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Tappigraphy: continuous ambulatory assessment and analysis of in-situ map app use behaviour

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ABSTRACT

While map apps on smartphones are abundant, their everyday usage is still an open empirical research question. With tappigraphy – the quantification of smartphone touchscreen interactions – we aimed to capture continuous data stream of behavioural human-map app usage patterns. The current study introduces a first tappigraphy analysis of the distribution of touchscreen interactions on map apps in 211 remotely observed smartphone users, accumulating a total of 42 days of tap data. We detail the requirements, setup, and data collection to understand how much, when, for how long, and how people use mobile map apps in their daily lives. Supporting prior research, we find that on average map apps are only sparsely used, compared to other apps. The longitudinal fluctuations in map use are not random and are partly governed by general daily and weekly human behaviour cycles. Smartphone session duration including map app use can be clearly distinguished from sessions without any map apps used, indicating a distinct temporal behavioural footprint surrounding map use. With the transfer of the tappigraphy approach to a mobile map app use context, we see a promising avenue to provide research communities interested in the underlying behavioural mechanisms of map use a continuous, in-situ momentary assessment method.

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Mobile map apps; mobile map app use; tappigraphy

1. Introduction

Maps play an important role in humans' everyday activities. Map use encompasses the acquisition of spatial knowledge from maps, sense-making of the environment, development of a mental representation of space, and finally the acquisition of spatial knowledge about geographic features and their relations, including space-time events and processes at various scales (Kimerling et al. 2016; MacEachren 2004). Map use involves the reading, analysis, and interpretation of space-time processes (Kimerling et al. 2016). During the last two decades, map use has shifted from static

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paper maps to interactive mobile map apps. Mobile maps can be defined as any cartographic product or application explicitly designed for display and use on a portable and movable computing device (Ricker and Roth 2018), such as a smartphone or tablet (Muehlenhaus 2013). With recent technological advancements in mobile communication and positioning technology, smartphone hardware, and online geographic databases, geographic information is increasingly consumed in everyday activities often on the go in the form of so-called map apps. The map app category is, however, loosely defined, and can include dedicated map apps (e.g. *Google Maps*, *Apple Maps*, *maps.me, etc*.), travel apps with a map interface, tracking apps, and basically any location-based services (LBS) relying on map interfaces. Touch-based user interfaces found on smart, assistive devices, in particular, have changed the way in which maps are consumed and being used and offer new ways of studying map use. Still, ambulatory in-situ assessment methods aimed at collecting a continuous stream of map use data to study mobile map use behaviour 'in the wild' are still rare (Riegelsberger and Nakhimovsky 2008; Savino et al. 2021). Instead, aggregated map app download statistics and self-reports still serve as a first proxy for mobile map use. Averaged download statistics do not offer fine-grained insights on map use behaviour itself, and self-reports on digital media use are notoriously inaccurate (Parry et al. 2021). Hence, basic research questions from a location-based and geographic information science perspective still remain open: *How much do people use mobile map apps in everyday life? When and for how long do people use mobile map apps? How do people use mobile map apps?* To answer these basic and pertinent questions would allow cartographers, geographic information scientists, or location-based services (LBS) developers to better understand mobile map use behaviour 'in the wild', and this, in turn, would support the user-centred design and development of future human and context-dependent map apps for an intended target audience (Huang et al. 2018; Thrash et al. 2019). However, the first challenge would be to obtain continuously collected, in-situ map use data which is typically not openly available yet for the research community.

Possible reasons for the scarcity of ecologically valid fine-grained mobile map use data and research may relate to the significant effort required to run large-scale empirical studies, requiring substantial monetary, temporal, technical, and human resources; in addition, aside from the difficulty of finding an adequately sized and willing participant pool, other reasons include the complex technical and experimental setups, controlling for potentially confounding variables occurring 'in the wild', handling additional privacy concerns of participants, and the obtrusiveness of observational procedures, including draining batteries and push notifications.

In light of steadily progressing digital transformation, ecologically validated empirical evidence is indispensable for informing and improving the design for useful and usable mobile map apps, location-based services, and smart navigation systems that support the mobility of a broad set of individuals in various rapidly changing use contexts in their everyday lives.

In sum, despite the ubiquity of mobile devices, we still know very little about fine-grained typical mobile map app use with smartphones. We thus introduce *tappigraphy* to the LBS and GIScience fields, as a complementary method for continuous, unobtrusive collection and analysis of 'natural', ecologically valid smartphone touch data as a proxy for everyday in-situ map use behaviour. The main point of this article is thus to explore how far one can push tappigraphy as the sole method to infer map app user behaviour, without the need of any other typical human behaviour tracking methods. With the current empirical map app study, we propose to bridge micro-level behaviour analysis known from cognitive neurosciences and psychology with macro-level field studies typically conducted in GIScience.

It is important to note here that tappigraphy is different from classical, typically small-scale user studies out in the world, including usability studies or controlled lab experiments that are commonly used in cartography and LBS studies (see Table 1). Tappigraphy follows instead the approach of typically remote, in-situ ambulatory assessment and ecological momentary assessment (EMA) of a large quantity of users in their everyday settings. Fahrenberg et al. (2007) define ambulatory assessment as 'the use of (mainly) electronic devices and computer-assisted methods of data collection suitable for use in the field to collect self-report data, behaviour observation data, psychometric behaviour measures, and physiological data in unrestrained daily life settings' (p.207). Similarly, EMA involves 'repeated sampling of subjects' current behaviours and experiences in real time, in subjects' natural environments' (Shiffman, Stone, and Hufford 2008, 1).

Hence, tappigraphy is defined here as the remote, inobtrusive, and almost continuous registering and quantification of smartphone touchscreen events in people's everyday use situations. It records every single tap of a user on the smartphone screen with its timestamp. It has historically been developed and

Table 1. Comparison of classic user tracking methods in the field compared with tappigraphy.

Experiment design	Classic user tracking methods	Tappigraphy
Sample size	30 – 50	>200
Ecological validity	Low	High
Experimental control	High	Low
Direct interaction with participants	Yes	No
Experiment goals and tasks	Determined	Not determined
Obtrusiveness	Method-dependent	Low
Observation duration	Discretely, set minutes to hours	Continuously days to months
Data sampling	Milliseconds to minutes	Milliseconds
Ease of use/running costs	High	Low
Data	Highly variable	Touches on smartphone display

applied in the domains of cognitive and behavioural neuroscience, and thus data is collected on the temporal scale of milliseconds. Tappigraphy has an emerging role in quantifying hidden human health variables such as sleep patterns, cognitive processing speeds, and human disease activities (Balerna and Ghosh 2018; Borger, Huber, and Ghosh 2019; Duckrow et al. 2021; Huber and Ghosh 2021). Studying the frequency and speed of taps over longer time periods during humans' natural usage situations allows, for instance, for the tapping behaviour to be related to various cognitive processes. Certainly, the LBS and GIScience community is very familiar with commonly known empirical methods to digitally observe mobile map use, such as human-map display interaction logging, automatic map screen recording, mobile eye tracking, think aloud protocols, digital surveys, etc. Unlike tappigraphy, classic usability tracking methods typically require either at some point of the empirical data collection campaign direct interventions or contact with study participants by researchers, or these are still typically run in a controlled empirical study setting outside or (even remote online) indoors. Tappigraphy, on the other hand, provides in its purest form the capacity to unobtrusively capture, ecologically valid, everyday, fine-grained ambulatory human-system interface interaction in situ (i.e. tap events are continuously recorded in milliseconds), over a long period of time (i.e. weeks and months, etc.), and for a large number of totally anonymous participants (i.e. hundreds of users can be studied in parallel) without any intervention or direct contact by researchers, and all this at considerably low effort and running costs (see Table 1).

