UNDERSTANDING WILLINGNESS TO SHARE SMARTPHONE-SENSOR DATA

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Abstract The growing smartphone penetration and the integration of smartphones into people's everyday practices offer researchers opportunities to augment survey measurement with smartphone-sensor measurement or to replace self-reports. Potential benefits include lower measurement error, a widening of research questions, collection of *in situ* data, and a lowered respondent burden. However, privacy considerations and other concerns may lead to nonparticipation. To date, little is known about the mechanisms of willingness to share sensor data by the general population, and no evidence is available concerning the stability of willingness. The present study focuses on survey respondents' willingness to share data collected using smartphone sensors (GPS, camera, and wearables) in a probability-based online panel of the general population of the Netherlands. A randomized experiment varied study sponsor, framing of the request, the emphasis on control over the data collection process, and assurance of privacy and confidentiality.

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Respondents were asked repeatedly about their willingness to share the data collected using smartphone sensors, with varying periods before the second request. Willingness to participate in sensor-based data collection varied by the type of sensor, study sponsor, order of the request, respondent's familiarity with the device, previous experience with participating in research involving smartphone sensors, and privacy concerns. Willingness increased when respondents were asked repeatedly and varied by sensor and task. The timing of the repeated request, one month or six months after the initial request, did not have a significant effect on willingness.

In recent years smartphones have been widely adopted and deeply integrated into people's daily routines, which has led researchers to view them as novel data-collection tools for studying human behavior. In addition to survey completion, smartphones offer possibilities of *in situ* measurement through Experience Sampling Methods (Harari et al. 2016) and the collection of rich data using built-in sensors such as geolocation (GPS), camera, QR-code scanner, as well as connection to wearables such as fitness bracelets (Link et al. 2014).

Smartphone-sensor data collection can be passive, such as tracking geolocation, calls, and messaging; or active, such as when a participant uses a camera to take pictures, videos, or scan bar codes of purchases (Wenz, Jäckle, and Couper 2019). Using smartphone sensors for research can help resolve the issues of nonresponse and oversurveying with which traditional surveys are confronted, can potentially reduce costs, and can replace self-reporting, which potentially may reduce respondent burden and measurement error. In situations where self-report is not possible, such as studying small children, pictures taken with smartphones can provide more accurate measurements (Plowman and Stevenson 2012).

Furthermore, smartphone-sensor measurement potentially can expand the types of research questions considered, since it enables the collection of detailed behavioral information on time use (e.g., Fernee and Sonck 2013), geographic mobility (e.g., Geurs et al. 2015), and health behaviors and physical activity (e.g., Rosli et al. 2013; Kapteyn et al. 2018) that are difficult or impossible to obtain with other methods. Smartphone-sensor measurement enables the participation of special populations and hard-to-reach groups such as homeless youth (Tyler and Olson 2018), the elderly (Fritz et al. 2017; York Cornwell and Cagney 2017), and persons recently released from prison (Sugie 2018).

All these situations rely on respondents' willingness and ability to collect such data. However, consent rates to allow passive measurement are low, ranging between 5 percent and 56 percent (Couper, Antoun, and Mavletova

2017). If the behavior of the people who agree to smartphone-sensor measurement differs from the behavior of those who do not agree, research results can be biased. Presently, the willingness rates mostly are estimated using online access panels (e.g., Pinter 2015; Keusch et al. 2019; Revilla, Couper, and Ochoa 2019), which may be misleading due to participants being more motivated than respondents recruited using probability sampling (Hillygus, Jackson, and Young 2014). A few studies have assessed the general population's willingness to share sensor data (e.g., Scherpenzeel 2017; Kreuter et al. 2020; Jäckle et al. 2019), but these studies rarely focused on the mechanisms of willingness (however, see Wenz, Jäckle, and Couper 2019). In addition, previous studies have focused on one-time willingness to share smartphone-sensor measurements.

The current study aims to estimate participants' willingness to share sensor measurements using data from the general population of the Netherlands. We focused on the mechanisms of willingness for various sensor-based measurements, and whether repeated asking had detrimental effects on willingness to share.

Background, Research Questions, and Hypotheses

MECHANISMS OF WILLINGNESS TO SHARE SENSOR-COLLECTED DATA

Studies have shown that willingness to share data collected using smartphone sensors varies substantially by country (Revilla et al. 2016) and by the type of sensor or task (Scherpenzeel 2017; Kreuter et al. 2020; Jäckle et al. 2019; Keusch et al. 2019; Mulder and de Bruijne 2019; Wenz, Jäckle, and Couper 2019). The differences also can be associated with the type of sample (non-probability- vs. probability-based). Participants can be recruited through a non-probability route (e.g., flyers placed in points of interest) or a probability route (e.g., an invitation sent to an existing panel or a cross-section of the target population). For the probability route, general steps precede participation (fig. 1):

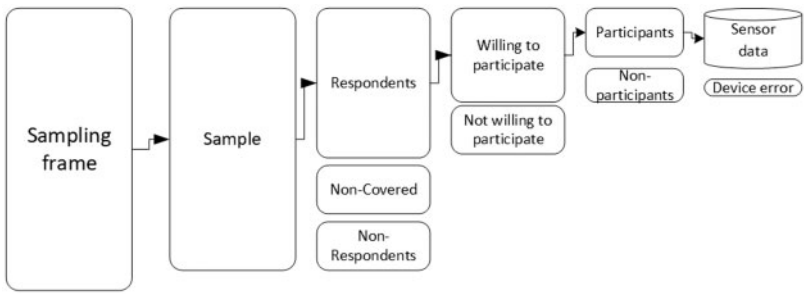

Figure 1. The process of providing consent to sensor measurement.

acquiring or creating a sampling frame; drawing a sample from the sampling frame; recruiting respondents (some will not have smartphones, and thus will not be covered); asking respondents about their willingness to participate in the sensor-based measurement; and collecting data from those who adhere to the request and whose devices provide sensor data.

Potential participants have to make a decision about whether or not to accept the request. The mechanisms underlying willingness to participate in smartphone-sensor measurements are similar to general survey participation, but some aspects are unique due to the novelty of technology involved (Keusch et al. 2019). Similar to surveys, the study sponsor affects willingness: Sponsorship by a university evokes a higher willingness to download a research app than sponsorship by a market research agency or governmental organization (Keusch et al. 2019). Promising incentives increases willingness in nonprobability panels (Pinter 2015; Keusch et al. 2019); higher incentives increase sharing rates in probability-based panels (Haas et al. 2020).

The mechanisms unique to willingness to share smartphone-sensor data include: (1) respondents' control over the data they provide, (2) privacy concerns, and (3) smartphone skills (Keusch et al. 2019). Willingness is higher for tasks when respondents have real or perceived control over their data transmission. Revilla, Couper, and Ochoa (2019) found that willingness to take pictures or scan bar codes was about $54-56$ percent, much higher than the willingness to provide access to Facebook profiles (19 percent) or install apps tracking smartphone use (18 percent) or geolocation (21 percent). Keusch et al. (2019) found that an option to switch off data collection increased willingness to install a research app. Privacy and data security concerns negatively influence stated willingness. Respondents with higher privacy concerns have a lower willingness to download research apps (Jäckle et al. 2019; Keusch et al. 2019). Also, privacy concerns are the main reason for nonwillingness (Keusch et al. 2019; Revilla, Couper, and Ochoa 2019). Smartphone use habits such as frequency of app downloads, frequency of using GPS, and the number of installed apps are associated with a higher willingness to download a survey app that tracks geolocation (Pinter 2015). Keusch et al. (2019) found that respondents who had previously downloaded a research app were more willing to do so for research purposes.

These willingness mechanisms have been developed using the data from online access panels (Keusch et al. 2019; Revilla, Couper, and Ochoa 2019). Studies in probability-based panels (e.g., Wenz, Jäckle, and Couper 2019) have been observational, which has limited our understanding of what causes the variability in willingness across studies and populations. This present study aims to systematize the proposed mechanisms and test them in a probability-based setting. Furthermore, studies have focused on asking respondents about a one-time willingness, and so it is unclear what effects repeated requests

might have. Some evidence exists that asking panel respondents to download a research app that passively collects data leads to somewhat higher attrition (Trappmann et al. 2018). Studies asking for consent to link to administrative data have shown that an initial refusal to provide consent is aggravated by a repeated asking for consent (Sakshaug and Antoni 2017). Whether this translates to a willingness to share smartphone-sensor measurements is unclear.

