective measures in capturing active living in free-living conditions.

Although not statistically significant, irrespective of the intensity of PA (overall PA, light, and moderate-to-vigorous PA), citizen scientists consistently over-reported activity with IPAQ in comparison with EMA. However, when PA intensities were compared across the 4 physical domains (workplace; active transportation; household; and recreation, sport, and leisure), PA reported via IPAQ in active transportation; and recreation, sport, and leisure domains was significantly greater than PA reported via EMAs.

These findings corroborated a longitudinal validation study by Swendeman et al., (2018), who concluded that the inter-method reliability between smartphone-based EMAs and their corresponding recall reports was low and no significant associations were observed.[23] Another validation study that compared PA EMAs with IPAQ and accelerometer measures concluded that EMA measures correlated better with accelerometers.[4] Several studies have been conducted to compare self-report estimates of PA with objective measures (an accelerometer),[4,24,25] with evidence suggesting that an ideal approach potentially lies between traditional validated self-report measures and accelerometry,[24] especially because accelerometry is unable to capture context.

This is indicative of EMAs being the potential solution for comprehensively capturing PA by minimizing recall bias. However, a key gap in current methodologies is that EMAs are used in more controlled experiments, where identical mobile devices running on same operating systems are to participants.[26] Moreover, EMA methodologies lack standardization and sufficient rigour such as inclusion criteria for valid data. A key advancement of our study is including only those participants who completed EMAs on at least 3 days, an inclusion criterion which provides the necessary rigour to arrive at valid data.

EMAs are currently novel methods that are in need of standardization. We applied a strict inclusion criterion, where we included only participants with PA data on at least 3 out of 8 days in the final analysis, which resulted in exclusion of most participants. We did this even at the risk of reducing our sample size because this rigorous inclusion criterion is an essential step in standardizing EMA measures, and obtaining valid and reliable data. This is not very different from accelerometry standardization methods, where data are considered valid if participants wear accelerometers for at least several hours (e.g. 10 hours) on at least 2-3 days in a one-week study period.[27,28]

Another gap in current methodologies is the inability of existing EMAs to capture important physical and social contexts within which PA is accumulated. We developed an innovative looped linking mechanism that sequentially triggers questions about type, volume, and context of

PA. The findings showed that citizen scientists reported accumulating most PA while at home, through active transportation, at the gym, at their work places, and in parks.[16,29] The distribution of accumulation of overall PA across these physical contexts provides important evidence to develop interventions modifying physical spaces to address physical inactivity.[30-33] The findings also showed that most citizen scientists accumulated PA by themselves[29], which points towards informing individual-level interventions that facilitate intrinsic motivation.[34-36] Although these findings are not novel by themselves, the methodology of using a single time-triggered EMA per day to capture volume, intensity, and physical and social contexts of PA is innovative.

Although EMAs are valid and reliable measures to measure PA, current evidence indicates that there is no gold standard in assessing prospective PA using mobile EMAs.[3,5,21] Our study advances a methodology that introduces conceptual and technological advancement (citizen science approach utilizing citizen-owned devices functioning on both iOS and Android systems), scientific rigour (stringent inclusion criteria for valid data), and comprehensiveness of data collection (volume, intensity, and contexts). In working towards standardized EMA methodology, future studies need to address the balance between capture of prospective PA and participant burden/compliance in repeatedly responding to EMAs. Future studies should could combine EMAs with objective measurement to measure PA,[37,38] to concretely capture PA.

Nevertheless, EMAs for PA measurement have the potential to reliably record active living and could substitute accelerometers when needed.[2] In our study we addressed existing gaps in EMA methodology to measure PA by adopting a citizen science approach[39] in deploying a comprehensive, yet generic EMA that captures type, volume, and context of PA. More importantly, participants used their own smartphones, which operated on either iOS or Android systems. Thus, this methodology is not only replicable, but also expands the scope of leveraging ubiquitous tools such as smartphones[40] to conduct ethical surveillance[8,41] of PA among large populations. Citizen science approaches are increasingly being considered in active living research[42], and it is important that methodological advancements are in step with conceptual and technological innovations. With more than 3 billion smartphones currently in circulation globally,[40] standardized and generic EMA methodologies can enable real-time engagement through crowdsourcing[43,44] for ethical active living surveillance.[8]

Strengths and Limitations

The primary strength of the study is the development of novel and replicable methodology to capture prospective PA from large populations using citizen-owned devices. This citizen science approach, if replicated appropriately, can transform surveillance of physical PA among large populations by leveraging citizen owned-devices. Implementing such innovative approaches of PA surveillance will be critical to develop appropriate interventions to address global physical inactivity.