The reason for using tappigraphy in the current study is to evaluate this type of EMA method for unobtrusively studying the complex human- and context-dependent process of daily map use including map reading, map analysis, map interpretation, space-time decision-making and spatial behaviour of many users in the 'wild'.

We thus set out to find different types of map use behaviours captured only by map app touches with respect to individual and user group differences of participants, geographic context, movement modalities, and purposes of use that are totally unknown.

We hypothesise that map use during longer periods of immobility (e.g. at home, sitting and/or standing for a long time in public transport, during work, or in a café, etc.) will show significantly different map app touch patterns from map app touch patterns during self-propelled locomotion, because these will be interrupted by only a few and short periods of immobility. When exploring new and unknown environments on the map, or while planning a route, this most likely will result in longer map use sessions with many map app tap interactions. This will include map app taps to manipulate the map view, as well as to zooming panning touches, or when searching for information on the smartphone. In contrast, while en route, map use should manifest as a series of short and less frequent map app touch interactions, for example, when users try to self-localisation on a GPS-enabled smartphone. With the availability of fine-grained map use data captured by map app touches, we thus expect to identify map use behaviour patterns that can be linked to specific map purposes and use situations. We already know that people differ in their spatial abilities, background, and training (Hegarty and Waller 2005). We thus expect not only to be able to infer intra-individual differences in map use behaviour, as described above, but also group differences, even though we have no background information about tracked participants, except for their tapping behaviour. We aim to detect clusters of individuals with similar map use behaviours based on their map app touches, as detailed in Section 3.

With this current study, we therefore aim to transfer the tappigraphy method from cognitive neuroscience to GIScience, cartography, and LBS as a complementary unobtrusive and ambulatory empirical user monitoring approach to better understand how people use map apps for everyday mobility tasks on their own smartphones with least experimental control. In doing so, on the one hand, we aim to provide a first step to be able to upscale findings from low-level map app use behaviour obtained from small-scale controlled user studies to aggregated and publicly map app use statistics currently available. On the other hand, tappigraphy offers the opportunity to eventually downscale map app touches collected from a large uncontrolled user sample to neural correlates of human map use behaviour at individual level (Fabrikant 2022).

In summary, we seek to 1) introduce tappigraphy borrowed from cognitive neuroscience into the research context of GIScience, in particular for empirical user-centred research in LBS and cartography, 2) detail the in-situ tappigraphy data collection and analysis approach in the context of mobility, and 3) demonstrate by means of examples how tappigraphy data could be analysed for getting at individual map use patterns that ultimately might help improve large-scale urban mobility.

2. Related work

We review related work with respect to large-scale (aggregated) download statistics and studies of general app use, followed by small-scale studies on map app use from GIScience, cartography, and human-computer interaction.

2.1. General app download statistics and app use studies

Publicly available data on map app use is non-existent for the open academic research community. As map apps are considered a market share of the mobile app business, most data on mobile map app use are based on market surveys and app download statistics from the major mobile operating systems providers, i.e. the Google Playstore and the Apple App Store. These data provide a macroscopic approximation of map app use in comparison to other app categories, such as gaming, social media, communication, or entertainment. For instance, a survey showed that in 2018 62% of people in Japan used maps on their smartphones (Sugimoto et al. 2021). Such statistics also reveal that map app use is infrequent. While Google Maps is ranked sixth with mobile apps users in the UK in 2019, with about 50% penetration of the total adult mobile app users, the total app minutes spent on Google Maps is only 5% of the time spent on YouTube, and less than 10% of time spent on Facebook (UKOM 2019).

In a large-scale survey of mobile app usage Böhmer et al. (2011) measured the app usage of 4125 users with a specially developed app called *AppSensor*. Their results showed an average smartphone use of about 59 minutes per day and an average app session time of 71 seconds. For the app category travel that includes Google Maps or Waze, they found an average usage time of 44.72 seconds. Furthermore, total app usage was lowest at 5 am and peaks at 6 pm. However, at 5 am, relative app usage for the category 'travel' was highest, at 2.6%. Similar results were reported by Falaki et al. (2010) in a study with 255 users. However, they found a range of use time per day between 30 and 500 minutes with users uniformly distributed within this range. Average session times were found to be between 20 and 250 seconds. Interaction sessions with maps were the longest.

A similar data collection approach was used for another survey of app usage (Do, Blom, and Gatica-Perez 2011). In addition to app usage logs for 77 smartphone users, the location when using an app was recorded too. Results for the category of maps showed the lowest numbers compared to *SMS*, *Voice Call*, or *Web* related apps. Regarding location, maps were used most on holiday, when relaxing, at restaurants, and to a lesser degree, during transport.

In an even smaller study, Carrascal and Church (2015) observed 18 participants for 2 weeks in-situ with an app logger. While they found an average mobile usage of over four and a half hours per day, they registered an average duration of sessions in the category *Travel&Local* (including map apps) of 111.6 seconds, which was half of the duration for *Entertainment*, but in a similar range as *Social Networking*. For app launches, *Travel&Local* accounted for 1.92%, while *Social Networking* accounted for 17.98%, *Browser&Search* for 1.3%, and *SMS/Texting* for 11.04%, respectively.

In another study (Banovic et al. 2014) the authors categorised the smartphone use of ten participants over a period of 18–36 days into three different interaction behaviour groups, based on duration and type. They defined very short interactions on the locked or home screen as *glance sessions*. *Review* *sessions* encompass relatively short interactions periods with one or more apps. Finally, *engage sessions* occur when users engage for longer interaction with apps. *Engage session* were found to be longer than 60 seconds.

In a large-scale study, Church, Cherubini, and Oliver (2014) collected data on participants' information needs and the addressing of these needs in-situ with a snippet-based diary technique using SMS and MMS data. Their data set included everyday information needs data for 108 users. Of all information needs reported by participants, 5890 (61.5%) were satisfied. Of the 5890 satisfied information needs, 106 were addressed by online maps on the internet (1.8%). A total of 55 information needs (0.8%) were addressed by GPS/map routing services when a clear destination had to be reached.

In a recent study on navigation app use for pedestrians, Fonseca et al. (2021) collected responses from 1438 people recruited in the cities of Bologna (Italy) and Porto (Portugal). While 92% of the respondents reported using smartphones intensively, only 42% stated that they used map apps, mainly to find locations and to obtain the shortest routes between two locations. Google Maps was reported to be the most used map app. As the main reason for not using map apps more extensively, study participants stated a lack of need. As the study authors suggest, this might indeed be an expected response, as most people navigate daily within a well-known familiar environment, and an increased need for a map app is only relevant for navigation and wayfinding in a novel and unknown environment, for example, when tourists explore a new holiday location. Another finding of the study was the individual factors that explain variations in navigation app use. In particular, the study revealed age to be an important factor. For the age group of 24 years old or younger, reported map app use was 50%, compared to only 25% for those aged 65 and older. As suggested earlier, if map app use is related to background knowledge of a traversed environment, it would make sense that older respondents might have a lesser need to use a map, as they might have been exposed longer, and thus have accumulated more local knowledge of their residential environment and local neighbourhoods than younger adults.

