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The impact of COVID-19 on daily lives of transnational people based on smartphone data: Estonians in Finland

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ABSTRACT

Global crises such as the COVID-19 pandemic affect both the functioning of our societies and the daily lives of people. Yet the impact of the crisis and its mitigation measures have exerted disproportionate influence on different population groups. In March – May 2020, COVID-19 mitigation measures such as closures of national borders affected transnational people who cross borders frequently for work, shopping, services, family reasons and socialising. We have examined the influence of the COVID-19 pandemic on the daily lives of transnational Estonians residing in Finland, based on a unique longitudinal smartphone tracking survey. Findings show that besides a drastic but expected decrease in trans-nationals' spatial mobility, the pandemic has especially affected their cross-border mobility patterns to and time spent in Estonia. Interestingly, during the lockdown, some transnationals decided to stay not in their primary home in Finland, but in Estonia. Mobile phone communication activity followed moderately the downward trend of spatial mobility, but the crisis changed the division of communication partners by country: Finnish contacts diminished, whereas Estonian partners remained active. We reflect on our findings for future research and discuss the applicability of the smartphone tracking approach for capturing the socio-spatial interactions of transnational people.

1. Introduction

The global coronavirus (COVID-19) pandemic (Dong, Du, and Gardner 2020) has changed how our societies function. Most evidently, COVID-19 has had an enormous impact on our daily spatial behaviour and ways of communication. As the virus is transmitted through close contacts between people, and people's spatial behaviour is the prerequisite for their face-to-face interactions and social activities, the mobility of people is seen as a threat of virus spread. Thus, the

most prevailing COVID-19 containment and mitigation measures aim to limit the mobility of people and close contacts between them (Hsiang et al. 2020).

In spring 2020, most countries restricted or banned international travel by closing country borders and halting passenger traffic. Several countries used national containment measures by isolating certain geographical regions to control local outbreaks. Further, governments in several countries took drastic measures in limiting the daily lives of people by temporarily closing factories, schools, retail shops, eating and entertainment facilities, and enforcing curfews. People were strongly advised or even ordered to work from home, while social gatherings and face-to-face interactions were banned for both professional and leisure purposes.

COVID-19 has had a disproportionate effect on some population groups compared with others, particularly the elderly, people with poor health, and people with higher exposure to others (Dingel and Neiman 2020; Robinson et al. 2020; Yaya et al. 2020). Moreover, the changes engendered by various containment and mitigation measures have exposed and deepened existing inequalities (Kullar et al. 2020; Yaya et al. 2020), but also revealed new vulnerable groups (Robinson et al. 2020). For instance, mobility restrictions place homeless people and families living in inadequate housing conditions in an invidious position (Mendes 2020). The orders forcing people to stay at home have increased alcohol consumption (Da, Im, and Schiano 2020), and domestic violence against women and children (Chandan et al. 2020). While people with higher education and white-collar office workers were able to switch to remote working, blue-collar employees had to work on-site and risk being exposed to the virus (Dingel and Neiman 2020). At the same time, the notion of togetherness has increasingly been used in international and national calls to combat the crisis. However, its practical implementation is largely based on an in-group solidarity that neglects more vulnerable groups such as the poor, refugees, and the marginalised, and therefore risks deepening already existing social divides (van Uden and van Houtum 2020).

Measures such as tightening border control and introducing self-isolation requirements for incoming international travel critically affected people whose lives involve crossing national borders. Preliminary surveys indicate that cross-border travel decreased by up to 80% since the start of the COVID-19 pandemic (Lara-Valencia et al. 2020). Refugees and asylum seekers were trapped at borders due to tightening immigration regimes (Jauhiainen 2020a), while in times of uncertainty, return migration to a home country increased among people living abroad temporarily (Asis 2020). People with temporary but recurrent work and study-related migration patterns were forced to choose between home and work, and in extreme cases, were not even able to reach their workplace abroad (Charles 2020; Guadagno 2020). People with high work-related mobility, such as professional athletes, scholars, artists and business people working in transnational corporations, but also people with lifestyle-led mobilities and location-

independent work (Hannonen 2020), had to put their travel on hold (Bowes, Lomax, and Piasecki 2020). Not least, border closures and self-isolation requirements affected transnational people whose daily lives are not confined to a single country. For instance, in the European Union (EU), there are about two million cross-border commuters, whereas 150 million people live in cross-border regions and are usually able to cross borders for daily shopping, leisure and recreation, meeting friends, and attending social events (European Commission 2017).

Put differently, both transnational people and cross-border communities are vulnerable to disruptive global changes. The COVID-19 crisis is a good example of this, as the closure of national borders during the first wave of COVID-19, neglected and sacrificed the well-being of transnational people for the sake of national interest. In contrast, borders remained open for cargo, as the importance of the international economy was acknowledged. However, the rapid decisions on limiting the mobility of transnational people may have long-term consequences, such as dysfunctional cross-border communities that have been built over decades, such as those in the Danish-German border region (Klatt 2020) and the Greater Region of Luxembourg (Hesse and Rafferty 2020).

We have a well-established research tradition and knowledge about migration and tourism, but transnational people and their concurrent cross-border practices are less known. This has led to the neglect of transnational people and their wellbeing in (national) policies and regulations. Lack of knowledge about transnational people is driven mainly by limited data availability – their complex activity spaces and social practices across national borders are a challenge to reveal and study using traditional data collection methods. However, recent studies (Blanford et al. 2015; Silm et al. 2020) indicate that novel big data sources such as mobile phones, social media platforms, credit cards, and customer loyalty cards could narrow this knowledge gap. One method for providing more nuanced understanding about the daily lives of transnational people could be a longitudinal smartphone-based tracking approach, which would enable researchers to record individuals' spatial behaviour and social interactions on a daily basis over a prolonged period (Licoppe et al. 2008; Molloy et al. 2020).

In this study, we made use of a unique smartphone tracking study that started well before the COVID-19 crisis involving data on the spatial mobility and social interactions of transnational people over a prolonged period. Our case study focuses on Estonians who live in Finland according to the official residential registry, but are strongly connected to both countries. We examined their daily lives before, during and after the COVID-19 outbreak in spring 2020, by seeing how the COVID-19 crisis influenced their 1) spatial behaviour, 2) cross-border spatial behaviour, and 3) social interactions.

Our aim in this paper is to provide new insights about the impact of COVID-19 crisis on the daily lives of transnational people from the perspective of their

spatial behaviour and social interactions. By using the smartphone-tracking approach for data collection, our aim was also to evaluate its applicability for capturing the socio-spatial interactions of people who are difficult to examine using traditional data sources, such as transnational people.