In terms of limitations, all observations are self-reported by citizen scientists. The study sample size was also small after applying the inclusion criteria, however, smaller sample sizes are not uncommon in smartphone-based EMA studies.[45] Another limitation is that IPAQ and EMAs measured PA in different timeframes. As IPAQ captures data retrospectively and EMAs capture data prospectively, they cannot be issued simultaneously. Nonetheless, although IPAQ could have been issued on day 8, we refrained from such late deployment based on the evidence from our pilots, which showed that compliance to burdensome traditional recall surveys such as IPAQ is much higher when it is issued as close to participant enrolment in the study as possible.

CONCLUSION

With growth of smartphones projected to only magnify in the future[16], these ubiquitous tools can be leveraged via citizen science to capture accurate active living patterns of large populations in free-living conditions through innovative EMAs. This digital epidemiological and citizen science methodology adapted mobile EMAs to minimize recall bias and capture not only prospective PA, but also important physical and social contexts within which individuals accumulate PA.

LIST OF ABBREVIATIONS

EMAs: Ecological momentary assessments

PA: Physical activity

IPAQ: International physical activity questionnaire

DECLARATIONS

Ethics approval and consent to participate: All citizen scientists provided informed consent through the app and confirmed their age (≥18 years) before being recruited. Ethics approval was obtained from the universities of Regina and Saskatchewan through a synchronized review protocol (REB # 2017-29).

Consent for publication: Not applicable

Availability of data and materials: The corresponding author will make the data available upon reasonable request.

Competing interests: Authors declare no conflict of interest.

Funding information: This study was funded by the Saskatchewan Health Research Foundation's Establishment Grant. This funding body had no role in study design; data collection, analysis and interpretation; or in writing the manuscript.

Authors' contributions: TRK contributed substantially to the study design, acquisition and interpretation of data, and writing the manuscript. LMC contributed substantially to the acquisition and interpretation of data, and writing the manuscript. All authors read and approved the final manuscript.

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495 **Table 1. Demographic characteristics of the final sample**

Demographic Characteristics	Categories	n	%
Sex	Male	26	29.21
	Female	46	51.68
	Did not identify	17	19.11
Age in years, mean (SD)		71	37.15 (15.92)
Body Mass Index, mean (SD)		73	28.46 (7.78)
Annual Household income	< 40,000	14	15.73
	40,000- < 70,000	21	23.60
	≥ 70,000	35	39.32
	Did not respond	19	21.35
Educational attainment	Some or completed secondary/high school	7	7.86
	Some post-secondary (university or college)	18	20.22
	Received university or college degree/diploma	46	51.68
	Did not respond	18	20.24

496 Note: SD: Standard deviation

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500 **Table 2. Overall physical activity and intensity measurements: IPAQ vs. EMA**

	Mean (minutes/day)	Standard Deviation	Percentiles (minutes/day)			p-value*
			25th	50th	75th	
Overall physical activity measurement: IPAQ vs. EMA						
IPAQ	194.39	266.10	63.80	122.14	175.72	0.331
EMA	140.91	98.31	73.07	123.75	183.48	
Light and moderate-to-vigorous physical activity measurement: IPAQ vs. EMA						
Light PA (IPAQ)	116.99	171.24	36.00	67.86	110.00	0.322
Light PA (EMA)	87.16	64.44	41.25	68.33	103.67	
Moderate to vigorous (IPAQ)	98.42	175.18	17.14	49.44	92.86	0.995
Moderate to vigorous (IPAQ)	70.38	63.48	40.00	52.50	87.50	

501 Note: Based on Wilcoxon Signed Ranks Test; IPAQ: international physical activity
502 questionnaire; EMA: ecological momentary assessment
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504 **Table 3. Spearman correlation coefficients between IPAQ and EMA across physical**
505 **activity intensities**

Intensity	Spearman correlation coefficients	
	ρ (p-value)	n
Overall PA	0.414 (0.001)	89
Light	0.258 (0.012)	87
Moderate-to-vigorous	0.316 (0.009)	67

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Table 4. Overall physical activity measurement across physical domains: IPAQ vs. EMA