2.2. Small-Scale mobile map use studies in GIScience, cartography, and human-computer interaction

The few studies that have already been conducted are not typically dedicated to specific mobile map app use analysis, but rather study map use as a by-product, and either focus on navigation and wayfinding processes, or on the usability and human-computer interaction with mobile map displays. Specifically, numerous field studies have already been conducted that investigate wayfinding in situ (Brügger, Richter, and Fabrikant 2016, 2019; Delikostidis and van Elzakker 2011; Huang, Schmidt, and Gartner 2012). Commonly used data collection methods for such studies are questionnaires, interviews, eye-tracking, and video recordings and interaction logging. One of the few map use studies in the field focusing solely on human-computer interaction issues using a map-based web browser is described by Riegelsberger and Nakhimovsky (2008). Other studies focus on understanding the interaction of users with maps by recording touches on smartphones or touch screens. For example, to evaluate the usability of smartphone screen interfaces for elderly people in the context of classic human-computer interaction (HCI) research, Kobayashi et al. (2011) monitored the display interactions of 20 participants with a classic HCI Wizard-of-Oz prototype, including participants' tapping, pinching, or dragging behaviour. Colley and Häkkilä (2014) tested the performance of a novel interaction concept based on the distinction of different fingers used, and in three user studies with small user samples of 37, 13, and 25 participants, respectively. These authors showed that multi-finger interaction was perceived to be faster and more valuable to users. Another study looking into differences between 'digital natives' and 'digital immigrants' (e.g. adults) investigated users' performance in spatial tasks on touch screens when interacting with 3D environments. Response time and gestures were recorded accordingly (Herman and Stachoň 2018). While these studies also investigated human display interactions using touchscreens, they mainly focused on typical HCI usability issues, based on predefined user tasks in a controlled lab experiment setting. As typical in HCI usability studies, small samples (<100 participants) were being monitored in the above reviewed studies.

Perhaps the most comprehensive study on mobile map app use that comes closest to the sample sizes that tappigraphy is designed for was conducted by Savino et al. (2021). With their developed wrapper app *MapRecorder* Savino et al. (2021) continuously monitored participants' interactions with the Google Maps app on their own smartphones (e.g. coordinates of map screen touchpoints, type of touches, keyboard inputs, changes of map zoom level or map display centre, etc.). MapRecorder requires participants to instal this wrapper app on their smartphones, and to be willing to use it over the native Google Maps app. As in previously reviewed studies above, only a small sample of 28 participants familiar with their environment in total used *MapRecorder* for four consecutive weeks. While the number of participants was relatively small compared to our tappigraphy study, this is justified by their specific aim to focus on usability issues and compare residents and tourists in a given location. The average number of Google Maps sessions per participants in the 'local user' sample was only 15, and their Google Maps app session had a duration of 65 seconds on average. The second sample comprised 60 tourists who used the *MapRecorder* app for one single day. The average number of sessions per tourist was 19, and their map app sessions lasted on average 52 seconds. The authors identified four typical Google Maps app use types: *map-view manipulation*, *directions*, *place*, and *search*. The proportion of map use types for local participants was 67.5% for *map-view manipulation*, 21.1% for *direction*, 8.2% for *place*, and 3.2%

for *search*, which had great similarity with the tourist sample. Local Google Map users had a typical app use type sequence of *map-view manipulation – search – place – direction*. This sequence and the large proportion of *map-view manipulations* suggests that for local Google Map app users, a central characteristic of Google Maps use is of exploratory spatial search behaviour, such as zooming and panning the map app. Additionally, logging text input and thus revealing actual search terms offers potentially deeper insights into the purpose and context of a de-facto standard map app use. This, however, also raises critical privacy issues, especially if the map app is of commercial nature, and aimed for economic interests. This hinders the scalability of such a targeted wrapper approach for empirically studying a large and diverse user sample, and limits open science research.

Next, we present the design, deployment, and analysis of a first tappigraphy study with more than 100 users, focusing on smartphone touch interactions related to map apps, and conceptualised as a steppingstone for studying map use behaviour.

3. Map app tappigraphy study design and deployment

Unlike the above reviewed app user studies, we take a quite different user monitoring approach. Specifically, we do not invite participants to a research lab to be given a pre-loaded phone to take home to use. We also do not ask participants to perform specific tasks either at home, in a controlled lab environment, or remotely online. Our approach lets participants naturally live their everyday lives in their own settings, using their own smartphones whenever and for whatever they wish, while we continuously record their smartphone tapping behaviour. We do not know who the participants are, why they participate, where they live, or any other personal information, except that they allow us to track their smartphone touches with their informed consent. This very naturalistic study setting comes with great benefits of high ecological validity and large user sample recruitment, but at the cost of information parsimony, thus no further knowledge about the users, and limited experimental control.

The map app data showcased below in our first case study of map app use is a secondary use example of smartphone tappigraphy data (Balerna and Ghosh 2018; Borger, Huber, and Ghosh 2019; Ghosh, Pfister, and Cook 2017; Huber and Ghosh 2021). As mentioned earlier, tappigraphy relates to the inobtrusive, almost continuous, in-situ recordings of smartphone touchscreen events without any direct interactions with the user. In a classic tappigraphy campaign, a smartphone user is tracked for weeks and month, and their taps initiated for various reasons on the smartphone screen, in different periods of times, and within many smartphone sessions are continuously recorded at high temporal resolution (i.e. in the range of milliseconds) without any direct interactions or observation by experimenters. In contrast to lab experiments or field studies, tappigraphy is a form of ambulatory assessment, i.e. a device-supported recording of human behaviour in everyday activities. Of course, tappigraphy can complement existing well-known monitoring methods being used to study human-map interactions, such as interaction logging, video tracking, eye-tracking, or similar.

As tappigraphy data are continuously recorded over a long campaign period, the combined data collection from the University of Zurich and Leiden University was frozen in August 2018 for this study. Specifically collected tappigraphy data for this case study ranges from 2014 to 2018.

3.1. Participants

Participants were recruited via on-campus flyers and promotional emails at the University of Zurich and at Leiden University. Subjects who were not right-handed, healthy, or with any permanent hand injuries were eliminated (self-declared). All 211 participants included for analysis provided informed consent to the anonymously stored and shared smartphone data collection. The studies were approved by the Ethical Committee of the Institute of Psychology, and by the Canton of Zurich, enforcing the Swiss Human Experimentation Act. The first participant included in this analysis was recruited in January 2014 (from one of the authors). The raw data were gathered by the Cognition in the Digital Environment Laboratory (CODELAB), at Leiden University. For representative demographic information from a largely overlapping database at Leiden University (see Huber and Ghosh 2021). As the use of maps may be indicative of additional location services, to preserve user privacy any associated demographic information was eliminated prior to data sharing.

3.2. Materials

We applied the TapCounter app, provided by QuantActions in Lausanne, Switzerland, to collect tapping data. This app requires a smartphone with a touchscreen running on the Android operating system. This was an inclusion criterion for participation to which participants had to consent. The market share for Android operating systems from 2014 to 2018 was on average 58%, and for iOS 39%.[1] Once installed, the TapCounter app runs in the background and continuously records the name and timestamps of all touchscreen interactions on the app in the foreground of an unlocked smartphone. The recordings have an approximate error margin of 5 milliseconds. Only user taps to unlock and lock a smartphone, and the sequence of touches on apps in the foreground, that is, immediately used by the phone user, are recorded. This means that touches on apps such as Facebook, Twitter, or Google Maps are recorded, but no other data or information content is registered to assure the privacy of the user. Moreover, as individual app labels might allow identifying characteristics of individuals and possibly infringe their privacy, the individual app names were not used in the analysis.