2. Related work

2.1. Transnational people and COVID-19

The constant mobilities and interactions of everything – people, objects, information (Sheller and Urry 2006) – that crosses nation-state borders and relates to the global network society (Castells 1996) have proliferated the phenomenon of transnationalism (Vertovec 2009). Broadly speaking, transnationalism is about cross-border relationships, affiliations and belongings, processes, and the maintenance of social practices and formations that transcend national borders. The main body of research on transnationalism is linked to transnational people – people whose social relations and practices take place in, and/or whose notion of belonging, loyalty and identity is linked to, more than one nation-state (Levitt and Glick Schiller 2004; Vertovec 2001). Transnational people are mainly considered migrants (Levitt and Jaworsky 2007), but increasingly attention is given also to skilled professionals, transnational elites and (im)mobile cosmopolitans (Glick Schiller and Salazar 2013), digital nomads (Hannonen 2020), border surfers (Terlouw 2012), and cross-border commuters (Gerber 2012; van Houtum and Gielis 2006).

Social relations and practices, and the belonging of transnational people, have mainly been examined from economic, religious, cultural, social, legal and political perspectives (Vertovec 2009). Certainly, scholars have recognised the importance of the spatial perspective in studying transnational people (Levitt and Jaworsky 2007), calling attention to the linkage between physical transnational mobility and engagement with the sending/receiving society (Dahinden 2010), and to individuals instead of flows of transnationals (Dunn 2009). Several studies focusing on daily cross-border commuters have been undertaken in the Greater Region of Luxembourg (Drevon et al. 2016; Gerber 2012). Studies indicate that transnationals have widely varying strategies for managing their daily lives across borders (Gerber 2012). The recent study by Silm et al. (2020) reveals how transnationals living between Finland and Estonia exhibit various weekly and seasonal cross-border mobility patterns.

However, little is yet known about the geographies of habitual cross-border mobilities and the social interactions of transnationals, and how these affect cross-border communities (Gerber 2012; Terlouw 2012). This not only undermines the fuller understanding of the integration processes of transnationals (Spencer and Charsley 2016) and the functioning of transnational spaces (Allmendinger and Haughton 2009), it also hinders cross-border cooperation

and governance of functional border regions, and causes mismanagement of functional cross-border regions in times of crisis.

The COVID-19 case demonstrates this vividly. In a preliminary survey among border experts (Lara-Valencia et al. 2020), nearly half the respondents agreed with the notion that border constraints and closures were decided without any consultation with neighbouring countries. The country borders were closed to people on an emotional and national security basis – 'the virus threat comes from outside' and 'our nation first' – without considering solidarity with all people (Klatt 2020; van Uden and van Houtum 2020). Anecdotally, country borders in the EU were closed and border control was (re)established only after the virus was already spreading within a country – when the focus ought to have been on identifying local virus hotspots and isolating infected people. Initial studies indicate limited impact of international travel controls on virus spread (Askitas, Tatsiramos, and Verheyden 2020), and even show that national border closures were the least effective policy at curbing the virus spread (Chinazzi et al. 2020).

Functioning cross-border communities were cut apart around Europe while only work-related cross-border commuters and returning residents were allowed to cross borders, with examples from the Danish-German border region (Klatt 2020), border regions around Switzerland (Willi et al. 2020), and Luxembourg (Hesse and Rafferty 2020). As a common feature, re-established border controls led to significant traffic jams, increased border crossing times for commuters and uncertainty for work. In extreme cases, working across the border was made almost impossible due to self-quarantine requirements for all border crossers, as in the case of the Finnish borders with Estonia (Yle 2020a). That said, other transnational people with motives aside from work were often unable to cross borders, including those who live in more than one home and have family across country borders, or whose routine practices such as grocery shopping, health services, and leisure and recreational activities take place on the other side.

2.2. The impact of COVID-19 on human mobility

Studies show how restricting or banning international travelling and imposing national containment measures changed the daily lives of people – their spatial behaviour and social interactions. At an individual level, individuals' daily mobility as well as their activity spaces (the extent of physical space one can interact with) decreased dramatically, such as in Austria (Heiler et al. 2020). Various sources have quantified sharp drops in routine spatial practices such as grocery shopping, visiting retail shops and recreational venues such as gyms and cinemas, and in particular workplaces (Google 2020; Green 2020a). Instead of being stranded at one's primary home during the COVID-19 lockdown, some people escaped from bigger cities to their second homes – seasonally-visited holiday home or another secondary home for

those living in more than one place and having multiple homes as 'anchor points' (Schier et al. 2015). This has been the case in Finland, at least (Järv et al. 2020b). The changed daily lives and decreased mobility of people also meant a significant decrease in transport use. For example, public transport usage dropped by 60 – 75% in Finland and Estonia in April 2020 (Apple 2020). Walking and private vehicle use decreased less in the given countries, but the decline was still 40% to 50% in April 2020. Similarly, in Austria, commuters' underground transit (*U-Bahn*) usage in Vienna dropped by 80% (Heiler et al. 2020).

Overall human presence in the busiest urban centres dropped by more than half. For example, city-wide comparisons in the UK show a drastic 50% decrease in the number of people across the biggest centres by the first five weeks of the lockdown (Wisniewska and Ehrenberg-Shannon 2020). In extreme cases, such as Rome in mid-March, the number of people moving within the city dropped by over 80% compared to mid-February (Green 2020b). After the lifting or easing of the restrictions, the mobility of people and their social practices have recovered to some extent (Apple 2020; Google 2020). Yet, the activity spaces of people have remained more concentrated than before the crisis, such as in Austria (Heiler et al. 2020). On the country-wide perspective, the structure of mobility flows of people changed as flows between regions within a country decreased, as in Italy (Cintia et al. 2020), and resulted in the formation of smaller connected communities, as in Austria (Heiler et al. 2020).

On a Europe-wide regional perspective, a comparison of human mobility in 15 countries shows how spatial behaviour has changed due to the containment and mitigation measures by country – from the least changes in Sweden to the most severe decrease of mobility in Spain and France (Santamaria et al. 2020). The overall tendency clearly shows the impact of the crisis on spatial mobility, while in most of the countries it had not recovered as at July 2020. Comparison studies, both between and within countries, reveal differences in recommendations and restrictions between the different national governments, but also regional variations, as in the case of presence of people at workplaces in the Nordic countries (Grunfelder 2020). Similar patterns emerge from a global perspective – daily mobility in 36 selected countries on several continents show similar trends, with some exceptions (Huang et al. 2020). Studies have found that the least rates of decrease in mobility until May 2020 were found in Russia and Australia, and the worst mobility-based responsiveness was in the US in March 2020 that led to a severe outbreak prior to government actions in April (Huang et al. 2020).

One noteworthy aspect in all the studies mentioned above, besides their univocal empirical evidence on changes in human spatial behaviour and social practices, is that all these studies relied on novel data sources. That is, the

COVID-19 crisis has been a global showcase to demonstrate the value of novel big data sources in tackling crises and promoting social good.

2.3. Novel data sources to reveal socio-spatial interactions of people

Novel big data sources have diverse characteristics (Kitchin 2014), whereas sources that provide information on people from spatial and temporal perspectives are also referred to as mobile big data (Poom et al. 2020). These sources range from mobile phone communication data (Cintia et al. 2020; Silm, Järv, and Masso 2020) and transactional smart card data (Zhong et al. 2014) to data collected through personal wearables, GPS tracking, and citizen science platforms (Kitchin and McArdle 2016). In recent years, location and human mobility data has increasingly been collected and used by global corporations such as Google and Facebook, and more location-data oriented companies like X-Mode (X-Mode 2020), Cuebiq Inc. (Pepe et al. 2020), and Huq Industries (Huq Industries 2020; Wisniewska and Ehrenberg-Shannon 2020) through software development kits installed in mobile devices.