Domain		Mean (minutes/day)	SD	Percentiles (minutes/day) 25th	50th	75th	p-value *
Workplace	Survey	32.14	34.97	7.86	12.86	66.07	0.345
	EMA	20.50	17.87	5.63	15.00	38.13	
Active Transportation PA	Survey	43.97	24.32	25.36	40.00	66.43	0.002
	EMA	16.41	11.51	7.56	10.00	25.69	
Household	Survey	38.27	35.01	9.04	28.50	74.46	0.117
	EMA	25.33	46.29	5.16	10.31	19.84	
Recreation Sport and Leisure-time PA	Survey	145.90	306.95	15.00	34.29	72.86	0.003
	EMA	20.88	16.19	7.50	17.50	37.50	

Note: Based on related-samples Wilcoxon Signed Rank Tests; IPAQ: international physical activity questionnaire; EMA: ecological momentary assessment

Table 5. Spearman correlation coefficients of overall physical activity between EMA and IPAQ across physical domains

Domain	Spearman correlation coefficients ρ (p-value)	n
Physical Activity (PA) at workplace	0.500 (0.391)	5
Transportation PA	0.166 (0.587)	13
Housework, house maintenance and caring for family	0.607 (0.036)	12
Recreation, Sport and Leisure-time PA	0.587 (0.021)	15