3.3. Procedure

After providing anonymously informed consent through a website to be again anonymously observed, study participants were asked to download and instal the TapCounter app on their own Android smartphones. Participants were instructed to not share their smartphone with others during the campaign and to run the app for at least two consecutive weeks. All recorded data was assigned a unique user code, encrypted, and streamed to cloud storage, from where the data was later accessed through cloud-based services provided by the QuantActions platform.

3.4. Data and processing

The raw tapping timestamps were pre-processed and stored in MATLAB files using the parser *extractTaps* (QuantActions Ltd. Lausanne, Switzerland). For this pre-processing step, all taps were grouped into two app categories based on the type of app, i.e. map apps and all other apps. We categorised taps on map apps including *Google Maps*, *CityMaps2Go*, *Maps.me*, *Citymapper*, *MMApp*, and *MapMyRun*. The second category encompasses those we considered non-map apps. These two categories were coded with 1 for map apps, and 0 for other apps, respectively. The collected smartphone touchscreen timestamps were then extracted from the MATLAB files and loaded into a Postgres database[2] for further analysis. All tapping analyses were run in Jupyter Notebook,[3] using Python version 3.8.8.

Below, we show an extract of the raw tappigraphy data. The first column is a sequentially increasing unique ID to identify each tap, and the second column contains a participant ID (293), followed by a timestamp in seconds. The next column stores the tap type, i.e. 0 for unlocking, 10 for locking a phone, and 1 for any other tap on the smartphone within an unlocking and locking session. The last column holds the app category code, i.e. 1 for map apps and 0 for all other apps.

```
54476530,293,1521299792.768,0,0
26210380,293,1521299793.521,1,0
26210381,293,1521299797.427,1,0
55875211,293,1521299799.827,10,0
54476531,293,1521303003.902,0,0
26210382,293,1521303006.439,1,0
26210383,293,1521303007.082,1,0
26210384,293,1521303007.791,1,0
```

26,210,385,293,1,521,303,010.233,1,0
26210386,293,1521303011.603,1,0
26210387,293,1521303012.282,1,0
26210388,293,1521303016.718,1,0
26210389,293,1521303050.46,1,0
26210390,293,1521303063.754,1,0
26210391,293,1521303075.009,1,0
26210392,293,1521303081.619,1,0
26210393,293,1521303082.869,1,0
26210394,293,1521303092.675,1,0
26210395,293,1521303121.852,1,0
26210396,293,1521303146.705,1,0
26210397,293,1521303161.935,1,0
26210398,293,1521303204.943,1,0
26210399,293,1521303241.82,1,0
55875212,293,1521303302.458,10,0

Once participants activated the TapCounter app on their smartphone, all taps were automatically recorded for the campaign period until the moment when users deactivated the app again (Figure 1). The tappigraphy data is structured by three different types of events: start (0) and stop (10) events that correspond to unlocking and locking the smartphone, defining a phone session, and all other tap events on apps in the foreground (1). A phone session may contain many, one or no taps at all, and they can be of varying durations. The unevenly spaced small dots in Figure 1 represent a sequence of display touches, i.e. the continuous sequence of taps by a user.

3.5. Results

Returning to the fine-grained map app use questions posed in the introduction: *How much do people use mobile map apps in everyday life? When and for how long do people use mobile map apps? How do people use mobile map apps?* we structure the answers to those questions in below results section.

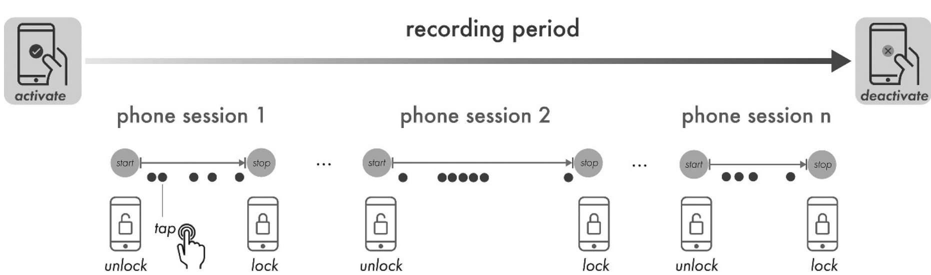

Figure 1. Structure of tappigraphy data: the black dots symbolise individual taps on the display within phone sessions.

3.6. How much do people use mobile map apps?

For analysing how often people use mobile maps we only included 170 participants (80.6%) out of the total of 211 participants who tapped at least once on a map app during their monitoring period. Map taps were defined as smartphone touches on an app categorised as 'map app' used in the foreground. The total number of map taps for our sample was 256,397 (0.7%), compared to 36,241,971 taps (99.3%) on other (non-map) apps. A total of 41 participants (20%) never used a map app during the data collection campaign, which, on average, lasted 55 consecutive days. The number of map taps per participant ranged from 1 to 21,433, on average 1,508 taps, with a standard deviation of 2,647 taps. However, as the recording period varied considerably between participants (7–430 days), we assumed the larger number of map taps for some of the participants to be the result of longer total use time (Figure 2, left).

To compensate for this effect, we normalised the raw map tap counts by the total use period duration for each participant. The histogram (Figure 2, right panel) shows the normalised map counts as the number of map taps per total use time. Note that we excluded 11 outliers with more than four map taps from the histogram to increase legibility. Almost 50% of the participants tapped fewer than 0.5 times per hour on a map app over the entire recording period (Figure 2, right panel).

Overall, the total numbers of map taps were very low. We thus interpret this as map app use is rather scarce in monitored participants' everyday life. On average, map taps accounted for only 0.89% of all taps. In other words, non-map app taps far outnumbered map taps and support the infrequency of map app use for our studied population. The overall extent of map app use revealed insights into everyday mobile map use behaviour, particularly the scarcity of map app use, compared to other apps used on smartphones.

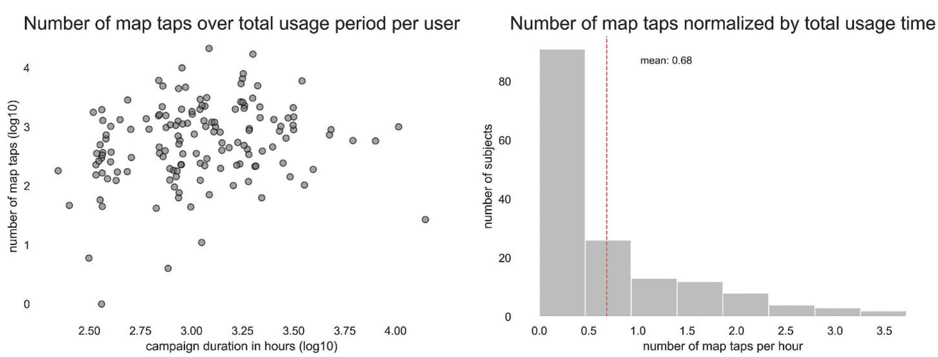

Figure 2. The number of map taps across participants greatly varies due to different lengths of campaign periods (left panel); most participants had very few map taps; on average map apps overall were used only once (right panel).