A plethora of academic and applied social sciences research (Silm, Järv, and Masso 2020; Wang et al. 2018) and beyond (Toivonen et al. 2019) has demonstrated the feasibility of novel data sources to examine the spatial behaviour and social interactions of individuals as well as to uncover the networks of mobility flows and interaction communities at the societal level. This allows us to provide insights on a broad variety of socio-spatial phenomena and processes, including population dynamics (Deville et al. 2014), commuting and functional economic regions (OECD 2020), migration (Kamenjuk, Aasa, and Sellin 2017), socio-spatial segregation and inequality (Järv et al. 2020a; Shelton, Poorthuis, and Zook 2015), travel behaviour and accessibility to services (Järv et al. 2018; Wang et al. 2018), tourism and tourist behaviour (Li et al. 2018; Saluveer et al. 2020), and environmental management and ecology (Heikinheimo et al. 2020).

In the context of societal disruptions, mobile big data have been used to examine natural hazards (Shelton et al. 2014) and virus spread, and their impact on people (Kraemer et al. 2018; Wesolowski et al. 2012). Moreover, mobile big data have demonstrated strong potential in improving crisis preparedness and management (Akter and Wamba 2019; Cinnamon, Jones, and Adger 2016), as the COVID-19 crisis has shown. Its most important characteristic is the timeliness, as information can be retrieved in near real-time for monitoring human mobility and interactions. Second, it can cover the majority or a large proportion of the population that can be reliably extrapolated to the entire population (Santamaria et al. 2020). Third, data sources can cover whole countries (Santamaria et al. 2020), or even have global coverage (Google 2020; Huang et al. 2020). Fourth, data are continuous and can cover longer time periods to uncover pre-crisis, crisis and post-crisis changes. Finally, social media data allow

spatio-temporal knowledge to be combined with social content (Banda et al. 2020; Shelton et al. 2014).

However, the critical view about mobile big data sets reveals some concerns, and the COVID-19 crisis has highlighted some of these. (For an overview, see Poom et al. 2020). Large global corporations, including mobile network operators, and mobile device operation systems and platform companies such as Apple, Google and Facebook, tend to provide preprocessed and/or aggregated data products. While such data products are obtained using in-house 'black box' methodologies (Pasquale 2015), it is difficult to evaluate their validity and further process them for more detailed analysis of the socio-spatial interactions of people. That is, these data are often sliced into one-day subsets and focus only on the movements and locations of people without reasoning about them – thus neglecting the temporally dynamic activity-travel behaviour of people (Schönfelder and Axhausen 2010). It is also often impossible to separate locals from visitors as a 'place of residence' is found for each day based only on a mobile phone user's location on the preceding night (Heiler et al. 2020). However, exceptions exist (Ahas et al. 2010; Pepe et al. 2020). Anonymised and aggregated data products often do not provide information about the socio-spatial interactions of people belonging to different social groups beyond gender and age. Transnational people are difficult to examine, as both raw data from mobile network operators and data products from global platform companies are only bound to a country's borders (Apple 2020; Google 2020; Santamaria et al. 2020). Above all, privacy protection and ethical discussions question whether the social benefits outweigh the risks regarding privacy and surveillance (Poom et al. 2020).

Given the above, to understand the behaviour of more specific social groups, we need more targeted data collection methods such as active mobile phone positioning (see, Silm, Järv, and Masso 2020) and smartphone tracking based on GPS, Wi-Fi and Bluetooth (Licoppe et al. 2008; Molloy et al. 2020; Prelipcean, Gidófalvi, and Susilo 2018). With the prior consent of the respondent, this allows us to combine tracking and smartphone usage information with complementary questionnaire surveys. These approaches allow truly longitudinal analysis of a respondent's social and spatial behaviour over time, whereas smartphone tracking is not bound to a country's borders and provides accurate spatio-temporal data. Further, it allows us to examine the link between social interactions and spatial behaviour (Licoppe et al. 2008). Thus, the smartphone tracking method is a promising approach for studying transnational people, whose socio-spatial behaviour across borders is otherwise difficult to reveal quantitatively (Ortúzar et al. 2011).

3. Case study – Estonians in Finland and COVID-19

The study area covers two countries, Finland and Estonia, which are separated by the Gulf of Finland (ca. 80 kilometres). Finland (population 5.5 m inhabitants) and Estonia (1.5 m) share strong cultural, linguistic and historical connections. Physical mobility between the countries to promote cultural and intellectual exchange began to grow in the 19th century. Mobility and social interactions further increased in the 1990s and early 2000s even before Estonia joined the European Union in 2004, along with the rapid establishment of economic ties (Jauhiainen 2020b). Since then, both migration and mobility have further intensified – about 10,000 Estonian-speaking people lived in Finland in 1999, and in 2017 the number had grown to 50,000 (Jauhiainen 2020b). The main reason for Estonians migrating to Finland is the higher standard of living in Finland, in the form of wages and social security (Anniste, Pukkonen, and Paas 2017). Around two-thirds of Estonians live in Uusimaa county, where the capital Helsinki is located and which is the closest part of Finland to Estonia (Jauhiainen 2020b). As a result, there was intensive cross-border mobility in both directions in 2014–2016: the average mobility from Estonia to Finland amounted to 1.3 million visits per year (382,860 visitors), and from Finland to Estonia 2.4 million visits per year (1.5 million visitors) (Silm et al. 2020).

Currently, Estonians are the largest group of foreign citizens in Finland due to the freedom of movement within the EU, whereas their population size is evaluated to be significantly higher than in the official statistics (Lagerspetz 2020). In addition to migration between the countries, a significant number of people have daily lives and activities that take place in both countries (Telve 2019). It is estimated that about 20,000 transnational people from Estonia regularly visit Finland (for work) – they make up 5% of the people travelling from Estonia to Finland and 1.5% of the Estonian population (Silm et al. 2020). These transnational people make over 300,000 visits in total, which amount to 23.0% of all visits from Estonia to Finland (Silm et al. 2020). Typically, these people tend to have 5-day or 10- to 11-day long stays in Finland (Silm et al. 2020). Many of the transnational people work in Finland or even in both countries at the same time.