We answer the following research questions: (1) To what extent are smartphone users in the general population willing to share data collected via smartphone sensors and wearables? (2) Does willingness differ by the types of sensors? (3) What are the mechanisms of willingness to share smartphone-sensor data? (4) What are the reasons for nonwillingness and under what conditions would respondents be willing to share? (5) How is willingness affected by a follow-up request and its timing?

CONCEPTUALIZATION AND HYPOTHESES

Following Keusch et al. (2019) and Wenz, Jäckle, and Couper (2019), we distinguish between respondent-level and task-level characteristics that influence willingness to participate (WTP). Our conceptual framework for WTP vis-à-vis sensor measurements resembles the framework of survey participation (Groves and Couper 1998) and leverage-saliency theory (Groves, Singer, and Corning 2000). Potential participants weigh the potential benefits of their participation, such as helping researchers, and the potential costs, such as risks of disclosure or misuse of sensor-based data and the respondent effort required to share them. The main difference between WTP in sensor-based measurements and WTP in a survey is the level of uncertainty about the respondent task.

The literature on consent to linkage to administrative records is relevant since both tasks—linkage and sharing sensor data—can have unforeseen consequences for respondents. Some research has shown that framing of the consent request in terms of benefits (i.e., as reduced burden) increased respondents' willingness to share data from the administrative records. For example, Bates, Wroblewski, and Pascale (2012) found that framing as a reduced effort increased hypothetical willingness, and Sakshaug and Kreuter (2014) and Sakshaug et al. (2019) found that time-savings framing significantly increased consent rates, compared to neutral framing.

Similar to the decision to participate in surveys that is not preformed but based on heuristics (Groves, Couper, and Cialdini 1992), so is the WTP in sensor measurements. However, some respondents may hold strong attitudes about privacy that result in nonwillingness, or they may hold certain attitudes about the potential benefits of participation for themselves or society. Across studies on data linkage, the desire to be helpful and respondents' trust are associated consistently with higher consent, whereas the main reason for

nonconsent is confidentiality concerns (Sala, Knies, and Burton 2014). Thus, the present study also considers the characteristics of task presentation (framing) and the perceived social norms about data sharing. We distinguish between four sets of factors that influence willingness to share: features of the task; features of the request; respondent characteristics; and perceived social norms (fig. 2).

Task features differ in terms of their (a) active or passive nature, (b) potential intrusiveness, (c) perceived effort, and (d) ability to control the task. Features of the request include the framing and the factors related to task characteristics: revealing the study sponsor, which may evoke higher or lower trust; benefit vs. neutral framing; emphasis on the ability to view data prior to sharing; and addressing privacy concerns. Among respondent characteristics are privacy concerns that respondents might associate with increased risks of sharing data and certain attitudes and experiences that might lower the perceived risks: trust that the research is useful, respondents' familiarity with their smartphone, and experience of participating in studies that collect sensor-based

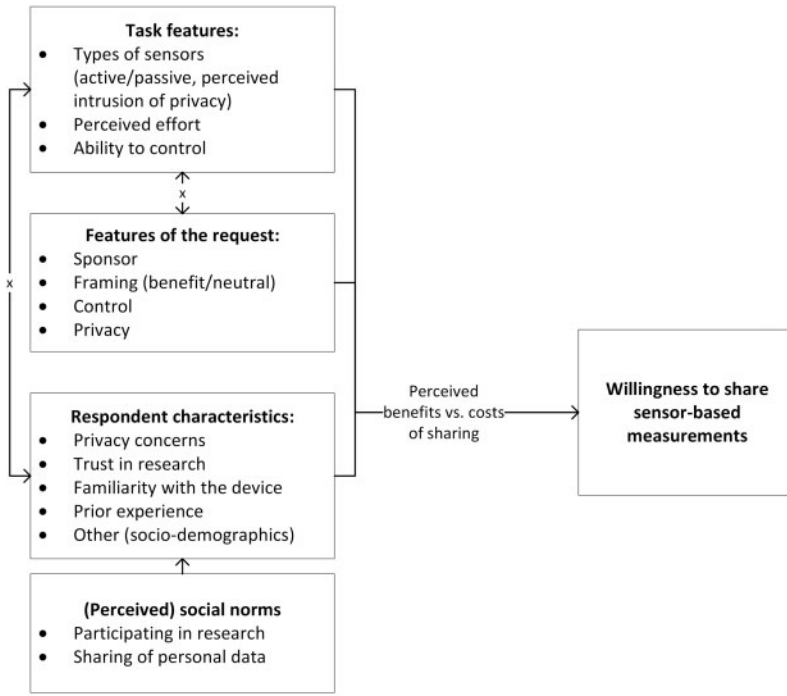

Figure 2. Conceptualization of willingness to share sensor-based measurements.

measurements. Perceived social norms and the risks of data sharing are weighted against the saliency of the norm of helping researchers and the value of the research.

The willingness mechanisms were empirically tested via four sets of hypotheses. The first set relates to the tasks, based on studies showing that stated willingness varies by task. Specifically, willingness to use the smartphone camera for research was higher than the willingness to share geolocation: 50 percent vs. 20 percent (Revilla, Couper, and Ochoa 2019) and 65 percent vs. 39 percent (Wenz, Jäckle, and Couper 2019), respectively. However, willingness to use a smartphone camera can depend on the content of photos or videos: compared with the 56 percent willingness to take photos of products, only 18 percent would allow researchers to record a video of their face (Revilla, Couper, and Ochoa 2019), probably due to the sensitivity of the content. The willingness to wear a fitness bracelet was shown to be 61 percent (Wenz, Jäckle, and Couper 2019). Thus, we hypothesized:

H1.1: The willingness to wear a fitness bracelet and to use a smartphone camera will be higher than the willingness to share geolocation.
H1.2: Respondent's willingness to take a picture of her/himself will be lower than taking pictures or videos of other content.

The second set of hypotheses addresses study features and the features of the request. Previous studies have shown that a familiarity with the survey sponsor, trust in the sponsor, reputation, and the sponsor's authority increased WTP in online surveys (e.g., Keusch 2015). For traditional surveys, Groves and Couper (1998) have shown that government surveys produce higher cooperation rates than market research surveys. Concerning the willingness to share passively collected data, Keusch et al. (2019) found that relative to a market-research-sponsored study, WTP is higher for a university-sponsored study and lower for a statistical agency sponsor. However, this study was conducted in a panel housed at a market research agency. The trust toward the sponsor of the study in which the questions are asked can potentially influence willingness. Singer and Couper (2011) found the opposite for willingness to share data with a government vs. market research sponsor: Respondents of a panel housed at a university— the Dutch general population online LISS Panel— had higher willingness to share passively collected data about the survey process (paradata) for a government sponsor than a market research sponsor. Since we collected data in the LISS Panel, we hypothesized:

H2.1: Respondents' willingness to share sensor measurements will be the highest in a university-sponsored study compared with a study sponsored by a statistical agency or a market research firm.
H2.2: Respondents are more willing to share sensor measurements when the sponsor is a statistical agency rather than a market research firm.

In line with previous findings regarding control over data collection (Keusch et al. 2019; Revilla, Couper, and Ochoa 2019; Wenz, Jäckle, and Couper 2019), we hypothesized:

H2.3: If a request emphasizes that respondents have more control over data collection or transmission, they will be more willing to share compared to a request in which control is not mentioned.

H2.4: If respondents are promised to receive feedback about the data they provide, they will be more willing to share sensor-collected data.

In line with the research findings on data linkage consent concerning benefit framing vs. neutral framing, we hypothesized:

H2.5: If a request emphasizes benefits (lower burden), respondents will be more willing to share sensor-collected data compared to neutral framing.

Regarding privacy/security concerns that lower stated WTP (Keusch et al. 2019; Revilla, Couper, and Ochoa 2019; Wenz, Jäckle, and Couper 2019), we hypothesized:

H2.6: Respondents will be more willing to share sensor-collected data when a request emphasizes privacy protection, compared to a request in which privacy protection is not mentioned.

The third set of hypotheses addresses respondent characteristics and the influence of the social environment. In line with previous findings of privacy concerns' negative association with willingness (Keusch et al. 2019; Revilla, Couper, and Ochoa 2019; Wenz, Jäckle, and Couper 2019) and being a main reason for nonwillingness (Keusch et al. 2019; Revilla, Couper, and Ochoa 2019) or nonparticipation (Jäckle et al. 2019), we hypothesized:

H3.1: Privacy concerns will be negatively associated with a willingness to share sensor-collected data.

Consistent with the finding that respondents trusting that a survey guarantees anonymity are more willing to perform additional tasks on smartphones (Revilla, Couper, and Ochoa 2019), we hypothesized:

H3.2: Trust that the questionnaire guarantees anonymity will be positively associated with willingness to share sensor-collected data.