3.7. When and for how long do people use mobile map apps?

Next, we wished to investigate temporal patterns of mobile map use and how the frequency of map use is distributed over participants' hours of their day, and days of the week. The average number of map taps over a whole day showed a clear day-night pattern (Figure 3). From 7 am the average map tap numbers steadily increase with a first peak of about 100 taps around 1 pm (highlighted in red). The highest average number (113 map taps) was observed around 5 pm (highlighted in red). After that, the numbers of map taps dropped slightly before they became significantly lower from 10 pm onwards. Between 2 and 6 am they fell below 10 map taps.

Extending our analysis to a whole week, we can observe a weekly use pattern (Figure 4). The aggregated number of map taps showed a clear day-night pattern over the week with noticeable peaks around midday and in the early evening. The pattern appeared very uniform, and weekdays and weekend days did not substantially differ in the number of map taps. Looking more closely at the aggregated numbers of map taps over the course of a week, we can detect the highest numbers of map taps occurring on Thursday evening; Friday afternoon, and early evening; Saturday around noon; and on Sunday afternoon (Figure 4). On Saturday, the number of map taps was again lower and more in the range of the Monday to Wednesday pattern. Moreover, the peaks around midday and early evening were not as distinct compared to the pattern during the rest of the week.

Different map use frequencies over time suggest that there may also be different modes of map use, e.g. a longer series of map taps when looking up a location and planning the route to that location, versus one short map tap to confirm the current position. Aside from the question of how much and when people use map apps, we further extend our analysis of map app touches to explore how map apps are used by studying the sequences of map taps within phone sessions (see Figure 1).

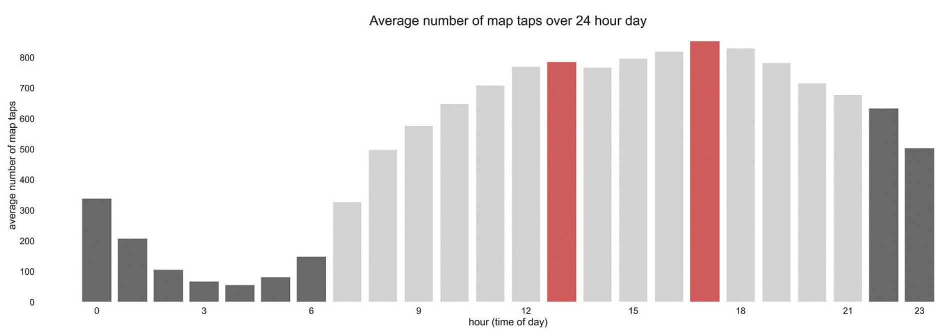

Figure 3. The map taps followed a day (light grey) night (dark grey) usage pattern and showed clear peaks around lunch (13h) and before dinner time (18h) (red bars).

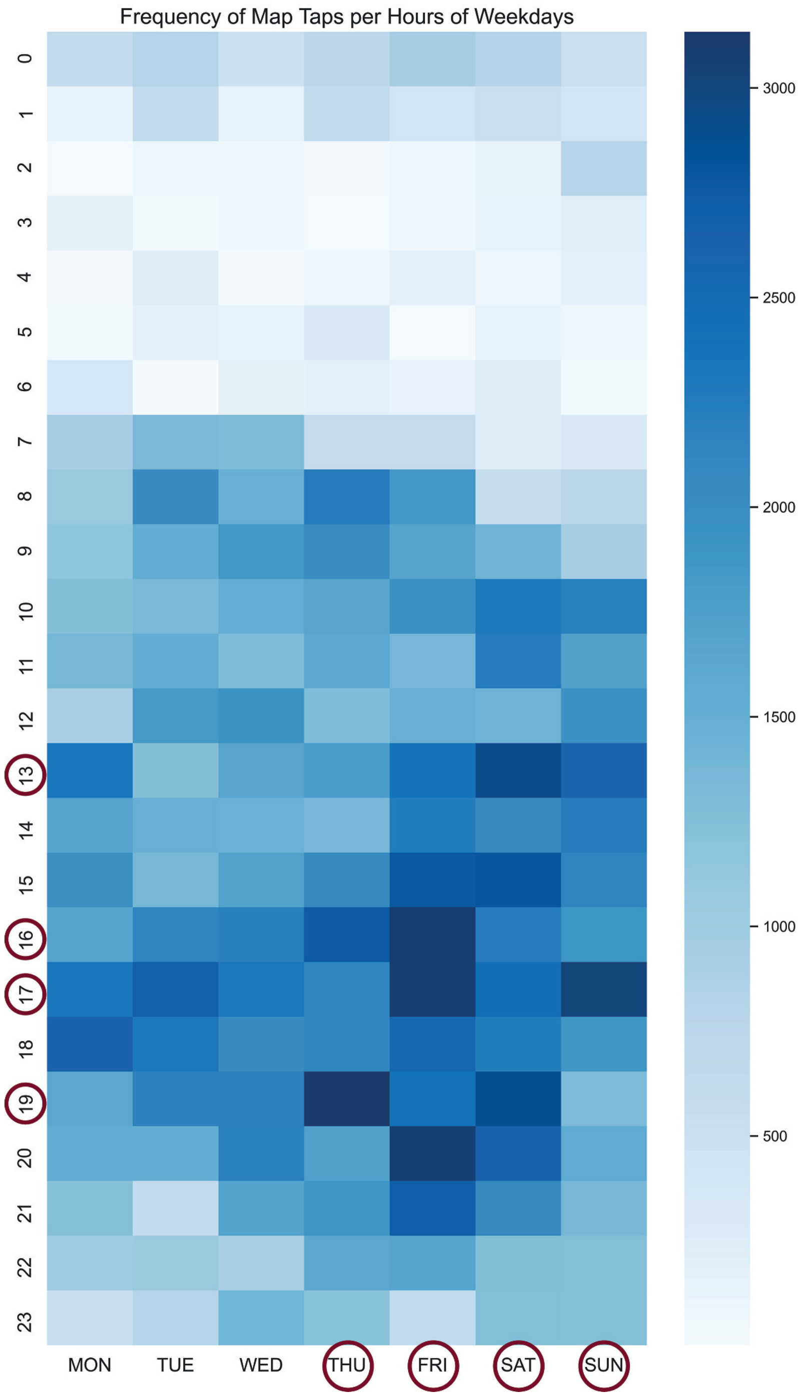

Figure 4. The weekly pattern showed the highest map tap numbers per hour (dark blue cells) mainly in the afternoon and evening hours of the weekend (Thursday to Sunday).

3.8. How do people use mobile map apps?

As mentioned earlier, a phone session was defined for our study as the time span between unlocking (start) and locking (end) of the smartphone screen. We found a total of 453,452 such phone sessions in our collected dataset.

Analysing map taps at the level of individual phone sessions allowed us to study map tapping behaviour in more detail. Our intention was twofold. First, as we can determine from the daily and weekly pattern of map taps (Figures 3 and 4), there were longer periods with no touchscreen events at all, for example during the night when participants are sleeping. Tap sequences thus seem more likely to happen within brief and distinct periods of times, during the day/week. We also contend that most map use tasks require more than one single map app tap, and thus the analysis of map use behaviour should lend itself to analysing multiple taps and characteristics of such tap sequences at various levels of granularity, including a single phone session.

The histogram of map phone session duration shows a similarly skewed distribution (Figure 5, left panel) as the overall number of recorded map taps (Figure 2, right panel). Note that we removed 680 outliers with phone session duration of 20 minutes and longer from the histogram to increase legibility. From the remaining 9830 phone sessions, about 40% had a duration of equal to or less than 60 seconds. Most phone sessions with map taps had a duration between 0 and 1200 seconds, i.e. approximately 20 minutes. If we compare these numbers with the duration of the phone sessions containing taps that were not related to map apps, we observe a similar distribution, although with 442,942 non-map app tap sessions, the magnitude was significantly larger.