During the COVID-19 crisis, both Estonia and Finland took strict measures to tackle the virus spread – measures were introduced during Weeks 11 and 12 and were finally lifted at the end of Week 24 (in Finland). Given the different timing and duration of the various restrictions in both countries, we can broadly divide this period into five stages from the perspective of cross-border mobility between Finland and Estonia: 1) pre-COVID, 2) transition, 3) lockdown, 4) reopening, and 5) post-restrictions stage (Figure 1). The transition stage characterises the gradual introduction of restriction measures and declaration of the state of emergency in both countries. The lockdown stage is characterised by closing the borders of Uusimaa county (the capital region of Finland), the
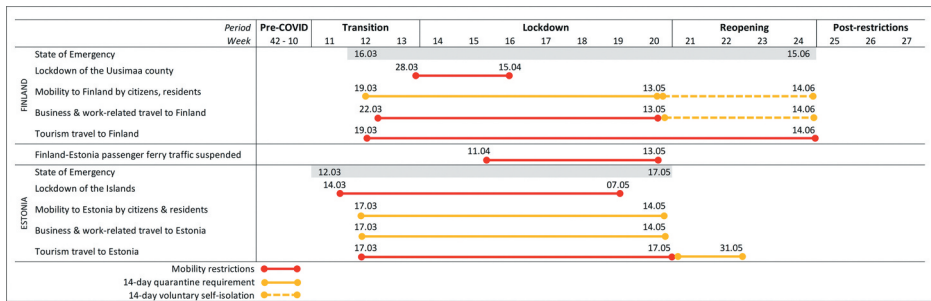
Figure 1. Timeline of the key restrictions and confinement measures during the COVID-19 first wave in the first half of 2020 in Finland and Estonia.

suspension of Estonia-Finland ferry ticket sales for regular passengers, and the strictest containment measures under the state of emergency legislation in each country. The reopening stage characterises gradual restriction relaxing until the state of emergency ended in Finland. We have used this five-stage division in our analysis.

As shown in Figure 1, legislative measures either directly restrict mobility of people, such as suspending non-essential movement across the borders of Uusimaa county (Finnish Government 2020) and ceasing the sale of passenger tickets to ferries between Finland and Estonia (Yle 2020b), or indirectly influence the decisions about cross-border mobility by demanding that people stay in 14-day mandatory quarantine or voluntary self-isolation at their residence after crossing state borders (Yle 2020a).

4. Materials & methods

4.1. Smartphone data and sample

The data used for this study comprise smartphone-based positioning data collected by the MobilityLog – an application developed by Mattias Linnap and the Mobility Lab, University of Tartu (Linnap and Rice 2014; Poom 2019). This application was designed for long-term mobility tracking and capturing social network interactions. The data collected include: 1) location data from GPS coordinates; 2) timestamps of the coordinates; 3) call activity type – phone call and text message; 4) call activity direction – incoming and outgoing; 5) time of the activity – start and end time. Our dataset covers a 38-week period starting from Monday 14 October 2019 (Week 42) until Sunday 5 July 2020 (Week 27). Given that the data are from an ongoing longitudinal study, we obtained as long a study period as possible to cover the recovery period after the peak period of the COVID-19 crisis – March–April 2020. Approximately 71% of respondent days were used in the study, as the remaining user days were excluded due to data gaps. In total, our dataset includes 19,251,546 GPS records and 81,031

call activities. For each respondent, on average, there are 2,211 GPS points and 9.31 call activities per day. In addition, quantitative pre-tracking interviews were conducted face-to-face with each participant after obtaining their written consent to participate in the study. From the interviews, we obtained information about the actual locations of residence (home), second home (if applicable), workplace and school (if applicable), and socio-demographic characteristics.

Our research population consists of 46 people who migrated from Estonia and reside in the capital region of Finland – the cities of Helsinki, Espoo and Vantaa. The research population consists of 35% men and 65% women, aged between 23 and 71 years. The largest age groups are aged between 30–39 and 50–59 (13% each). Most live in a partnership (65%) and 90% have children, but 50% have children with whom they live together. A significant proportion of people have either higher education (41%) or vocational education (43%), while 13% have secondary education as the highest completed level of education. Respondents are mainly skilled workers and middle-level specialists, often employed in the construction sector. Half the people have a second home (54%), 92% of which are in Estonia. The small research population is not representative of the entire Estonian population in Finland, but it provides relevant insights about the cross-border interactions of transnational people.

4.2. Quantification of spatial behaviour and social interactions

To examine the impact of COVID-19 on people's daily lives, we analysed three aspects: 1) overall spatial behaviour, 2) cross-border spatial behaviour, and 3) social interactions. Each of these aspects is affected by the COVID-19 containment and mitigation measures. This is especially the case for transnational people who have to consider the restrictions of several countries in their daily lives (Klatt 2020; Willi et al. 2020; Yle 2020a).

The overall spatial behaviour was examined through three indicators, based on location data from GPS coordinates and actual locations of residence (home, second home). *1) Daily travelled distance* as a characteristic of human mobility is the absolute length of the trajectory formed by sequential GPS coordinates. *2) Daily activity space* as a characteristic of the geographical extent of one's daily life (Järv et al. 2015) is defined as the area of a 200 metre buffer surrounding each travel segment, whereas all overlapping buffers are dissolved into a single feature (Schönfelder and Axhausen 2010)., *3) Daily time duration at home* as a proxy for evaluating the change in daily practices is the time spent at home – the main anchor place of our lives. This also includes the time spent at a second home, which is an important anchor place for many transnationals. The physical presence at home and second home was identified from GPS tracks by using the stop-methodology developed by Positium during the project 'Campus Areas as Labs for Participative Urban Design' (Poom 2019). Time duration is measured as the proportion of time spent in a 100 metre buffer

around a respondent's self-reported home and second home location, according to the pre-tracking interview. Here, we excluded abnormal days when a respondent had not been in their daily activity space at all – had not spent any time near or in their home, secondary home, work or school locations, which were identified during the pre-tracking interview.

Cross-border spatial behaviour as a characteristic of the physical linkage to the origin country of transnationals was examined through three indicators based on GPS coordinates by country: Finland, Estonia, and other countries. *4)* ***Number of weekly border crossings*** between Finland and Estonia in both directions characterises the frequency of border crossings. *5) **Daily time duration by country*** indicates the temporal division of the presence between countries, as the proportion of time spent in Estonia and Finland from the total time of each day. In the case of days with partial data, due to data gaps, we considered the time available as the total time for a given respondent. *6)* ***Proportion of respondents who have visited Estonia*** indicates the frequency of visiting Estonia for various reasons, including their second homes.

Social interactions were examined through two indicators based on mobile phone communication metadata. *7)* **Daily *communication activity*** as a characteristic for the intensity of social interactions is the sum of all communication events including phone calls and text messages (SMS) regarding both self-initiated (outgoing) and received (incoming) communication. We also examined outgoing and incoming communication separately. *8) **Daily communication partners*** as a characteristic for the diversity of social interactions is the sum of unique calling partners. We also examined partners from Estonia and Finland separately. MobilityLog gives a unique anonymised ID to each phone number that interacts with a respondent's phone and records only the origin country of the calling partner, based on the country code of the phone number (+372 for Estonia and +358 for Finland).

We first calculated each indicator for each user for each day from which we derived weekly averages for each user. To account for data gaps, we removed days with missing data for each user by identifying days for which there was no information created by the respondent in the log-file. That situation could occur for one of two reasons: firstly, MobilityLog may have been turned off, or secondly, the respondent did not use or move his/her phone for the whole day. As most data gaps lasted for several days or weeks, rather than for one day, we considered the first option to be relevant in most cases. While calculating weekly averages from daily averages, we did not include data gaps: this means that if a user had a data gap lasting for two days in a week, we took the mean from the five days for which we had data. After we had calculated weekly averages for each user, we calculated the average for the entire week. In taking the average in mobility (daily travelled distance) and use of space (daily activity space) indicators, we used the 2nd quartile (median) to exclude the

influence of a few very high values that were connected with long-distance trips abroad. In the case of other indicators, we calculated arithmetic mean.