In line with the evidence that higher smartphone skills (Pinter 2015; Couper, Antoun, and Mavletova 2017; Keusch et al. 2019; Wenz, Jäckle, and Couper 2019), more smartphone-mediated activities, and prior research app download (Keusch et al. 2019) are associated with higher willingness to share sensor data, we hypothesized:

H3.3: Respondents' skills in using their smartphone will be positively associated with a willingness to share sensor-collected data.

H3.4: Frequency of using specific sensors (e.g., sharing geolocation or using a smartphone camera) will be associated with an increased willingness to perform tasks using these sensors for research purposes.

H3.5: Respondents who previously shared sensor-collected data with researchers or downloaded a research app will be more willing to share sensor-collected data than those who have not.

Revilla, Couper, and Ochoa (2019) showed that respondents with positive attitudes toward surveys and market research have higher willingness to perform additional tasks on smartphones; and trust and altruism were among the reasons for willingness to share. The social environment, value of research, and norms about sharing of personal data are expected to influence willingness to share as follows:

H3.6: Respondents' evaluation of the questionnaire as being important to science will be positively associated with a willingness to share sensor-collected data.
H3.7: Respondents' estimation of people's willingness to share sensor-based data will be positively associated with respondents' stated willingness to share.
H3.8: Respondents' evaluation of the questionnaire as too personal will be negatively associated with a willingness to share sensor-collected data.

In the fourth set of hypotheses, we expected the influence of some respondent characteristics to vary across sensor tasks. Keusch et al. (2020) have shown that respondents are more concerned about sharing passively collected data such as GPS and activity tracking than actively collected data such as taking photos. Thus, we hypothesized:

H4.1: The influence of privacy concerns on willingness to share will be more pronounced for GPS and a fitness bracelet use, compared to using a smartphone camera for taking photos or videos.

Consistent with the low willingness to take videos of one's face (Revilla, Couper, and Ochoa 2019), we hypothesize:

H4.2: The influence of privacy concerns on willingness to share will be more pronounced for photos of oneself compared to photos and videos of other content.

To our knowledge, studies have not investigated whether the mechanisms of the influence of a sponsor, framing, control, and privacy assurance vary for different tasks. However, the framework of contextual integrity (Nissenbaum 2009) states that information sharing is governed by context-specific norms depending on the type of data, with whom, and for what purpose the information transmission is appropriate. Individuals can form different expectations about the intended use of different types of information depending on who is requesting it. For example, sharing geolocation with a government agency might be perceived as surveillance, while sharing this information with a university will not produce such expectations. Also, these expectations about intended use—depending on who is asking—can differ across tasks. Thus, we considered the possibility that the mechanisms may vary across tasks. This

part of the study is exploratory, since it has not been tested prior to the present study, but it can help inform future studies on sharing sensor data.

STABILITY OF WILLINGNESS

In a randomized experiment about consent to record linkage, Sala, Knies, and Burton (2014) found that about 60 percent of respondents consented to linkage in wave 1 of the Understanding Society Innovation Panel. Of these respondents, 68 percent consented when asked again in wave 4. Of those who did not consent in wave 1, 46 percent consented in wave 4. This finding suggests that consent rates can increase over time, although the decisions about consent can be unstable. Thus, we expect:

H5.1: Stated willingness will increase when respondents are asked repeatedly.

Furthermore, in the Sala, Knies, and Burton (2014) study, a reminder of the wave 1 decision in wave 4 produced a 24 percent consent rate for non-consenters and 94 percent for consenters. These rates were more consistent with the initial decision. We thus hypothesized that the time interval, which decreases respondents' recall of the previous decision, will influence the willingness in sensor-based measurement:

H5.2: Stated willingness will be more stable when less time has passed since the initial request.

Methods

The data were collected in the LISS Panel, a Dutch probability-based online panel of the general population. It consists of approximately 7,000 Dutch-speaking individuals permanently residing in private households in the Netherlands who are aged 16 and older. Panelists are invited to take monthly online surveys of $15-30$ minutes for an incentive of 15€ per hour. The Dutch national statistical office drew a simple random sample of addresses for the panel recruitment from a detailed population register, which is centrally available in the Netherlands (Scherpenzeel and Das 2011). At each address, one household member was randomly selected for the purpose of addressing the advance letter, but all household members were asked to participate.

The panel used a mixed-mode recruitment protocol: After the initial mailing, households whose telephone could be found in the telephone book were contacted by telephone, and interviewers visited the remaining households. Non-Internet users were provided with computers connected to the Internet (Scherpenzeel 2011; Scherpenzeel and Das 2011). Since 2007, the LISS Panel has undergone four refreshments, approximately every two years. In its setup, the LISS Panel is comparable to other European probability-based online

panels (Blom et al. 2016). With respect to the United States, the LISS Panel is similar to the Understanding America Study (UAS), with some exceptions: the UAS used address-based sampling and a mail and telephone mode-mix for the recruitment, and provided non-Internet users with tablets (Alattar, Messel, and Rogofsky 2018).

Our two-wave study consisted of two randomized experiments. In the first wave, we tested the conditions of framing the consent questions. In the second wave, we tested the stability of willingness. The fieldwork for the first wave occurred in November 2017. Overall, 3,023 panel members who owned smartphones were invited to participate; 2,682 completed the questionnaire with a response rate (AAPOR RR1) of 88.7 percent (American Association for Public Opinion Research 2016).[1] Excluded from the analysis are nine respondents (0.3 percent) who broke off and five respondents (0.2 percent) who did not answer at least one of the sensor measurements, bringing the analytical sample to 2,673. (The regression models excluded another four cases due to listwise deletion of missing values.) The median duration of wave 1 was 5.73 minutes. Respondents could complete the questionnaire on a PC, tablet, or a smartphone. Wave 2 included only one question about the respondent's willingness to perform one sensor measurement. To exclude order effects, wave 2 repeated only the first request and the experimental conditions and the question wording of wave 1. Data collection for wave 2 occurred in December 2017 and May 2018: Half of the sample was invited to participate one month after the initial wave and the other half six months after the initial wave. All respondents who participated in wave 1 were invited to participate in wave 2.[2] Overall, 2,468 respondents completed the wave 2 questionnaire, which yielded a retention rate of 92.3 percent. The median duration of wave 2 was 37 seconds.

MEASURES

In wave 1, we asked respondents about their stated willingness (i.e., we made it clear that no actual measurements would be taken) to perform the following sensor-based tasks, the order of which was randomized: share their current geolocation, take a photo of their house, take a video of their surroundings, take a photo of themselves, and wear a fitness bracelet *(H1.1, H1.2)*. The geolocation measure asked for a one-time sharing of location. The location

1. We compared respondents and nonrespondents with regard to their demographic characteristics (table A5 in the Supplementary Material). Nonrespondents did not differ from respondents in gender and education. However, smartphone users aged 16–34 were somewhat less likely to respond, whereas smartphone users aged 65+ were more likely to respond. We controlled for respondents' demographic characteristics in the regression models, including age.
2. A total of 2,992 respondents were invited, of whom 2,518 participated (84.1 percent). Of these, we excluded 173 who did not participate in wave 1.

from which the photo of the house would be taken was not specified, nor was the length of the video or the period of wearing a fitness bracelet. Respondents were randomly assigned to the following conditions that tested willingness-to-share mechanisms that were reflected in the text of the request (QA1–QA5, question wording in the appendix):

First, the *sponsor (H2.1, H2.2)* appeared as Statistics Netherlands (CBS), a university, or a market research agency.

Benefit framing (H2.5) was reflected in the question specifying that the survey will take less time. For each type of sensor, we provided information on which questions respondents could skip. For example, for requests for geolocation: "This way you do not have to answer questions about where you traveled today and with which means of transportation" (see appendix for other sensors). The control condition did not include text.

Control (H2.3) was reflected in the experimental condition, which stated that the respondents would be able to view and change their data later in the questionnaire. The control condition did not include text.

For *assurance of confidentiality (H2.6)*, the experimental condition stated that the information respondents provided would be treated confidentially and anonymously, and personal data could not be inferred from this information. The control condition did not include text.

Respondents received five questions that measured their stated willingness on a four-point scale (*very likely, rather likely, rather unlikely, very unlikely*). *Very likely* and *rather likely* were grouped as "willing" (1); *rather unlikely* and *very unlikely* were considered "non-willing" (0).[3] The random assignment to the experimental conditions was performed at the respondent level, which means that the conditions into which a respondent was randomized were repeated for all five questions.[4] The four factors—sponsor, framing, control, and assurance of confidentiality—as a combination were repeated for geolocation, photos, video, and fitness bracelet questions throughout the study.