To differentiate between possible use modes of map apps (e.g. map use for planning, map use while navigating), we needed to consider the frequency of taps within map phone sessions. The histogram of map taps per map phone session showed that almost 50% of phone sessions with map taps had fewer

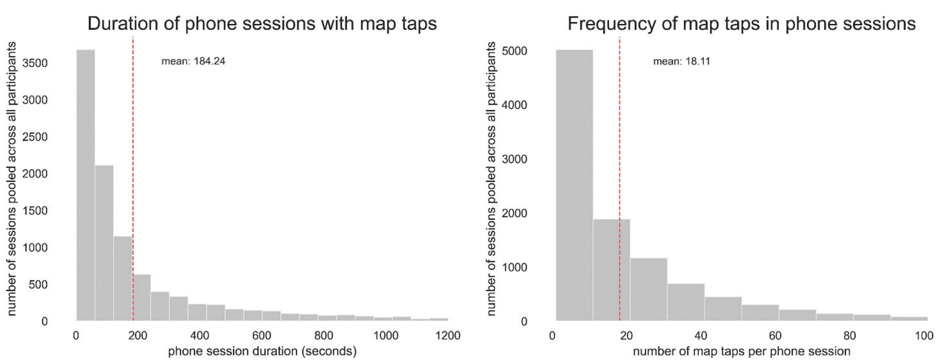

Figure 5. The majority of the 9830 map tap phone sessions had a duration of fewer than two minutes (left panel); about half of the 10,001 map tap phone sessions had no more than 10 taps (right panel).

than 10 taps per session (Figure 5, right panel). Please note that we removed 399 outliers with more than 100 map taps per phone session for a better legibility of the histogram. The frequency of taps in phone sessions with other app taps was higher, on average 52.89 (SD 78.08), and with a maximum of 434 app taps. It is noteworthy that the average number of other taps per phone session was almost three times higher than the number of map taps. If we study the cumulative distribution function (CDF) for the number of taps in map app sessions compared to other app sessions, we notice some differences between the two groups, particularly for numbers of taps per phone session below 1000 (Figure 6).

Despite these differences, the data for the two groups appeared to have a similar distribution. A Kolmogorov-Smirnov test (D: 0.21; $p = 0$) showed that the two samples did not come from a population with the same continuous distribution. For the number of taps per phone session below 1000, the cumulative probability for map taps was higher than for other, non-map taps.

We also plotted the CDF of the duration of map sessions against other app sessions (Figure 7). Note that the right plot in Figure 7 depicts the same data as in Figure 7 left panel, but on a log scale.

A Kolmogorov-Smirnov test (D: 0.162; $p < 0.01$) revealed that the two samples were not based on the same distribution. In phone sessions up to 30 minutes, the cumulative probability for a non-map phone session was higher than for a map app phone session.

We also analysed the frequency and distribution of taps within map app sessions to get a better understanding of different types of map app uses. First, we grouped participants according to their session duration and the frequency of taps within phone sessions to achieve a discrimination

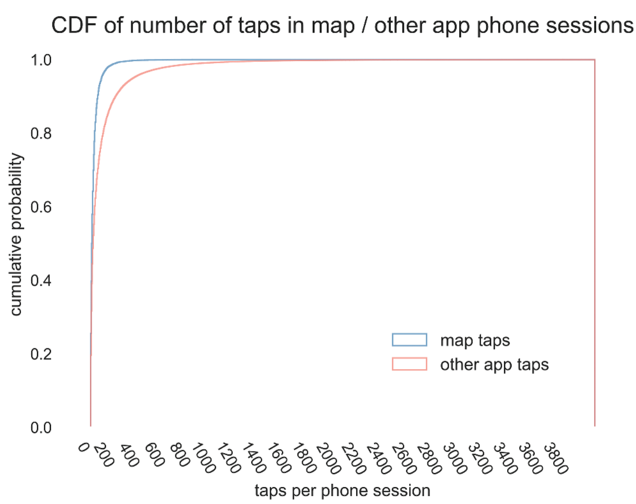

Figure 6. The probability for low number of taps and map taps per phone session is significantly different.

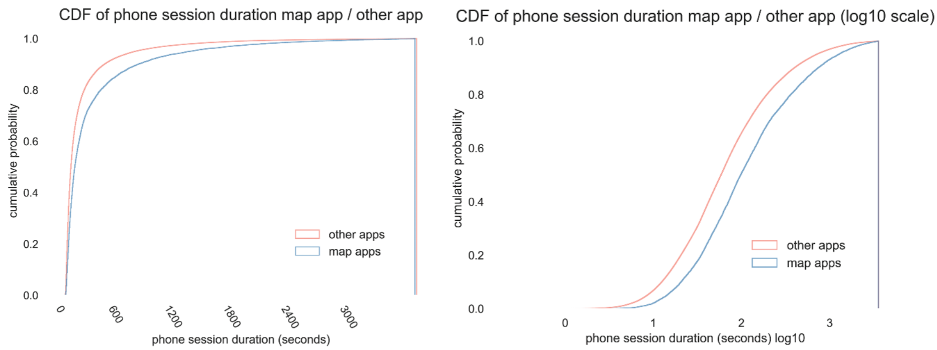

Figure 7. CDF for the duration of phone sessions with map app taps and other app (left panel) and in log scale (right panel).

between heavy and light users. For our sample, the average phone session duration was 5 minutes and 51 seconds. The average number of map taps was 24.4. To exemplify these different user types, we next look at two distinct participants.

The touch data of participant 13, for example, had an average phone session duration of 2 minutes and 16 seconds, with on average 20.35 map taps. At the other end, participant 87 had an average phone session duration of 12 minutes, and on average 18.75 map taps. Figure 8 shows the distribution of map taps within all app sessions. For participant 13 (Figure 8, left panel) there were many map taps at around 5% of the app session, and the maximum number of map taps is reached between 15% and 20%. The density then decreased, reaching the minimum at around 70%. The number of map taps increased again between 70% and 90%, and after 90% of an app session, there were fewer map taps in an app session. Figure 8 (right panel) shows a different distribution of map taps within app sessions for participant 87. This participant had many map taps at the beginning and towards the end of an app session.

Figure 9 shows the ten app sessions with most map taps of participant 13 (left) and participant 87 (right). Each row represents one app session from 0% (first tap on a map app) to 100% (last tap on a map app) and every stroke represents a single map tap within the app session. The app session lengths are thus normalised to an interval between 0% and 100% of the app session length.

For participant 13 (Figure 9, left panel) we can observe accumulations and clustering of map taps in app sessions 1, 5, 6, 7, and 8, particularly at the beginning of an app session, followed by fewer or no map taps, but then again, a cluster of outbursts at the end. In app sessions 2, 3, 4, 9, and 10, the map taps of participant 13 were very homogeneously distributed over the whole app session length and there was almost no clustering of map taps. App sessions 1 and 6 were special, since map taps were exclusively clustered in

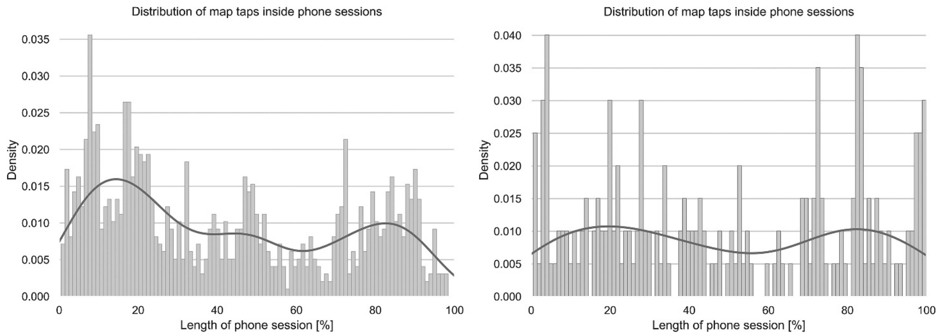

Figure 8. Kernel density estimation of map taps of all app sessions of participant 13 (left panel) and participant 87 (right panel).