To analyse the COVID-19 impact on an individual's spatial behaviour and social interactions, we calculated the average baseline values for each indicator (see, Table 1) as a proxy for a pre-COVID ordinary behaviour from the period October 14 to March 8, i.e. 77 days from Week 42 (2019) to Week 10 (2020). To assess whether respondents' indicators of spatial behaviour and social interaction differ between the baseline and other four stages, we used Wilcoxon signed-rank test, because our metrics are not normally distributed. To determine the statistical significance of the difference between the baseline and other stages, we calculated the average metric of each respondent for each stage and compare two stages using Wilcoxon test.

Finally, to study the interlinkages between spatial behaviour and social interactions, we examined correlations separately for each of the five study stages, according to the five-stage division of the study period (Figure 1). We examined five correlations between spatial and social behaviour metrics regarding weekly averages: 1) activity space (km^2) and number of all unique communication partners (n), 2) activity space (km^2) and all communication activities (n), 3) time duration in Estonia (%) and all communication activities (n), 4) time duration in Estonia (%) and number of unique Estonian communication partners (n), and 5) time duration in Estonia (%) and share of Estonian communication partners from all unique communication partners (%). In total, we correlated 1,238 data records, i.e., weekly averages for each respondent, whereas we excluded data points when a respondent's weekly average of the daily travel distance was 0, as an indicator of a data gap.

Table 1. The average values of the pre-COVID stage from Week 42 (2019) to Week 10 (2020) as the baseline for this study.

| Indicator	Unit	Mean	St deviation	St error
Daily activity space	km^2	10.9 (median 5.4)	22.00	0.79
Daily travelled distance	km	36.8 (median 22.2)	68.48	2.47
Daily time duration in home, primary	%	31.6	19.6	0.77
Daily time duration in home, secondary	%	2.8	8.0	0.32
Daily time duration in home, primary & secondary	%	33.9	18.8	0.74
Daily border crossings, from Estonia to Finland	n	0.022	0.053	0.002
Daily border crossings, from Finland to Estonia	n	0.022	0.054	0.002
Daily time duration in Estonia	%	15.4	28.9	1.04
Daily time duration in Finland	%	82.9	30.1	1.08
Daily communications, incoming	n	1.00	1.76	0.06
Daily communications, outgoing	n	2.36	3.37	0.13
Daily communications, all	n	3.36	5.01	0.18
Weekly communication partners from Estonia	n	2.89	3.77	0.14
Weekly communication partners from Finland	n	2.96	5.22	0.19
Weekly communication partners, all	n	5.93	7.02	0.25
Proportion of Estonian partners from all partners	%	30.5	11.6	3.38

5. Results

5.1. Spatial behaviour

The impact of the COVID-19 pandemic and mitigation measures on respondents' spatial behaviour is evident as was expected (Figure 2). Before COVID-19, respondents' daily mean travelled distance was 37 km, whereas the median value was 22 km. The extent of daily mean activity space was 11 km^2, whereas the median value was 5 km^2. While at the beginning of the transition stage (Week 11) spatial behaviour did not change much despite the news on the approaching crisis and governmental recommendations to avoid travel and social interactions, there was a sharp decrease in spatial behaviour from Week 12 that lasted through the lockdown stage, and even decreased further in the latter part (Weeks 19 – 20). The median daily distance travelled decreased by 60% during the lockdown stage compared to the baseline, whereas the median extent of daily activity space dropped by 72%, respectively. The gradual lifting of restrictions from Week 21 resulted in quick recovery of spatial behaviour in the reopening stage that exceeded the baseline and even levelled up with the active Christmas holiday period (Weeks 51 – 52).

Since the transition stage, staying at home gradually increased and by the end of the stage, respondents spent 37% more time at primary homes compared to the baseline (Figure 3). Since then, time spent at the primary home slightly decreases during the lockdown stage, yet on average remains 27% higher than during normal times. Regarding second homes, respondents spent 2% of their daily time there during the baseline stage, on average. In contrast, presence at a second home steadily decreased during the transition stage and during Weeks 15–19 basically no one visited their second homes. From Week 19 onwards, respondents' visits to second homes quickly recovered after easing mobility restrictions, and from Week 25 respondents started to move from their primary homes to their second homes. In the final week
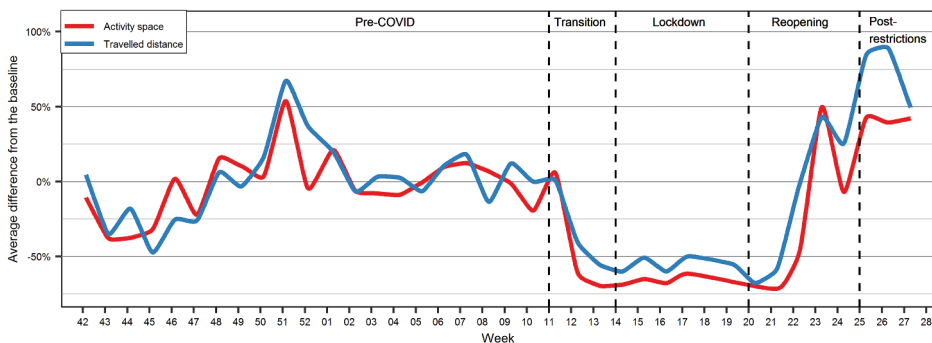
Figure 2. Weekly variations in daily median distance travelled and activity space extent compared to the baseline (Weeks 42-10).
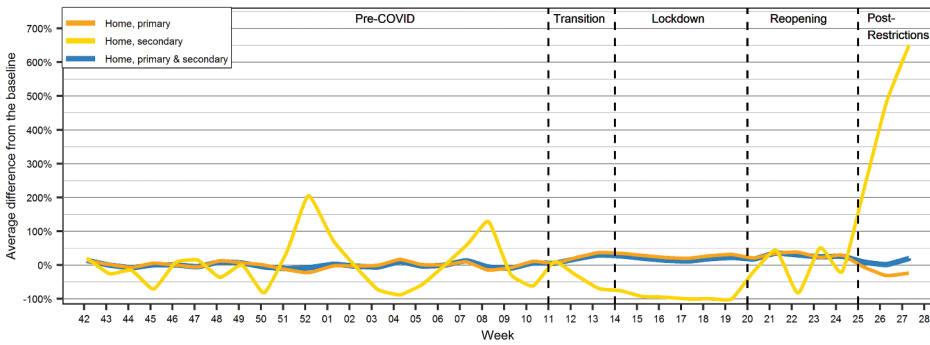
Figure 3. Weekly variations in average daily time spent at home compared to the baseline (Weeks 42-10). Presence in both primary home and second home are addressed separately and together.

Table 2. The statistical significance of the difference between pre-COVID stage as the baseline (BL) and later stages regarding respondents' average indicators examined. For each indicator, each stage is compared to the baseline using Wilcoxon test.