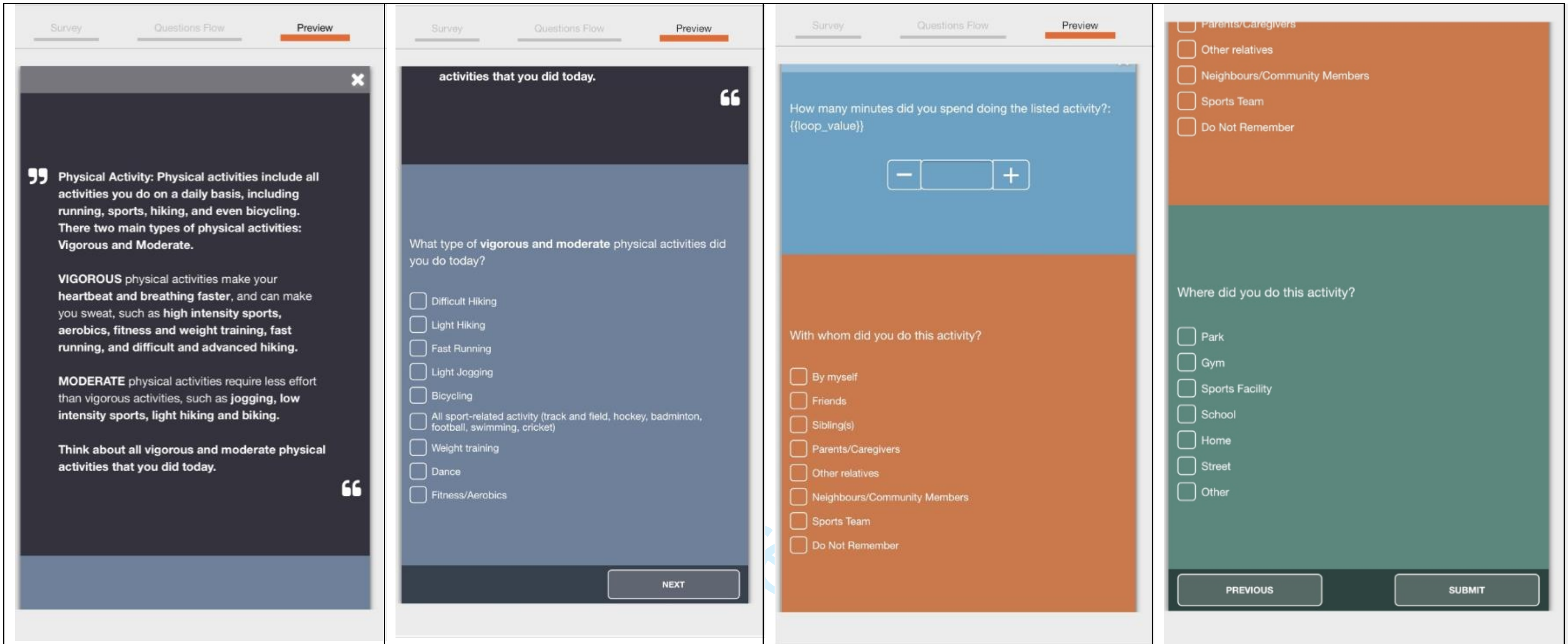


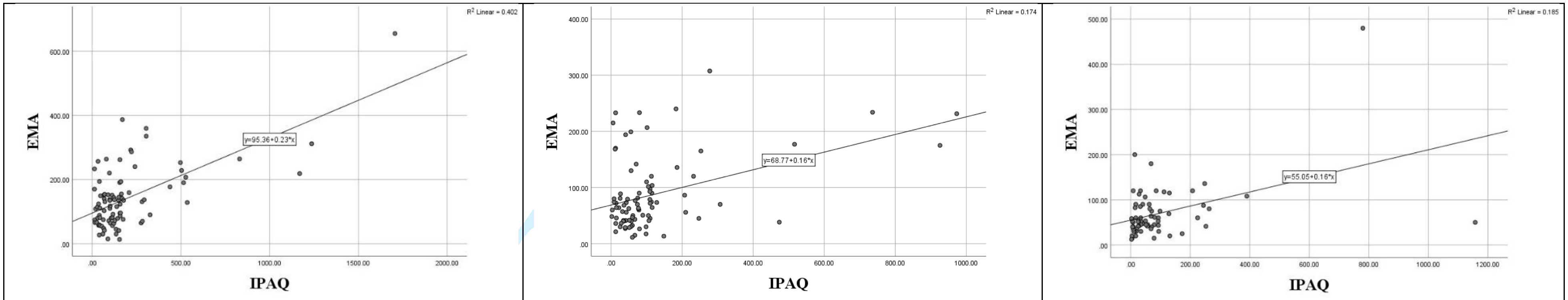
Figure 1A. Instructions of Physical activity intensity

Figure 1B. Questions of Physical activity intensity

Figure 1C. Social context question

Figure 1D. Physical context question

Figure 1. Time-triggered ecological momentary assessment capturing prospective physical activity



Overall Physical Activity	Light physical activity	Moderate to vigorous physical activity