After each willingness question, respondents were asked to estimate how many out of 100 persons would be willing to provide such sensor data (*H3.7*, QA1a–QA5a). We asked once whether receiving feedback would increase willingness (*H2.4*, QA7). Respondents who answered *rather unlikely* or *very unlikely* to at least one of the questions were asked about the reason for non-willingness and under what conditions they would be willing to share data (QA8–9).

In addition, we measured general smartphone skills (*H3.3*, QA16), frequency of taking photos, videos, and using location-aware apps (QA13–15,

3. This dichotomization is typical of studies of passive data collection (Singer and Couper 2011; Couper and Singer 2013; Keusch et al. 2019). A comparison of the dichotomized measures vs. the original four-point measures reveals consistent results.
4. See table A6 in the Supplementary Material for the randomization check.

H3.4), prior participation in studies that collected information using smartphone sensors (*H3.5*, QA10), general privacy concerns (*H3.1*, QA12), and respondents' trust that the questionnaire guaranteed anonymity (*H3.2*, QA11). In addition to standard LISS Panel evaluation questions, the end of the questionnaire asked about the value of the survey for research (*H3.6*, QA17f) and the survey burden (*H3.8*, QA17h). Descriptive statistics for these variables are in the Supplementary Material.

Wave 2 again asked about willingness *(H5.1, H5.2)*, using the exact question wording from wave 1 (QB2). To avoid order effects, only the first question from wave 1 was repeated at wave 2.

Results

TO WHAT EXTENT ARE SMARTPHONE USERS FROM THE GENERAL POPULATION WILLING TO SHARE SENSOR-COLLECTED DATA? ARE THERE DIFFERENCES BY SENSOR TYPES?

Stated willingness to share data collected using smartphone sensors varies considerably by type of sensor and task (see fig. 3 and cells "definitely yes" and "probably yes" in table A2 in the Supplementary Material). Overall, 29.9 percent of respondents would be willing or somewhat willing to share GPS location, 38.2 percent would definitely or probably take a photo of their house,

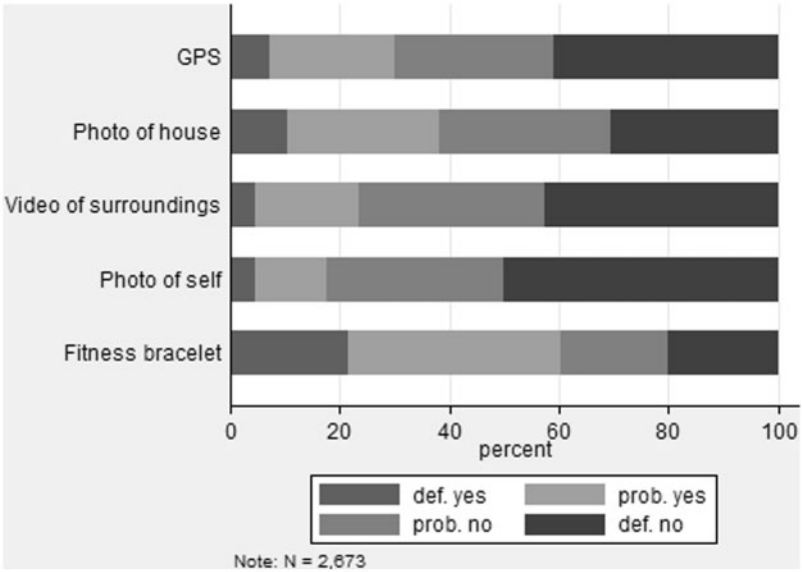

Figure 3. Stated willingness to share sensor data.

while 23.6 percent would take a video of their surroundings, and 17.7 percent would take a photo of themselves. Wearing a fitness bracelet evoked the highest willingness: 60.3 percent were willing and somewhat willing. We find partial support for *H1.1* since only willingness to wear a fitness bracelet and take some photos is higher than the willingness to share geolocation; *H1.2* is supported.

WHAT ARE THE MECHANISMS OF WILLINGNESS TO SHARE SMARTPHONE-SENSOR DATA?

To study the mechanisms of willingness, we fitted multilevel logit models[5] with task characteristics, wording experiments, and respondent characteristics (table 1). A baseline intercept-only model,[6] with an intraclass correlation (ICC[7]) of 0.371, showed that willingness is a characteristic of the task rather than of the respondent and experimental condition. Model 1 includes different types of tasks, and an indicator for the sensor asked first.[8] Model 2 additionally includes the experimental conditions, model 3 additionally includes the respondent characteristics, and model 4 additionally includes interactions.

Model 1 reiterates that willingness to share significantly differs by the type of sensor and task: relative to the fitness bracelet, using average marginal effects, respondents are 26 percentage points (p.p.) less likely to be willing to share their GPS location, take pictures of their house (AME –19 p.p.), make a video of their surroundings (AME –33 p.p.), or take a photo of themselves (AME –40 p.p.). The first question about willingness evokes higher willingness for all sensor measurements, except for taking a photo of their house (see also fig. A1 in the Supplementary Material).

Model 2 shows that the sponsor effect is significant, which supports *H2.1* and *H2.2*. Respondents' stated willingness is significantly higher for a university-sponsored study (AME +6 p.p.) and lower for a market research sponsor (AME –3 p.p.) compared to a statistical agency sponsor. Benefit framing has no influence on stated willingness (against *H2.5*), nor does emphasizing control (against *H2.3*) or privacy protection (against *H2.6*). Taking into account the features of the request raises the ICC to 0.511, which means that

5. Multilevel logit models account for the dependence of the observations, since every respondent answered multiple questions with different sensor-based measurements. Our lower level is the question for each sensor-based measurement (GPS, photo of house, video, photo of self, fitness bracelet), and our higher level is the respondent plus the experimental condition (sponsor and request wording).

6. A baseline model does not explain variance in willingness but decomposes the variance into two independent components (Hox, Moerbeek, and van de Schoot 2018, p. 12).

7. Models are compared based on intraclass correlation (ICC), a proportion of the variation at the higher level over the total variation (Hox, Moerbeek, and van de Schoot 2018, p. 13).

8. The variable for order of asking is dichotomized (sensor-measurement asked first or not) since we expected the answer to the first request to serve as an anchor (Tversky and Kahneman 1974). When faced with multiple data linkage requests, respondents show the highest willingness for the first request (Silber et al. 2018).

Table 1. Logit coefficients, standard errors, and average marginal effects (AME) from multilevel logistic regressions predicting likelihood of willingness to share sensor data

	Model 1				Model 2				Model 3				Model 4			
Fixed effects	Coeff.	(s.e.)	AME	(s.e.)	Coeff.	(s.e.)	AME	(s.e.)	Coeff.	(s.e.)	AME	(s.e.)	Coeff.	(s.e.)	AME	(s.e.)
Intercept	0.577***	(0.063)			0.563***	(0.115)			−2.322***	(0.294)			−1.549***	(0.426)		
Order (asked first)	0.425***	(0.060)	0.056	(0.008)	0.425***	(0.060)	0.056	(0.008)	0.422***	(0.059)	0.056	(0.008)	0.206**	(0.071)	0.020	(0.007)
Experimental conditions:																
Sponsor CBS (ref.)																
Sponsor university					0.466***	(0.106)	0.061	(0.014)	0.304***	(0.076)	0.040	(0.010)	0.918***	(0.150)	0.090	(0.015)
Sp. Market Research					−0.214*	(0.108)	−0.028	(0.014)	−0.126	(0.078)			0.258	(0.148)		
Benefit framing					−0.111	(0.088)			−0.136*	(0.063)	−0.018	(0.008)	−0.198*	(0.084)	−0.019	
Control					−0.169	(0.088)			−0.094	(0.063)			−0.150	(0.084)		
Privacy					0.139	(0.088)			0.018	(0.063)			0.038	(0.084)		
Sensors:																
Fit. bracelet (ref.)																
GPS	−1.989***	(0.077)	−0.261	(0.009)	−1.985***	(0.077)	−0.261	(0.009)	−1.980***	(0.077)	−0.262	(0.009)	−4.219***	(0.355)	−0.412	(0.034)
Photo house	−1.413***	(0.073)	−0.185	(0.009)	−1.409***	(0.073)	−0.185	(0.009)	−1.403***	(0.073)	−0.186	(0.009)	−4.329***	(0.381)	−0.422	(0.036)
Video surroundings	−2.493***	(0.082)	−0.328	(0.009)	−2.490***	(0.082)	−0.328	(0.009)	−2.486***	(0.082)	−0.329	(0.009)	−5.812***	(0.356)	−0.567	(0.033)
Photo self	−3.033***	(0.089)	−0.399	(0.010)	−3.029***	(0.089)	−0.399	(0.010)	−3.023***	(0.089)	−0.400	(0.009)	−6.006***	(0.423)	−0.586	(0.040)
Respondent characteristics:																
Smartphone skills									0.010	(0.037)			0.006	(0.049)		
Freq. GPS									0.090**	(0.029)	0.012	(0.004)	0.095*	(0.041)	0.009	(0.004)
Freq. photo									0.160***	(0.038)	0.021	(0.005)	0.170**	(0.054)	0.017	(0.005)
Freq. video									0.041	(0.046)			−0.014	(0.063)		
Shared GPS									0.373***	(0.098)	0.049	(0.013)	0.500***	(0.132)	0.049	(0.013)
Shared photo									0.175	(0.273)			0.192	(0.365)		
Downloaded app									0.224*	(0.100)	0.030	(0.013)	0.488*	(0.207)	0.047	(0.020)
Trust									0.459***	(0.042)	0.061	(0.005)	0.608***	(0.056)	0.059	(0.005)
Concern about privacy									−0.177***	(0.015)	−0.023	(0.002)	−0.107***	(0.030)	−0.010	(0.003)
Feedback									1.263***	(0.070)	0.167	(0.009)	1.698***	(0.097)	0.166	(0.008)