Indicator	BL vs Transition	BL vs Lockdown	BL vs Reopening	BL vs Post-restrictions
Activity space	***	***		*
Travelled distance	***	***		**
Time duration in home, primary	***	***	*	**
Time duration in home, secondary	**	***		***
Time duration in home, primary & secondary	***	***	*	
Border crossings, from Estonia to Finland	***	***	***	*
Border crossings, from Finland to Estonia	***	***	***	
Time duration in Estonia	***	***		***
Time duration in Finland	***	***		***
Incoming communications		***	***	
Outgoing communications		**		
All communications		***		*
Communication partners from Estonia	*			*
Communication partners from Finland				
All communication partners				*
Proportion of Estonian partners from all partners	***	**	***	***

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

(Week 27), respondents spent 13% of their daily time on average at their second homes – an increase of 650% from the baseline stage (Figure 3).

The statistical analysis confirms significant differences in respondents' average activity spaces and distances travelled between the baseline stage and the transition, lockdown and post-restrictions stages (Table 2). The statistical analysis has the same pattern regarding the differences in the average time spent in both primary and second home.

5.2. Cross-border behaviour

Cross-border mobility between Finland and Estonia was frequent before the COVID-19 restrictions. During the pre-COVID stage, roughly 31% of respondents on average made a one-way trip from Finland to Estonia or vice versa each week. Put differently, every week about 15% of respondents made a return trip to Estonia. While at the beginning of the transition stage (Week 11) spatial behaviour did not differ from the average baseline, a sharp decrease occurred from Week 12 and during the lockdown, basically no one crossed the border (Figure 4). Cross-border mobility steadily recovered during the reopening stage with the gradual lifting of restrictions. After lifting all restrictions by the end of Week 24, people started to travel more from Finland to Estonia than vice versa. The statistical analysis confirms significantly different border crossing behaviour during the transition, lockdown and reopening stages compared to the baseline (Table 2). Border crossings recovered only during the post-restrictions stage.

In addition to border crossings, the proportion of respondents present each week in Estonia revealed that during pre-COVID stage some 30% of our sample visited Estonia, on average. During the transition stage, the proportion steadily decreased to 7%, and remained until the end of the lockdown stage (Figure 5). From Week 20 onwards, the proportion of respondents visiting and staying in Estonia increased and from Week 25 onwards, at least half of respondents were present in Estonia each week. This was even more than compared to the Christmas holidays (Weeks 51–52).

In addition to respondents' visits to Estonia, it is important to know how long they stayed there. Before COVID-19, respondents' visits to Estonia were short, as each week some 15% of their time was spent in Estonia, although 30% of our sample visited Estonia (Table 1). During the latter part of the transition stage and during the lockdown stage, 7% of respondents' time was spent in Estonia (Figure 6). In other words, during that time about 7% of our sample stayed in Estonia, despite the location of their primary residence in Finland. During the
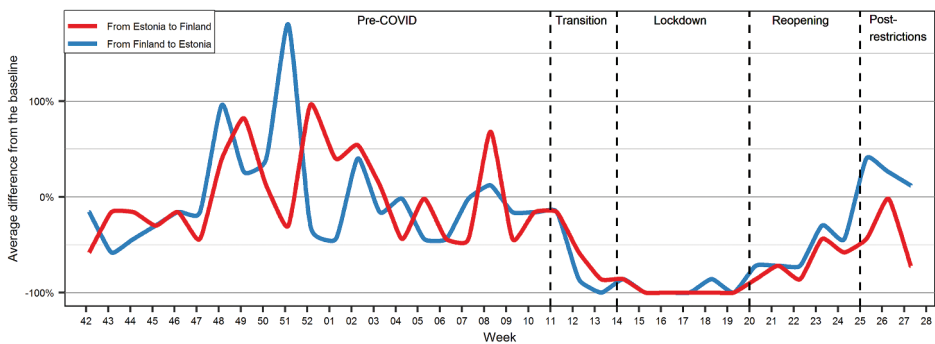
Figure 4. Weekly variations in average border crossing between Finland and Estonia compared to the baseline (Weeks 42-10) regarding both movement directions.
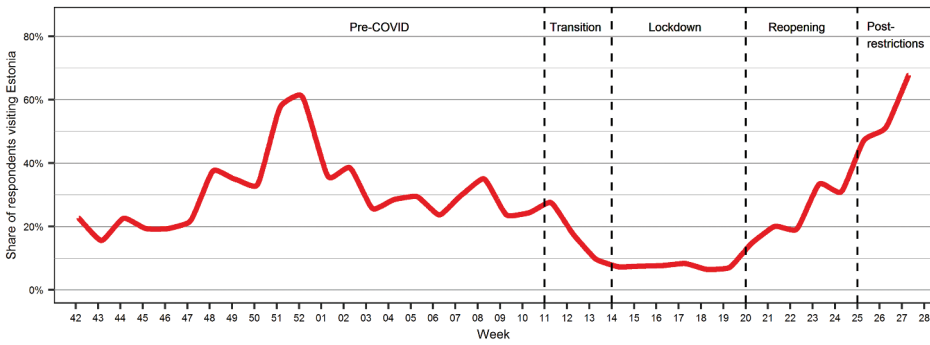
Figure 5. Weekly variations in the average proportion of respondents who visited Estonia.
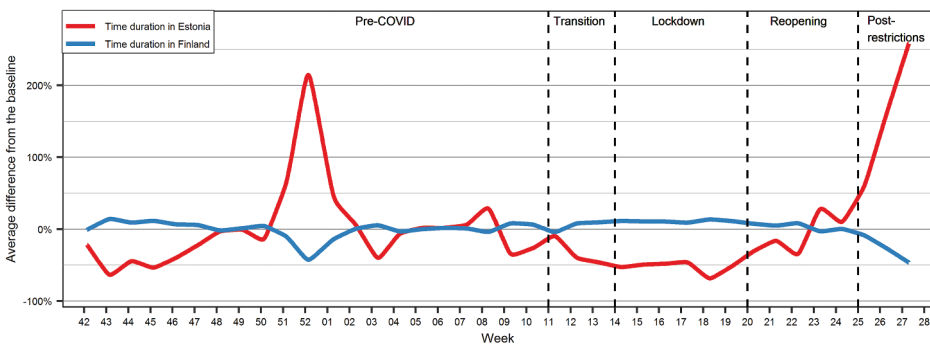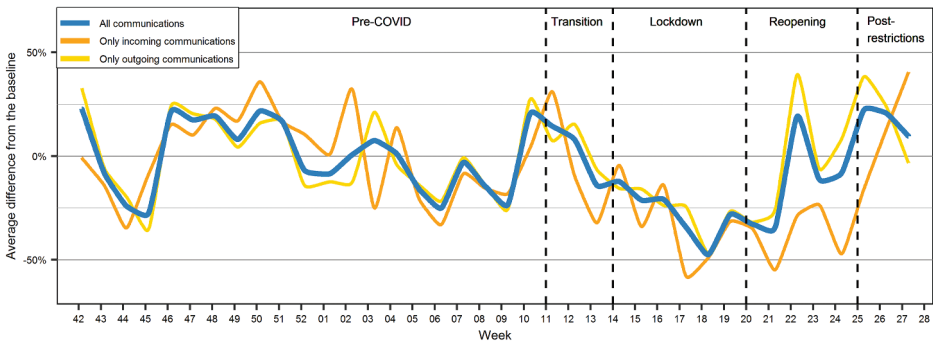

Figure 6. Weekly variations in the average time spent in a country during a given week compared to the baseline (Weeks 42-10).

reopening stage with gradual lifting of restrictions, not only more respondents started to visit Estonia, but they started to stay longer and gradually move to their second homes (Figure 3). During the Week 27, over 50% of respondents' time was spent in Estonia – some 2.5 times more time than before the COVID-19 crisis on average. The statistical analysis confirms significantly different time durations spent in both countries during the transition, lockdown and post-restrictions stages compared to the baseline (Table 2). These indicators are similar to the baseline only during the reopening stage.