Figure 2. Correlation between IPAQ and EMA measurements of physical activity

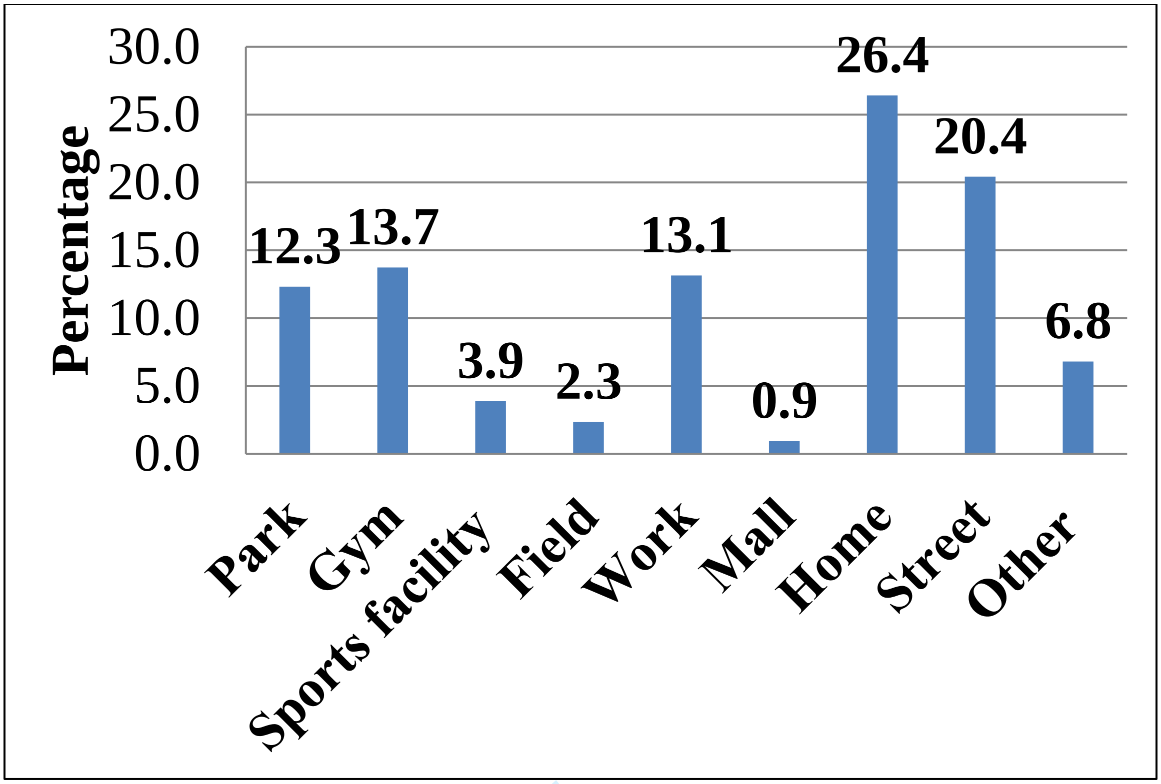


Figure 3. Distribution of Daily EMA Physical activity within physical contexts

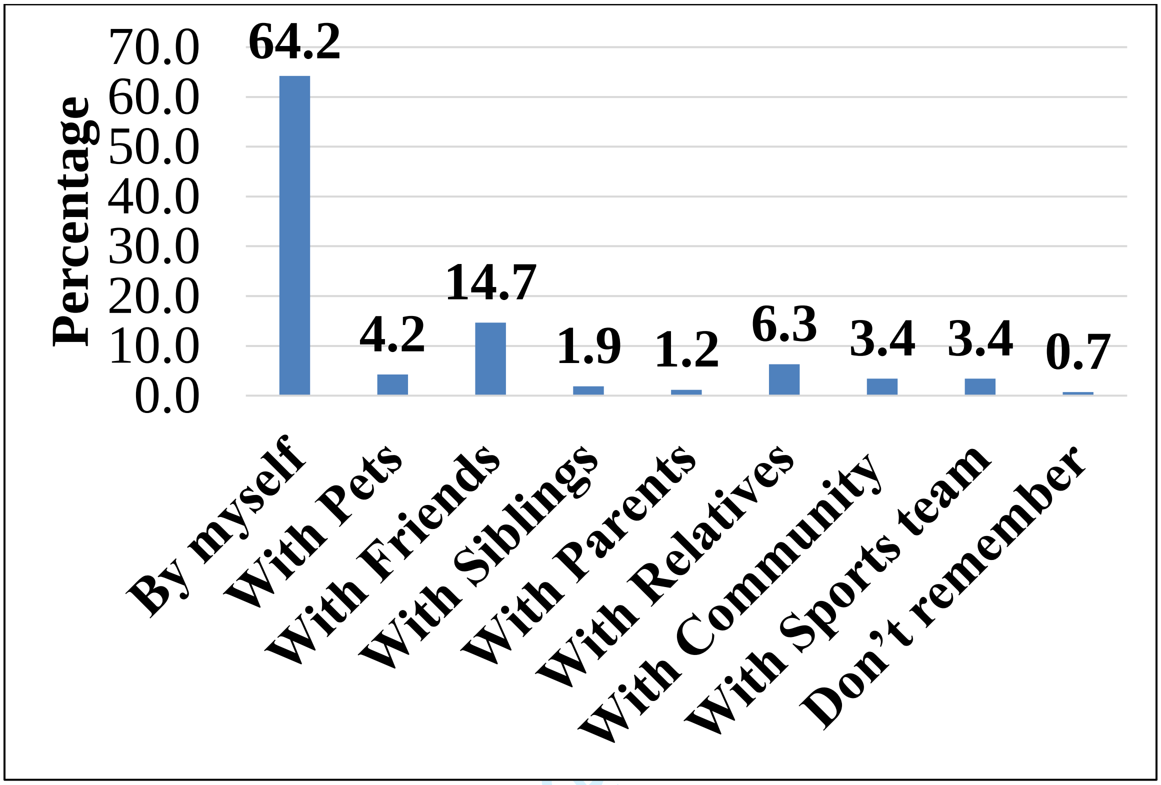


Figure 4. Distribution of Daily EMA Physical activity within social contexts

STROBE Statement

Checklist of items that should be included in reports of observational studies

Section/Topic	Item No	Recommendation	Reported on Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	6
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6,7,8,9
Data sources/measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6,7
Bias	9	Describe any efforts to address potential sources of bias	9
Study size	10	Explain how the study size was arrived at	9
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6,7,8,9
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	9
		(*b*) Describe any methods used to examine subgroups and interactions	
		(*c*) Explain how missing data were addressed	9
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	9
		(*e*) Describe any sensitivity analyses	

Section/Topic	Item No	Recommendation	Reported on Page No
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	10
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	10
		(b) Indicate number of participants with missing data for each variable of interest	
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	10, 11
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	10,11
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	
Discussion			
Key results	18	Summarise key results with reference to study objectives	12
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	14
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	12.13
Generalisability	21	Discuss the generalisability (external validity) of the study results	14
Other Information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	17

**Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.*

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.