(*continued*)

Table 1. (*continued*)

	Model 1				Model 2				Model 3				Model 4			
Fixed effects	Coeff.	(s.e.)	AME	(s.e.)	Coeff.	(s.e.)	AME	(s.e.)	Coeff.	(s.e.)	AME	(s.e.)	Coeff.	(s.e.)	AME	(s.e.)
Important for science									0.164***	(0.034)	0.022	(0.005)	0.219***	(0.046)	0.021	(0.004)
Questionnaire too personal									–0.118***	(0.029)	–0.016	(0.003)	−0.163***	(0.038)	−0.016	(0.004)
Estimation GPS									0.009	(0.016)			−0.150***	(0.023)	−0.015	(0.002)
Estimation Photo house									0.167***	(0.016)	0.022	(0.002)	0.045*	(0.023)	0.004	(0.002)
Estimation Video									0.063***	(0.017)	0.008	(0.002)	−0.077**	(0.024)	−0.008	(0.002)
Estimation Photo Self									0.018	(0.017)			−0.092***	(0.023)	−0.009	(0.002)
Gender: male									0.097	(0.066)			0.095	(0.088)		
Age (< 35 ref.)																
Age (35 − 64)									0.093	(0.079)			0.135	(0.105)		
Age (65 and older)									0.355**	(0.114)	0.047	(0.015)	0.413**	(0.152)	0.040	(0.015)
Educ. (low ref.)																
Educ. (medium)									–0.017	(0.091)			−0.016	(0.121)		
Education (high)									–0.166	(0.089)			−0.168	(0.118)		
Concern_GPS													−0.245***	(0.042)	−0.024	(0.004)
Concern_Ph. house													−0.141***	(0.039)	−0.014	(0.004)
Concern_Video													−0.142***	(0.041)	−0.014	(0.004)
Concern_Ph. self													−0.166***	(0.043)	−0.016	(0.004)
Freq. GPS_GPS													0.127*	(0.060)	0.012	(0.006)
Freq. Photo_Ph. house													0.043	(0.066)		
Freq. Video_Video													0.401***	(0.083)	0.039	(0.008)
Freq. Photo_Ph. self													0.254*	(0.077)	0.028	(0.007)
Downl. app_GPS													0.324*	(0.254)	0.032	(0.025)
Downl. app_Ph. house													−0.224	(0.249)		
Downl. app_Video													−0.355	(0.256)		
Downl. app_Ph. self													−0.674*	(0.270)	−0.067	(0.026)
Estim. GPS_GPS													0.913***	(0.039)	0.089	(0.003)
Estim. Ph. house_Ph. house													0.821***	(0.035)	0.080	(0.003)

(*continued*)

Table 1. (*continued*)

	Model 1				Model 2				Model 3				Model 4			
Fixed effects	Coeff.	(s.e.)	AME	(s.e.)	Coeff.	(s.e.)	AME	(s.e.)	Coeff.	(s.e.)	AME	(s.e.)	Coeff.	(s.e.)	AME	(s.e.)
Estim. Video_Video													0.886***	(0.039)	0.086	(0.003)
Estim. Ph. Self_Ph. self													0.786***	(0.038)	0.077	(0.003)
Sponsor uni_GPS													−1.012***	(0.210)	−0.099	(0.020)
Sponsor market_GPS													−1.067***	(0.217)	−0.104	(0.021)
Sp. uni_Ph. house													−0.800***	(0.199)	−0.078	(0.019)
Sp. market_Ph. house													−0.479*	(0.202)	−0.047	(0.020)
Sponsor uni_Video													−0.471*	(0.214)	−0.046	(0.021)
Sp. market_Video													−0.460*	(0.220)	−0.045	(0.021)
Sp. uni_Photo self													−0.629**	(0.224)	−0.061	(0.022)
Sp. market_Ph. self													−0.452	(0.232)		
Random effects																
Respondent variance	3.440	(0.195)			3.344	(0.191)			0.979	(0.087)			2.266	(0.174)		
ICC	0.511				0.504				0.229				0.408			
Model fit statistics																
LogLikelihood	–6,975.57				–6,951.67				–6,124.41				−5,089.31			
LR χ^2 to previous model	1,919.78***				47.80***				1,654.53***				2,070.19***			
AIC	1,3965.13				13,927.34				12,314.81				1,092.62			
BIC	14,017.63				14,017.32				12,562.27				10,720.06			
N respondents	2,669				2,669				2,669				2,669			
N observations	13,345				13,345				13,345				13,345			

NOTE.—ICC = intra-class correlation >0.5 means that more variance is located at the higher level; logistic models' lower-level variance is fixed at $\pi^2/3$ (Hox, Moerbeek, and van de Schoot 2018, p. 117), approx. 3.29. Listwise deletion of missing values. AMEs for significant predictors. For the baseline model (model 0): intercept = –0.906***, s.e. = 0.036; Respondent variance = 1.942; ICC = 0.371; LogLikelihood = –7,935.46; AIC = 15,874.92; BIC = 15,889.91.

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

the variance is located both at the question level and the respondent plus experimental condition level.

Controlling for respondent characteristics (model 3) lowers the ICC to 0.229, which means that the variance is located at the question level. The effect of sponsorship by market research is no longer significant, whereas the effect of the benefit framing becomes negative, although it is small (AME –2 p.p.). Self-reported smartphone skills do not influence willingness (against *H3.3*). However, smartphone use behaviors such as frequency of sharing geolocation and taking photos are predictive of willingness (AME +1 p.p. and +2 p.p.), as is having previously shared a geolocation (AME +5 p.p.), which is consistent with *H3.4*, and past downloading of a research app (AME +3 p.p.), which supports *H3.5*.

Consistent with *H3.1*, respondents with high privacy concerns are less likely to be willing to share sensor-collected data (AME –2 p.p.). Believing that a questionnaire guarantees anonymity is positively associated with the likelihood to share sensor-collected data (AME +6 p.p.), which supports *H3.2*.

Consistent with *H2.4*, respondents who would want to receive feedback are more likely to be willing to share sensor-collected data (+17 p.p.). Keeping in mind that emphasizing control was not a significant predictor of willingness, we come back to this finding in the discussion.

Respondents who evaluated the questionnaire as important for science are more likely to be willing to share data (AME +2 p.p.), consistent with *H3.6*. Supporting *H3.8*, the evaluation of a questionnaire as too personal is associated with lower likelihood to be willing to share sensor-collected data (–2 p.p. AME). Among demographics, age was a significant predictor: respondents aged 65+ were more likely to be willing to share sensor-collected data (AME +4 p.p.).[9]

Model 4 included interaction effects to allow the influence of some respondent characteristics to vary across sensor tasks. Judging by significant negative interactions, concerns about privacy apply to all sensors. The negative influence of general privacy concerns is somewhat more pronounced for the GPS; however, the difference is negligible (AME –2 p.p. each), providing no support for *H4.1*. The influence of privacy concerns is equally pronounced for all camera-related tasks (against *H4.2*).