5.3. Social interactions

In general, the COVID-19 crisis influenced respondents' social interactions via mobile phone somewhat differently than their spatial behaviour. Despite the weekly fluctuations during the pre-COVID stage from its average baseline, the number of daily communication activities increased during Week 10, mainly due to self-initiated (outgoing) interactions, and remained high during Week 11, due to received (incoming) interactions (Figure 7). From the high level of interaction

Figure 7. Weekly variations in the average number of daily communication activity compared to the baseline (Weeks 42-10) regarding outgoing and incoming communication, all communication together.
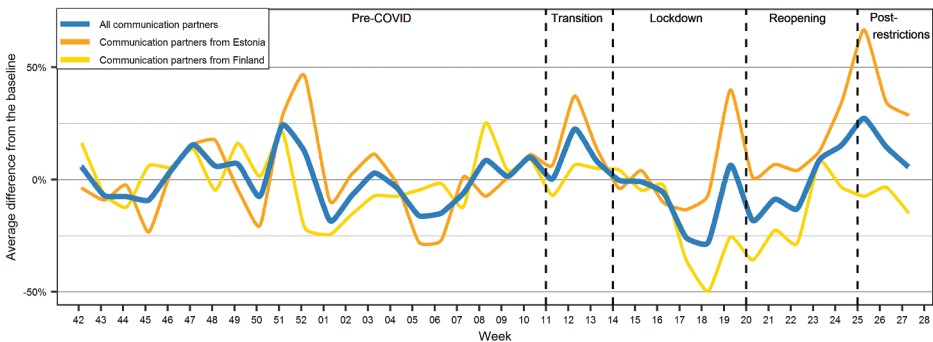
Figure 8. Weekly variations in the average number of unique weekly communication partners compared to the baseline (Weeks 42-10) in the case of all unique communication partners, and separately partners from Finland and Estonia.

bursts in Weeks 10 and 11 the overall interaction decreased steadily until Week 18 with the least daily communication activities (almost half from the baseline average). After Week 18, communication started to activate again and was exceptionally active in Week 22. The social interaction recovery relied mainly on self-initiated (outgoing) communications. Respondents' received (incoming) communication started to recover later, more rapidly from Week 25. The statistical analysis shows that the average number of daily communication activities was significantly different only during the lockdown stage compared to the baseline. However, the reopening stage was also significantly different regarding daily average incoming communication activity (Table 2).

Another aspect of social interaction is the diversity of communication partners. While the communication was active in Weeks 10 to 12, the latter week encompassed an increase in the unique number of communication partners – 24% more compared to the average baseline (Figure 8). Similar to the overall communication activity, the number of unique partners steadily decreased until

Week 18–28% less weekly communication partners in comparison to the baseline. Since then, the number of unique partners started to increase. In Week 25, when mobility restrictions and quarantine requirements ended, the number of the communication partners (27% more partners than the baseline average) was the highest. However, according to the division of our five stages, the statistical analysis did not confirm a significantly different number of unique communication partners compared to the baseline stage (Table 2). There could be some difference during the transition and post-restrictions stages, but the statistical significance is weak ($p < 0.1$).

The transnational people studied have strong social ties across country borders. Respondents' communication partners are equally from Estonia and Finland – respectively 2.9 and 3.0 unique partners on weekly average. However, the division of communication partners between the two countries fluctuates during the study period, especially during the COVID-19 crisis. The number of Finnish calling partners decreased drastically after Week 16 and recovered only from Week 23. Instead, the pattern with Estonian communication partners is different. First, there was no decrease in the weekly number of Estonian partners during the COVID restrictions. Second, there was a significant increase in the number of Estonian partners during Weeks 12 and 19–37% and 39% more compared to the baseline, respectively. Third, the increase in the number of communication partners in Week 25 results solely from the increase in the number of Estonian communication partners (66% more compared to the baseline). The proportion of Estonian communication partners is statistically different from the baseline stage during all later stages (Table 2).

5.4. The link between spatial behaviour and social interaction

The COVID-19 crisis not only changed individuals' spatial behaviour and social interaction, but also their interlinkage (Figure 9). The positive correlations
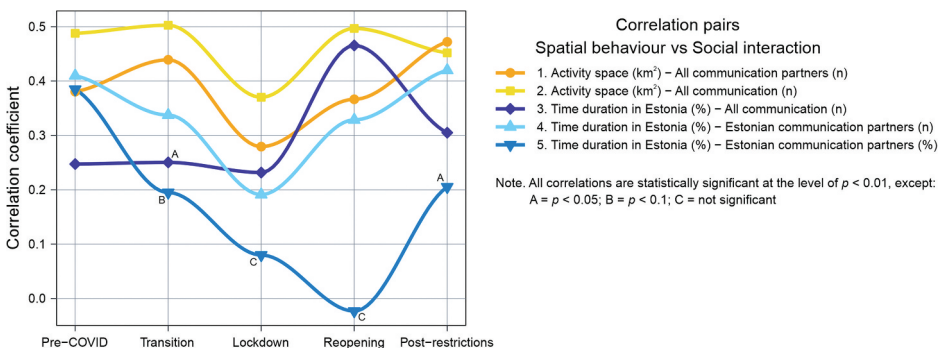

Figure 9. Variations in the correlation between individual's spatial behavior and social interaction indicators during the five different stages of the study period. Each of the five lines represents a correlation coefficient for given correlation pair.

between activity space extent and the number of weekly communication activities (Figure 9, line 1), and number of weekly unique communication partners (Figure 9, line 2) became weaker during the lockdown stage – on average, a person's social interaction did not decrease to the same extent as their spatial behaviour. With the gradual lifting of restrictions after the lockdown stage, the correlations strengthened. Yet the linkage between activity space extent and social interaction intensity remained lower than during the pre-COVID stage, also after lifting all restrictions.

The variation in the linkage between cross-border spatial behaviour (the share of time stayed in Estonia) and the unique number of communication partners from Estonia had a similar temporal pattern, whereas it recovered to be at the level it had been at during the pre-COVID stage (Figure 9, line 4). In other words, the more time one spends in Estonia the more Estonian communication partners one has, in general. This linkage became weaker when the opportunity to visit Estonia during the lockdown stage was almost impossible, yet communication with Estonian partners remained.