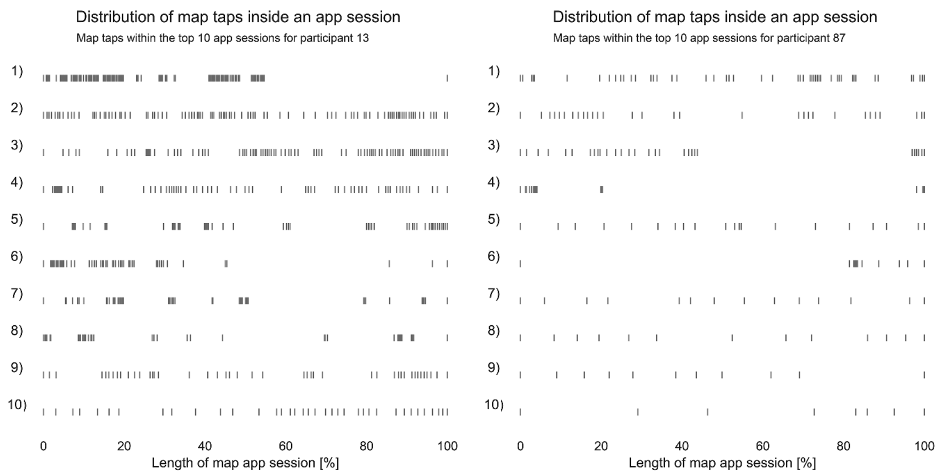

Figure 9. Distribution of map taps within the top 10 app sessions for participant 13 (left panel) and participant 87 (right panel). App session lengths are normalised to an interval of 0 to 100% of app session length and each tally mark represents a map tap within the respective app session.

the first half of the session, while the second half of the app session showed no map taps. There happened only one map tap for session 1, and three map taps for session 6 again at the very end of the app sessions.

Figure 9 (right panel) shows a fairly homogenous distribution of the top ten app sessions with the most map taps for participant 87. The map taps were distributed in almost regular intervals over the map app session. Exceptions were app sessions 4 and 6. App session 4 showed a concentration of map taps at the beginning of the app session. Thereafter there was a short period of no map taps followed by a small clustering of a few map taps after 20% of the app session duration. Then, there were no map taps until the very end of the app session. App session 6 showed almost the opposite pattern. There was a single map tap at the beginning and then a gap until 80% of the app session length, followed by a few map taps towards the end of the map app session.

4. Discussion

The goal of our long-term empirical research programme is to study how often, how much and in what ways people use mobile maps in their everyday lives. *With the science of tappigraphy – the quantification of smartphone touchscreen interactions – we aimed to capture of a continuous data stream of behavioural human-map app patterns remotely, underlying daily life.*

Our tappigraphy results based on map taps of 170 participants recorded during their everyday activities were in line with reported, aggregated publicly available app download statistics, and confirm, indeed, that map use of observed participants was rather sparse compared to the use of other apps on their smartphones, such as their social media consumption, chat, or gaming app uses.

On the one hand, we find that the proportion of our observed map taps over all taps was on average less than 1%. We may interpret this as map apps to be used very infrequently, and thus acknowledge the significantly greater popularity of non-map app use. On the other hand, one might also consider that observed non-map apps, for example, relating to communication or gaming might simply require far more taps during use. This can include typing for sending a text message, commenting on a social media post, or controlling the course of a game with keys or fingers. Given that Fonseca et al. (2021) report, 57.9% of their sample were non-map app users, and of the 42.1% map app users, only 25.1% used the map apps daily our map app numbers probably also support relatively sparse map use. This is in line with Böhmer et al. (2011), for instance, who report an average smartphone use time of 59 minutes per day, and average app use duration of Google Maps and Waze of 45 seconds, which corresponds to a proportion of 1.27% of total use app use time, on average. Infrequent map use statistics could also be a result of a narrow categorisation of map apps, for example, only apps that contain the Android store app label 'map'. Although travel support apps, real-estate apps, navigation support apps, and tourism apps might heavily rely on maps, they might not be directly labelled or categorised as a 'map' app. The more detailed labelling of map apps monitored on participants' smart phone will have to be considered for future tappigraphy studies.

Aside from the overall small number of map taps observed, we did find a meaningful temporal distribution over the course of the day and the week. For the daily map app use, we find a map tap peak around 5 pm, thus at a time of the day when most people end their work. It is not yet clear why the time of the evening commute might be so different from the morning commuting period when considering map taps. Possibly, the evening commute leads to more potentially novel destination options. That is, other than the well-known work-to-home route for users, perhaps allowing for less planned leisure activities into locales that might be less known or infrequently used. Interestingly, general smartphone-based proxy measures of cognitive performance such as tapping speed or app-locating speed also peaks at around 5 pm (Huber and Ghosh 2021). This might suggest that it is also a good time for performing spatial tasks with map apps.

While this general app use peak around 5 pm is also suggested by Böhmer et al. (2011) and is also evident in our data, their study also found a peak of app use in the category travel at 5 am, probably indicating the beginning of the morning commuting period (Huber and Ghosh 2021). As mentioned earlier, it would be useful in a future tappigraphy study to disentangle apps that are not labelled as map apps, but potentially also include maps such as travel apps, etc. to get deeper insights on map app use throughout the day.

For the weekly cycle, we observed a systematic, periodic pattern of map taps mostly outside of the work week, suggesting map apps are predominantly used for leisure activities, similarly to the 5 pm peak in the day analysis. Map taps peak on Thursday evening, Friday afternoon and evening, and Sunday noon. These kinds of leisure activities are likely to require more spatial planning and wayfinding than routine activities during the workday and weekend. As for the daily frequency pattern, the morning commute did not show a high frequency of map use, while the late afternoon and evening hours showed higher map use frequencies. Perhaps people use different apps (e.g. communication, news, games, social media) when commuting in the morning, compared to evening leisure planning when they are leaving work.

We find that phone sessions with map taps were on average more than 50% longer than those containing other app taps. In contrast, Böhmer et al. (2011) found that the average app use time in the travel category which often included maps or a map interface to travel content, was 50% shorter than the average app use duration. This difference could be explained by a different conceptualisation of what a use session is, and points to the difficulty of comparing results across published user studies. Böhmer et al. (2011), for instance, defined a session as an app use session, that is, as the duration between starting and closing one single app. In contrast, our phone session concept, bound by unlocking and locking the smartphone screen, could include the consecutive use of several apps, and therefore, overall, a phone session may, by definition, take longer. Regarding the frequency of taps per phone session then, we observed that sessions with no map taps at all contained, on average, almost three times more taps than phone sessions with map taps. We interpret this that phone sessions with higher numbers of taps more likely fall into the category of social media apps, chat/communication apps, or gaming apps, as they usually include larger portions of typing for text entries, which in turn comprise numerous short taps. Our findings suggested that map app sessions might take longer in time, but typical map app tasks can be achieved with fewer taps overall such as leaving a map app running for continuous self-localisation while navigating.