Positive significant interactions exist of the frequency of using GPS and being willing to share geolocation (AME +2 p.p.), frequency of taking videos and being willing to take a video (AME +4 p.p.), and frequency of taking photos and being willing to take a photo of oneself (AME +3 p.p.). Prior downloading of a research app is especially beneficial to being willing to share geolocation (interaction AME +3 p.p.), but not for taking a photo of oneself (AME –7 p.p.).

9. This finding may be connected to the overall higher likelihood of the smartphone users 65 and older to respond to our survey.

Consistent with our social norms hypothesis (*H3.7*), estimation of others' willingness to share sensor-collected data are associated with willingness to share this type of sensor data. For example, the higher the number of people that respondents think would be willing to share geolocation, the more willing respondents are to share geolocation (AMEs for interaction effects for each task are about +8 p.p.).

In models $1-3$, the main effect of university sponsor was significant; model 4 included the interactions of the university and market research sponsorship with sensor types. With the exception of the interaction of the market research sponsorship and a photo of oneself, the interactions were significant, which means that the sponsor effect differs by the type of sensor. Respondents were less likely to be willing to share all types of data compared to wearing a fitness bracelet. Although the interactions for both the university sponsorship and the market research sponsorship were negative and similar in magnitude, the influence of the sponsor is more pronounced for sharing geolocation (AME –10 p.p.) than for other sensors (AMEs ranging around –6 p.p.).

WHAT ARE THE REASONS FOR NONWILLINGNESS? UNDER WHICH CONDITIONS WOULD RESPONDENTS BE WILLING TO SHARE?

Responses to the open questions about nonwillingness are summarized in tables 2 and 3.[10] The most-named reason for nonwillingness is privacy and anonymity concerns (44.3 percent), followed by a general unwillingness without a provided reason (9.5 percent) and a respondent's desire to have more control over the process—to know who will be using the data and for what purposes (7.5 percent). Concerns about misuse of data and data safety account for 10 percent of the responses. Several other reasons are mentioned by less than 5 percent of the respondents: too much effort, feeling of being watched, and other emotional reasons.

When asked what would change respondents' nonwillingness, the most frequent response is *nothing* (29.3 percent, table 3) or *don't know* (9.6 percent). The following three most frequent responses for changing unwillingness are: (1) if researchers would ask less personal information (e.g., no pictures of a respondent's house or her/himself, 8.1 percent), (2) guarantee of privacy/anonymity (7.1 percent), and (3) if respondents could have more control over the use of their data (5.6 percent). Among the remaining responses were incentives, sponsor (which is most likely connected to the experiment), request to store respondent's information for a limited time, and feedback (all under 5 percent).

10. The coding scheme, developed by two coders, included 11 and 12 categories for each of the two questions. One coder coded the responses.

Table 2. Reasons for nonwillingness

Reason for not willing to provide data	Percent
Privacy/Anonymity/Too personal	44.3
Don't want to (without a reason)	9.5
Control (reason for asking, how will be used and by whom)	7.4
Misuse of data/Distrust of institution	5.5
Safety of my data	4.5
It requires too much effort from the respondent	4.0
Surveillance (being watched, followed)	4.0
Don't want to, due to feelings/emotions	3.5
Information is available elsewhere	0.5
Other	0.9
Noninformative	2.4

NOTE.—$N = 2{,}520$; percentages do not add up to 100, since multiple categories could be chosen.

Table 3. Conditions under which respondents would provide sensor data

Under what condition would provide data	Percent
Nothing can change my mind	29.3
Don't know what would change my mind	9.6
Ask less personal information	8.1
Guarantee privacy/anonymity	7.1
Control (reason for asking, how will be used and by whom)	5.6
Guarantee security	3.7
Incentives	3.5
Trusted sponsor/sponsor LISS Panel	2.3
Store for limited time	1.7
Feedback (want to view the results)	0.8
Other	3.3
Noninformative	4.2

NOTE.—$N = 2{,}520$; percentages do not add up to 100, since multiple categories could be chosen.

STABILITY OF WILLINGNESS TO SHARE

How is willingness affected by a repeated request? Table 4 summarizes the willingness to share for waves 1 and 2.[11] Wave 1 willingness is shown overall and for a balanced panel, which excludes respondents who did not

11. Change in willingness examined using McNemar's test for dependent proportions (McNemar 1947).

Table 4. Willingness (in percent) in waves 1 and 2

Stated willingness (definitely yes & probably yes)	GPS	Photo house	Video	Photo self	Fitness bracelet
Wave 1 (n=2,673)	30.09	37.60	22.82	17.26	60.51
Wave 1 (balanced)	29.55	37.83	21.97	19.25	63.15
Wave 2	39.88	42.48	25.73	22.57	62.93
n Wave 2	494	452	478	452	464
McNemar's χ^2 (1)	23.43***	3.64	3.24	2.47	0.01

NOTE.—*N* wave 2 (overall) = 2,340.
***$p < 0.001$

participate in wave 2.[12] Overall, willingness increases when respondents are asked repeatedly, ranging from 3 p.p. (photo of oneself) to 10 p.p. (GPS), except for the fitness bracelet, for which the difference is –0.2 p.p. However, only the increase in willingness to share geolocation is significant, which provides partial support for *H5.1*.

Compared to wave 1, 20.3 percent of respondents changed their willingness in wave 2. Table 5 shows the consistency of willingness irrespective of the timing of the second request. For example, 54.5 percent of respondents who answered *definitely yes* to the request to share geolocation in wave 1 said *definitely yes* in wave 2, while 33.3 percent switched to *probably yes*. Willingness to share has moderate stability over the waves: around 50 percent of respondents do not change their stated willingness (see also table A3 in the Supplementary Material). However, it differs by sensor: GPS, photo of the house, and wearing a fitness bracelet show moderate stability (weighted Kappa[13] 0.4 – 0.45), while taking videos or taking photos of oneself show fair stability (weighted Kappa 0.36).

Most changes happen between adjacent categories. Changes from *definitely no* to *definitely yes* and vice versa are uncommon, mostly under 10 percent. An exception is taking videos: 15.8 percent of those who said *definitely yes* in the first wave switched to *definitely no*. However, this is conditional on the very low proportion of respondents saying *definitely yes* to this task in wave 1 (4.75 percent). Using a fitness bracelet shows the most stable willingness (62.8 percent). Thus, the stability of willingness is dependent on the task. Overall, fair to moderate agreement between the willingness to share in wave 1 and wave 2 implies that willingness attitudes are changeable for most people.

12. We checked whether willingness in wave 1 was related to the participation in wave 2 (see table A4 in the Supplementary Material), and found that willingness to share sensor data in wave 1 did not predict the participation in wave 2.
13. Weighted Kappa accounts for the larger disagreement between nonadjacent categories (see Supplementary Material and Reichenheim (2004)).

Table 5. Consistency of willingness between waves 1 and 2 (in percent)

Wave 1 response	Wave 2 response					Weighted
	Definitely yes	Probably yes	Probably no	Definitely no	*n*	Kappa statistic with 95% CI
GPS					494	0.447 (0.391, 0.505)
Definitely yes	54.5	33.3	6.1	6.1	33	
Probably yes	22.1	54.9	19.5	3.5	113	
Probably no	3.9	31.4	49.0	15.7	153	
Definitely no	4.6	9.2	36.4	49.7	195	
Photo house					452	0.441 (0.389, 0.502)
Definitely yes	41.2	39.2	19.6	0	51	
Probably yes	15.8	50.8	25.8	7.5	120	
Probably no	6.0	27.3	50.7	16.0	150	
Definitely no	3.1	13.0	26.7	57.3	131	
Video					478	0.364 (0.300, 0.429)
Definitely yes	26.3	47.4	10.5	15.8	19	
Probably yes	12.8	45.3	32.6	9.3	86	
Probably no	3.8	20.1	46.5	29.6	159	
Definitely no	2.8	7.0	33.2	57.0	214	
Photo self					452	0.363 (0.297, 0.420)
Definitely yes	28.6	47.6	19.0	4.8	21	
Probably yes	15.2	34.8	40.9	9.1	66	
Probably no	5.6	19.0	45.8	29.6	142	
Definitely no	1.3	6.7	33.2	58.7	223	

(*continued*)

Table 5. (*continued*)

Wave 1 response	Wave 2 response					Weighted
	Definitely yes	Probably yes	Probably no	Definitely no	*n*	Kappa statistic with 95% CI
Fitness bracelet					464	0.400 (0.340, 0.468)
Definitely yes	62.8	25.7	6.2	5.3	113	
Probably yes	23.3	50.6	18.3	7.8	180	
Probably no	13.8	23.0	37.9	25.3	87	
Definitely no	9.5	22.6	29.8	38.1	84	

NOTE.—Shaded cells represent the stable responses. Bootstrapped confidence intervals.