The linkage between cross-border spatial behaviour (the proportion of time spent in Estonia) and overall communication activity (number of calls and SMSs) had a rather different pattern (Figure 9, line 3). While the linkage was weak during the pre-COVID stage until the lockdown stage, it increased significantly during the reopening stage and normalised again during the post-restrictions stage. That is, the more time a person spent in Estonia after the lockdown, the more overall communication activities they had. However, the linkage is different when examining the proportion of Estonian partners of all communication partners (Figure 9, line 5). This moderately correlated linkage was most clearly influenced by the COVID-19 crisis after the transition stage and even until the post-restrictions stage. That is, the tendency that a person who spends more time in Estonia also has more Estonian communication partners among their partners during the pre-COVID stage withers away along with the crisis.

6. Discussion and conclusions

With this study, we were striving to enhance our understanding of the impact of the COVID-19 pandemic on the daily lives of people, by providing new insights from the perspective of transnational people – the people whose daily lives were disrupted severely by various mitigation measures. By relying on a unique longitudinal smartphone tracking survey, we obtained new knowledge on how mobility restrictions and closures of national borders affected the daily lives of transnationals, on the example of Estonians residing in Finland.

As expected, the daily spatial mobility of transnationals decreased drastically, as both the extent of activity spaces and travelled distances more than halved compared to the average before the COVID-19 pandemic. In particular, individual activity spaces were more concentrated and anchored around homes,

which was also the aim of the containment and mitigation measures in force during the state of emergency. As a result, respondents stayed in their homes roughly one-third more than normally. Somewhat surprisingly, most respondents stayed in Finland, despite roughly half of them owning a second home in Estonia. However, they started surging to their second homes once restrictions were gradually eased and lifted. The analysis of cross-border spatial behaviour clearly revealed how actively transnational Estonians in Finland are tied to Estonian society and visit their country of origin, despite the two-hour ferry trip that this involves. Before the COVID-19 pandemic, roughly one-third of our respondents visited Estonia each week and about 15% of respondents' total weekly time was spent in Estonia. Thus, with the easing of cross-border mobility restrictions after the lockdown stage, the mobility across country borders recovered quickly and those owning a second home in Estonia moved there for longer stays, both for realising postponed trips and for seasonal movement to Estonia for the summer.

The analysis of transnationals' social interactions yielded both expected and unexpected outcomes. The increase in the number of communication activities in the week before and during the first weeks of the introduction of first restrictions was expected, as the media broke loose about the COVID-19 pandemic and the closure of national borders in Europe. However, in contrast to our expectations the number of communication activities decreased steadily during the lockdown and gradually recovered once the restrictions were eased, and in particular, when the state of emergency was lifted in Estonia (Week 20) and in Finland (Week 24). Instead, we expected a compensation effect, i.e. that the halted physical mobility would be compensated for with more active mobile phone communication. However, we have to remember that virtual channels such as Skype, WhatsApp, and Facebook that were not covered in this study are increasingly being used for communication. Nevertheless, we feel that phone communication activity (both calling and texting) can be considered to be a solid proxy for social interactions – for example, the 5.5 million inhabitants of Finland made 3.3 billion calls and sent 1.6 billion text messages in 2019 (Traficom 2020).

The analysis of the division of communication partners by country revealed interesting patterns. While the number of Finnish communication partners decreased to about half from the pre-COVID baseline value, the number of Estonian partners did not decrease. This could reflect the characteristics of the social networks of transnational Estonians in Finland – the stronger ties tend to be linked to Estonia, while the weaker ties are linked to Finland and are not sustained once daily practices change. Respondents' strong linkages to Estonian society and people is also revealed by the finding that they have more Estonian communication partners during significant societal changes – once mobility restrictions were introduced (Week 12), when the end of lockdown stage was publicly announced (Week 19), and after the restrictions

were lifted and the state of emergency was ended in Finland. The analysis also revealed how spatial behaviour and social interaction are moderately interlinked, and how societal crises such as the COVID-19 pandemic changed it.

Regardless of our small study sample and its limitations in drawing conclusions about the whole population of transnational Estonians in Finland, the findings provide new insights about transnationals' socio-spatial interactions within and across country borders, and how easily their daily transnational lives are affected by the national border actions of governments. Furthermore, this empirical study provides a unique quantitative snapshot of the interwoven daily lives of transnational people between different countries, and how the cross-border regions are (re)shaped by the practices of people. The COVID-19 crisis shows vividly how fragile the social fabric of cross-border regions is, and how the long-term process of building cross-border regions and communities can be disrupted by quick political decisions on closing national borders (van Uden and van Houtum 2020) that eventually had little effect on tackling the virus spreading (Chinazzi et al. 2020). As the COVID-19 crisis is still ongoing and we might face similar crises in future, countries at least in the EU, should consider creating separate restrictions and containment measures for cross-border regions with their neighbouring countries to safeguard both cross-border communities and transnational people.

This study demonstrates the applicability of the smartphone tracking approach, and highlights its value for capturing the socio-spatial interactions of people who are difficult to examine with traditional data collection methods (Licoppe et al. 2008; Molloy et al. 2020). In addition, several datasets from mobile network operators reveal overall human mobility and provide valuable information for understanding how the COVID-19 pandemic has affected society, and how effective are mobility restrictions and containment measures, but also for evaluating and monitoring the virus spread on a country level (Cintia et al. 2020; Santamaria et al. 2020). However, these data cannot reveal the impact of the COVID-19 pandemic on individuals and particular social groups. In the context of COVID-19, human mobility analyses covering a longer period are conducted based on data that are collected from software development kits installed in mobile devices (Pepe et al. 2020). The options for longitudinal analysis of such data are nevertheless not clear, and raise ethical and legislative (incl. privacy-related) questions, e.g. in the EU, where studies have to assure the compliance with the General Data Protection Regulation (GDPR) (Poom et al. 2020). For this reason, one global sample of similar data provided to scholars for the COVID-19 related research has excluded data from the EU countries (X-Mode 2020). Active mobile phone positioning could be one alternative data collection method requiring respondents' written consent, similarly to smartphone tracking studies (Silm, Järv, and Masso 2020). Both methods also allow us to combine spatial tracking data with questionnaire surveys (and in-depth interviews) to obtain

more detailed background information on respondents (and qualitative data for a more nuanced interpretation of quantitative analysis results). Yet, compared to active mobile positioning, smartphone tracking can also provide valuable information about social interactions, in addition to accurate spatio-temporal information.

This study provides a methodologically valuable step forward in studying spatial behaviour and social interactions of transnational people in general, and in exploring the effects of the COVID-19 pandemic on a specific population group in particular. The findings indicate the need to examine further the linkage between spatial behaviour and people's social interactions, and how it is influenced by social disruptions such as the COVID-19 crisis. More specifically, we revealed some unexpected patterns in social interactions within the social networks of transnational Estonians residing in Finland. This requires further investigation to provide valuable insights about the integration and engagement of transnational people to both societies.

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