The distribution of map taps within app sessions (Figures 9 and 10) revealed distinct tapping behaviours for two participants, suggesting different map app use types. While participant 13 showed clusters of map taps over a session, participant 87's map tap distribution was quite homogenous with equal intervals between taps. A possible interpretation of this distinct distribution could be that participant 13 changed the extent and the scale of the map to search for and identify locations on the map resulting in more clustered map taps. On the other hand, the behaviour of participant 87 could reflect another type of common map app use, where a navigator regularly checks their current position on the map display during wayfinding to ensure being on the right track during navigation.

Although our empirical results were based on a relatively large sample, both with respect to participant numbers and observation length, compared to similar user studies in the wild (i.e. Banovic et al. 2014; Carrascal and Church 2015; Do, Blom, and Gatica-Perez 2011), there are also limitations to our first tappigraphy study. First, the TapCounter app was available for the Android operating system only. As Apple Maps had at the time of our study an estimated overall market share of 10%, we might have missed out on a relevant share of potential users, and possibly a relevant user pool for tappigraphy analyses on map apps. The data source used here came from recruitment drives performed at university campuses and was thus dominated by student populations. Different recruitment strategies

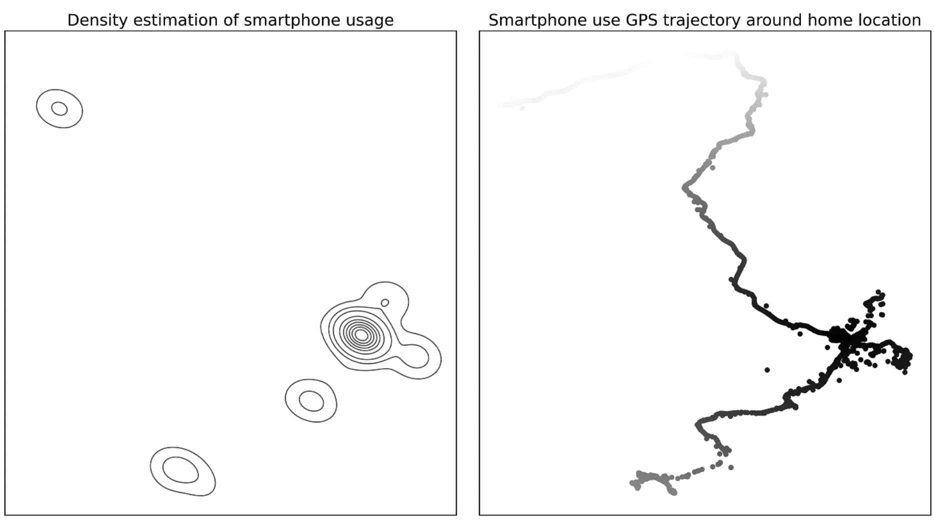

Figure 10. Kernel density estimation of taps from a participant in geographic space (left panel); taps along a recorded GPS trajectory around home location (right panel).

could be considered in future to include a broader and more inclusive study population. What is more, the data collection period from 2014 to 2018 might not reflect the latest developments in technology. Technological advancements, such as larger screen sizes of smartphones, the roll-out of 5 G cellular networks, improvement of Wi-Fi accessibility and the arrival of new map apps on the market including voice-assisted map interfaces (e.g. Siri and Alexa) or AI technology could possibly influence map use behaviour in the future and serves as a motivating source for future tappigraphy studies. Moreover, at this stage of the project we had predominantly analysed recorded taps as events within a phone session (see Figure 2). That is, the way we defined the phone sessions may not only have an influence on our reported results, but also limit comparison with other similar studies found in the literature. One could also aggregate individual taps first to individual app sessions within a phone session, as shown in Figure 10. By introducing different data analysis granularities, different map use behaviour patterns might emerge, which would allow the study of contextual embedding of map app use in a sequence of other app uses within a phone session. It would be interesting to further explore what kind of apps precede or follow map apps uses. Another limitation of the tappigraphy method is that it will not distinctively capture map use behaviour that includes no haptic interactions. For example, if a user is using a mobile map for navigation, traffic status information or self-localisation by only gazing at the smartphone screen, it will likely not be detected if tappigraphy is used as the only method. Finally, the next obvious step by researchers interested in the spatio-temporal context of map app use would be to capture and analyse taps in geographic space and over time to answer the key geographic question: *why there* and why *then*? Answers to these questions would support a deeper understanding of map use patterns in the context of human mobility.

To move in this direction, we are in the process of leveraging a powerful combination of tappigraphy with other data channels including map app use location. In the context of a novel geo-tappigraphy approach, we are currently collecting map use behaviour data with a modified version of the TapCounter app that also records spatial data, including the smartphone's geographic location, and the acceleration parameters of monitored smartphones.[4] In doing so, we wish to extend current, mostly temporal, analyses of map use behaviour to spatially dependent map use behaviour. This will allow us to gain further insights of where, when, and in what kinds of situations and environmental contexts mobile maps are used, thus linking map taps directly to geographic space, and to mobility analysis. Figure 10 shows as an example the plot of a participant's taps in geographic space as a kernel density estimation (left panel) and the taps around the home location along a movement trajectory from GPS locations (right panel).

5. Summary and future work

Taking advantage of tappigraphy borrowed from cognitive neuroscience, we set out to study mobile map app use in our everyday life. By using a tappigraphy dataset gathered from a large Android user base, we unobtrusively observed the frequency, timing, and mode of ambulatory map app use in-situ, with participants' own smartphones and in participants’ everyday environment. We identified clear differences between the use of map apps compared to other apps. Our results confirm a scarcity of map app use compared to all other apps, as suggested by aggregated app download statistics and related prior research. Going beyond aggregated download statistics, our approach allowed us to uncover a distinct diurnal map app use pattern, that closely followed people’s day-night rhythms. Also, we observed peaks of map use in the early evening hours and at weekends, typically leisure time periods. Moreover, we found that tapping behaviour during phone sessions with map apps was significantly different from non-map app phone sessions, both with respect to their duration and the frequency of taps within the sessions.

We wish to further extend the analysis of typical map use behaviour to specific use contexts and purposes, for example, for planning leisure activities, for spatial searches of environmental features, during navigation and wayfinding in familiar environments, or for exploring unfamiliar environments. We also hope to recruit a broad mix of mobile map users in the future to study potential group differences (e.g. gender and age), and individual differences (e.g. spatial abilities and attitude) in everyday mobile map use. And finally, we intend to align and combine the tappigraphy method with other, traditional user analysis methods from HCI and cartography (e.g. interaction logging and usability analysis) to capture a wider range of map use interactions, including non-tapping interactions and voice interfaces such as Siri or Alexa.

Notes

1. https://www.statista.com/statistics/640039/market-share-mobile-operating-systems-netherlands/.
2. https://www.postgresql.org.
3. https://jupyter.org.
4. https://www.geo.uzh.ch/microsite/mapontap.

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Disclosure statement

Arko Ghosh is a co-founder of QuantActions Ltd, Lausanne, Switzerland. The company focuses on converting smartphone taps to mental health indicators. For this research, software and data collection services from QuantActions were used to monitor the smartphone activity of participants.

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