Does timing of the follow-up request make a difference? To examine the effect of the timing of the request on willingness to share, we computed a logistic regression that included the binary timing variable, and we controlled for the type of task (table 6). The interval between the repeated request of 1 month versus 6 months had no influence on stated willingness in wave 2. None of the interactions of timing and type of sensor were significant. Thus, we find no support for *H5.2*.

Discussion

This study investigated the willingness of smartphone users in the general population to share data collected using smartphone sensors. Using such data potentially offers higher accuracy, lower costs, and a lower respondent burden. However, participants have to be willing and able to collect these data. Using data from a probability-based online panel of the Dutch general population, our study confirms previous findings that willingness is rather low and varies by sensors. Stated willingness of respondents to engage in different tasks varies from 18 percent for taking pictures of themselves to about 30 percent for sharing geolocation and 60 percent for wearing a fitness bracelet.

Consistent with previous research, a study sponsored by a university evoked higher willingness to share than when a sponsor is a statistical agency or a market research firm. Also, benefit framing of the request did not influence stated willingness. Emphasizing control has no influence on willingness, which is inconsistent with previous research (Keusch et al. 2019). However,

Table 6. Logistic regression predicting change in willingness between waves 1 and 2, odds ratios

	Model 1		Model 2	
	Odds ratio	(s.e.)	Odds ratio	(s.e.)
Intercept	0.281	(0.020)	0.321***	(0.038)
Six months interval	1.150	(0.113)	1.153	(0.113)
GPS			0.840	(0.127)
Photo house			1.063	(0.160)
Video			0.765	(0.119)
Photo self			0.733	(0.116)
Loglikelihood Ratio χ^2	2.04		10.78	
Pseudo R^2	0.001		0.004	

NOTE.—$N = 2{,}340$.
***$p < 0.001$.

respondents who indicated that they would want to receive feedback in the form of summary reports have a significantly higher willingness. A possible explanation is that new forms of measurements using smartphones and wearables may create expectations about feedback that influence willingness. Hence, the responsible factor here might be interest, rather than the ability to control data collection. This finding has important practical implications for the implementation of smartphone-sensor studies: Strategies of providing feedback in ways that motivate respondents to participate—and do not change the respondents' behavior that researchers intend to measure—are a topic to be considered in future research.

Emphasizing privacy protection does not influence willingness to share. However, consistent with previous research (Jäckle et al. 2019; Keusch et al. 2019; Revilla, Couper, and Ochoa 2019), respondents with high privacy concerns have significantly lower willingness. In addition, respondents who thought the questionnaire was too personal were less likely to be willing to share data, whereas respondents who indicated that they have a higher trust that the questionnaire guaranteed anonymity were more likely to be willing to share data. Furthermore, the most-named reason for nonwillingness is privacy and anonymity concerns. The absence of an experimental effect of emphasizing privacy protection in question wording suggests that respondents' privacy concerns might be multifaceted.

Research has shown that passive tasks (e.g., sharing geolocation) evoke higher privacy concerns than active tasks (e.g., taking pictures) (Keusch et al. forthcoming), and that respondents are more willing to perform active rather than passive tasks (Keusch et al. 2019; Mulder and de Bruijne 2019; Wenz, Jäckle, and Couper 2019). Our findings show that the content of tasks matters: Respondents might be willing to use their smartphone camera in general rather than share geolocation, but less willing to use their smartphone camera for sharing a picture of themselves that is possibly more private than geolocation. The combination of the content of the task, whether it is active or not, and the nature of the request are likely to drive the consent decision. How these aspects can be successfully combined to increase willingness needs further investigation.

Familiarity with the device—frequently using GPS, taking pictures and videos—and previous participation in studies that collected sensor data increases willingness to share, consistent with previous research (Pinter 2015; Keusch et al. 2019; Wenz, Jäckle, and Couper 2019). Also, respondents' willingness is influenced by beliefs about societal norms: Respondents rating the questionnaire as important for science and those who think the societal norm is sharing have higher stated willingness. Taken together, these findings suggest that with an increasing integration of smartphones into people's lives, sensor-based data collection will eventually not be a unique task for research participants.

On the one hand, stated willingness to share smartphone sensor-based data seems to be situational, rather than a stable, respondent characteristic. For example, the order of requests to perform sensor-based tasks matters: We found a higher willingness for whichever task is asked first. On the other hand, a proportion of respondents are consistently unwilling. When asked what could change their mind, they answered *nothing*. Also, for most of the sensor-based tasks—except sharing of geolocation, for which willingness increased about 10 percentage points—willingness did not increase with a second request. The timing of the second request, after 1 month or 6 months, had no effect on willingness. These findings suggest the existence of two distinct groups or people: those who have made set decisions on collecting sensor-based data and those whose decisions are request or situation dependent. Different types of tasks have varying stability, which is higher for sharing geolocation or taking pictures of one's house—compared to wearing a fitness bracelet, taking photos of oneself, or videos of one's surroundings. Determining why the stability varies for different sensor tasks is a relevant topic for future research.

Administering our study with an existing panel has its advantages, such as the possibility to study the stability of willingness that has not received attention previously. However, there are limitations. First, the LISS Panel respondents may be more positive toward innovative methods of data collection, since the LISS Panel was an innovative research tool when it started; also, it employed pilot experiments using smartphone-sensor measurements. Furthermore, the LISS Panel is housed at a university, so panelists might have a high trust in university-sponsored research, which could have influenced our findings about academic sponsorship. Also, LISS respondents have been panel members for several years, and respondents who have stayed longer in a panel might be more willing to share sensor data. Therefore, the absolute willingness rates that we found need to be interpreted with caution.

Second, although asking for willingness to share smartphone-sensor data collected through a browser that respondents use to complete the survey is a strong point of our study, many types of sensor data such as geolocation are in practice often collected using apps. In this case, respondents have to perform an additional task of installing an app, which may affect willingness negatively. Third, the requests in our study were hypothetical, since the respondents did not have to actually share sensor data, nor were they asked to share these data within the context of a substantive survey (e.g., sharing geolocation for a transportation survey). Research has shown that behavioral intentions to participate in a survey only weakly correlate with actual survey participation behavior (Hox, de Leeuw, and Vorst 1995; Bosnjak, Tuten, and Wittman 2005). To date, little is known about how stated willingness relates to actual participation in using sensor measurements. Thus, we encourage further research on this

issue. It would be useful to replicate our experiment in the context of substantive studies with the salience of data collection immediately evident to respondents. We encourage future studies to provide a specific rather than a generic study description to enable more insight into how the wording of requests for sensor-based data collection influences willingness to participate.

Note: For all analyses, we used Stata version 14.2.

Data archiving note: All data used in this study as well as codebooks in English and Dutch and the analysis code are stored at the LISS Panel data archive under a study number 201 "To participate in scientific research" https://www.dataarchive.lissdata.nl/study_units/view/911.

Appendix. Questionnaire (English Translation)

Wave 1: Question order of questions QA1, QA3, QA5, QA7, and QA9 was randomized (questions QA2, QA4, QA6, QA8 followed respective preceding questions).

In this survey we would like to ask you some questions about the possibilities of the Internet and other new technologies such as smartphones and tablets. We present a number of situations to you and ask you whether you would be willing to share this information.

The purpose of this questionnaire is to find out whether people are willing to take part in studies such as this one. We are not going to collect this information.

QA1. Please read the following research proposal carefully.

Suppose [CBS (Statistics Netherlands)/a university/a market research company] would like to collect information about your travel behavior by using sensors of your smartphone or tablet.

[experimental condition: benefit framing] *By sharing this information you can skip some questions in the questionnaire, so that the completion time is (considerably) shorter. This way you do not have to answer questions about where you traveled today and which means of transportation you used.*

[experimental condition: control] *You will be able to see what data you are sending and change it at a later point of the survey if you would want to.*

[experimental condition: privacy] *The information you provide will be treated confidentially. The results of the survey are anonymized. Personal information can never be derived from the statistical information.*

Would you give permission to share your location (this can be done in the settings of your phone) or would you refuse to do so? (Yes, I would definitely give permission; Yes, I would probably give permission; No, I would probably not give permission; No, I would definitely not give permission)

QA1a. Out of 100 people, how many do you think would give permission? Please fill in a number between 0 and 100; ____ out of 100 people would give permission.

QA2. Please read the following research proposal carefully.

Suppose [CBS (Statistics Netherlands)/a university/a market research company] would like to know in what type of dwelling you live (apartment, townhouse, detached house, etc.). To get information about this they would ask you to take a photo of your house.

[experimental condition: benefit framing] *By sharing this information you can skip some questions in the questionnaire, so that the completion time is (considerably) shorter. This way you do not have to answer questions about the type of dwelling you live in, its value, or the neighborhood characteristics.*

[experimental condition: control] *You will be able to see what data you are sending and change it at a later point of the survey if you would want to.*

[experimental condition: privacy] *The information you provide will be treated confidentially. The results of the survey are anonymized. Personal information can never be derived from the statistical information.*

Would you make a photo? (Yes, I would definitely make a photo; Yes, I would probably make a photo; No, I would probably not make a photo; No, I would definitely not make a photo)

QA2a. Out of 100 people, how many do you think would make a photo? Please fill in a number between 0 and 100; ____ out of 100 people would make a photo.

QA3. Please read the following research proposal carefully. Suppose [CBS (Statistics Netherlands)/a university/a market research company] would like to know more about the area where you are currently. For example, whether there is noise, and whether there are other distractions.

To get information about this they would like to ask you to make a video of your surroundings where you are at the moment.

[experimental condition: benefit framing] *By sharing this information you can skip some questions in the questionnaire, so that the completion time is (considerably) shorter. This way you do not have to answer questions about your surroundings, such as noise, other people being present, etc.*

[experimental condition: control] *You will be able to see what data you are sending and change it at a later point of the survey if you would want to.*

[experimental condition: privacy] *The information you provide will be treated confidentially. The results of the survey are anonymized. Personal information can never be derived from the statistical information.*

Would you make a video? (Yes, I would definitely make a video; Yes, I would probably make a video; No, I would probably not make a video; No, I would definitely not make a video)

QA3a. Out of 100 people, how many do you think would make a video? Please fill in a number between 0 and 100; ____ out of 100 people would make a video.

QA4. Please read the following research proposal carefully. Suppose [CBS (Statistics Netherlands)/a university/a market research company] would like to know more about your mood at the moment (happy, angry, sad, etc.).

To get information about this they would ask you to take a photo of yourself.

[experimental condition: benefit framing] *By sharing this information you can skip some questions in the questionnaire, so that the completion time is (considerably) shorter. This way you do not have to answer questions about your mood, such as your temper.*

[experimental condition: control] *You will be able to see what data you are sending and change it at a later point of the survey if you would want to.*

[experimental condition: privacy] *The information you provide will be treated confidentially. The results of the survey are anonymized. Personal information can never be derived from the statistical information.*

Would you make a photo of yourself? (Yes, I would definitely make a photo of myself; Yes, I would probably make a photo of myself; No, I would probably not make a photo of myself; No, I would definitely not make a photo of myself)

QA4a. Out of 100 people, how many do you think would make a photo of themselves? Please fill in a number between 0 and 100; ____ out of 100 people would make a photo of themselves.

QA5. Please read the following research proposal carefully. Suppose [CBS (Statistics Netherlands)/a university/a market research company] would like to know what the effect of physical activity is on health. To get information about this they would ask you to wear a wristband that registers your movements.

[experimental condition: benefit framing] *By sharing this information you can skip some questions in the questionnaire, so that the completion time is (considerably) shorter. This way you do not have to answer questions about how physically active you are and what kind of activity it is.*

[experimental condition: control] *You will be able to see what data you are sending and change it at a later point of the survey if you would want to.*

[experimental condition: privacy] *The information you provide will be treated confidentially. The results of the survey are anonymized. Personal information can never be derived from the statistical information.*

Would you be willing to wear such a wristband? (Yes, I would definitely be willing to wear such a wristband; Yes, I would probably be willing to wear such a wristband; No, I would probably not be willing to wear such a wristband; No, I would definitely not be willing to wear such a wristband)

QA5a. Out of 100 people, how many do you think would be willing to wear such a wristband? Please fill in a number between 0 and 100; ____ out of 100 people would be willing to wear such a wristband.

QA6. What is the maximum number of times you would share the following information for this research study? (GPS (information about your location) – number of days: _____; Photo – number of times: _____; Video – number of times: _____; Wearing the wearables such as a wristband – number of days: _____)

QA7. Would you be more willing to share information if you would receive one or more summaries with the information you shared, such as the travel distances you travel, the degree of environmental distractions due to noise, or your physical activity level? (Yes, I would be more willing to share my data if there will be a summary of my behavior; No, I would not be more willing to share my information)

QA8.* (asked if any of the questions QA1, QA2, QA3, QA4, QA5 were answered with "No, I would probably not..." or "No, I would definitely not..."). You have indicated for one or more questions that you would not be willing to share the information. Could you specify below why you would not want to do it? (open)

QA9.* (asked if any of the questions QA1, QA2, QA3, QA4, QA5 were answered with "No, I would probably not..." or "No, I would definitely not..."). What should [CBS (Statistics Netherlands)/a university/a market research company] change so that you would be willing to share the information? (open)

QA10.** Have you ever participated in a study where you were asked to share your geographic location, take photos or videos, or download an app? (Yes, I have shared my GPS location for a research study; Yes, I have taken photos for a research study; Yes, I have taken videos for a research study; Yes, I have downloaded an app for a research study; No, I have not taken part in the abovementioned type of research)

QA11.* To what extent do you trust that this survey guarantees anonymity? (Strongly trust; Somewhat trust; Little trust; Do not trust at all)

QA12.** In general, how worried are you about your privacy? (0 Not worried at all, 10 very worried, endpoint labels, numbers in between)

A couple of final questions about how you use your smartphone.

QA13.** How often do you take photos using your smartphone? (Several times a day or more frequently; About once a day; Several times a week; Several times a month; About once a month or less)

QA14.** How often do you take videos using your smartphone? (Several times a day or more frequently; About once a day; Several times a week; Several times a month; About once a month or less)

QA15.** How often do you use GPS/location-aware apps using your smartphone (e.g., Google Maps)? (Several times a day or more frequently;

About once a day; Several times a week; Several times a month; About once a month or less)

QA16.** How would you rate your skills of using your smartphone? (1 Beginner; 2; 3; 4; 5 Advanced)

QA17. Finally: what did you think of this questionnaire? (a) Was it difficult to answer the questions?; (b) Was it an interesting subject?; (c) Did the questionnaire make you think about things?; (d) Did you enjoy answering the questions?; (e) Was the questionnaire important for the science?; (f) Was the questionnaire long?; (g) Was the questionnaire too personal? (1 Certainly not; 2; 3; 4; 5 Certainly yes)

QA18. Do you have any additional comments about this questionnaire? (Yes [open answer box if yes]; No)

Background variables from the LISS Panel

QD1. Gender (Male; Female)

QD2. Age in CBS categories (14 years and younger; 15–24 years; 25–34 years; 35–44 years; 45–54 years; 55–64 years; 65 years and older)

QD3. Education in CBS categories (No high school degree (basisonderwijs); Degree from vmbo; Degree from havo/vwo; Degree from mbo; Degree from hbo; Degree from wo)

Wave 2: one question, whichever was asked first in wave 1. Below an example for GPS location.

In this survey we would like to ask you some questions about the possibilities of the Internet and other new technologies such as smartphones and tablets. We present a number of situations to you and ask you whether you would be willing to share this information.

The purpose of this questionnaire is to find out whether people are willing to take part in studies such as this one. We are not going to collect this information.

QB1. Please read the following research proposal carefully.

Suppose [CBS (Statistics Netherlands)/a university/a market research company] would like to collect information about your travel behavior by using sensors of your smartphone or tablet.

[experimental condition: benefit framing] *By sharing this information you can skip some questions in the questionnaire, so that the completion time is (considerably) shorter. This way you do not have to answer questions about where you traveled today and which means of transportation you used.*

[experimental condition: control] *You will be able to see what data you are sending and change it at a later point of the survey if you would want to.*

[experimental condition: privacy] *The information you provide will be treated confidentially. The results of the survey are anonymized. Personal information can never be derived from the statistical information.*

Would you give permission to share your location (this can be done in the settings of your phone) or would you refuse to do so? (Yes, I would definitely

give permission; Yes, I would probably give permission; No, I would probably not give permission; No, I would definitely not give permission)

QB2. Do you have any additional comments about this questionnaire? (Yes [open answer box if yes]; No)

*Question modeled after Revilla, Couper, and Ochoa (2019)

**Question modeled after Keusch et al. (2019)

Supplementary Material

SUPPLEMENTARY MATERIAL is freely available at *Public Opinion Quarterly* online.

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