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The link between spatial behavior and virtual interaction using smartphone data: a case of transnational Estonians in Finland during the COVID-19 pandemic

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Abstract

The mobility restrictions due to the COVID-19 pandemic affected the spatial and cross-border behavior of transnational Estonians living in Finland. The consequences in social daily life brought adaptations such as remote work, frequent food delivery, constant virtual communication, and leisure time in web surfing. The virtual mobility of people through smartphone could provide alternative options to meet other people while spatial mobility was limited. In this scope, the aim of this thesis is to examine the link between spatial and virtual behavior and how it changes during the COVID-19 pandemic.

The study relied on a dataset collected in a smartphone tracking experiment with 45 transnational Estonian in Finland using a specific smartphone app during 28 months in the period August 2019 to November 2021. Spatial mobility was measured with GPS tracking records and complemented with virtual interaction measurements based on screen-on events duration. The metrics reviewed to achieve this aim were at spatial perspective: daily traveled distance, daily activity space, and daily cross-border moves; at virtual perspective: daily duration of screen-on interaction, and the proportion of daily screen-on duration in Finland compared to Estonia.

Findings revealed a decline in spatial mobility in both countries when COVID-19 started. On the other hand, virtual mobility increased but only in their primary residence country (Finland). Virtual mobility is scattered in Estonia at main urban areas like Tallinn and Tartu but concentrated in Finland at Helsinki Region in 78%. In general, there was moderate link between spatial and virtual behavior. In Estonia at national scale the activity space and traveled distance explained the ~60% of changes in virtual mobility when Covid-19 started. In Finland at local scale the cross-border behavior is the main predictor of virtual mobility changes in ~50% during the entire Covid-19 transition. The use of smartphone tracking methodology proved to be a reliable approach for better understanding spatial and virtual mobility of transnational people.

Keywords: Covid-19, transnational people, spatial mobility, virtual mobility, smartphone tracking

CERCS Code: S230 - Social geography

Ruumilise käitumise ja virtuaalse suhtlemise omavaheline seos nutitelefoni andmetel: Soomes elavate hargmaiste eestlaste näide COVID-19 pandeemia ajal

Abstrakt

Covid-19 pandeemia tõkestamiseks sätestatud mobiilsuspiirangud mõjutasid Soomes elavate hargmaiste eestlaste ruumilist käitumist ja piiriüleseid liikumisi. Pandeemia tagajärjena kohaneti igapäevaelus kaugtööga, sagedase toidu kojuveoga, pideva virtuaalse suhtluse ja veebisurfamisega vaba aja veetmise viisina. Virtuaalne mobiilsus nutitelefonides pakkus inimestele alternatiivset võimalust kohtuda ajal, kui ruumiline mobiilsus oli piiratud. Uurimistöö eesmärk oli uurida ruumilise ja virtuaalse käitumise omavahelist seost ja selle muutusi Covid-19 pandeemia ajal.

Uurimistöö põhineb 45 hargmaise eestlase andmetel, kelle peamiseks elukohaks oli Soome. Andmeid koguti spetsiaalse nutitelefoni rakendusega 28 kuu jooksul 2019. aasta augustist kuni 2021. aasta novembrini. Ruumilist mobiilsust mõõdeti GPS-andmete põhjal, mida täiendati virtuaalsete interaktsioonide mõõdikutega, mis põhinesid telefoni ekraaniaja kestusel. Ruumilise mobiilsuse mõõdikutena kasutati päeva jooksul läbitud teepikkus, päevase tegevusruumi suurust ja päevast piiriületuste arvu. Virtuaalse suhtlemise mõõdikutena kasutati ekraani sisselülitatud oleku päevast kestust ja ekraani sisselülitatud oleku kestuse osakaalu Soomes võrdluses Eestiga.

Uurimistöö tulemused näitasid ruumilise mobiilsuse vähenemist mõlemas riigis alates Covid-19 algusest. Virtuaalne mobiilsus suurenes üksnes Soomes. Virtuaalne mobiilsus oli Eestis jaotunud linnaliste piirkondade ümbrusesse nagu Tallinn ja Tartu, kuid Soomes kontsentreerunud 78% ulatuses Helsingi regiooni. Ruumilise ja virtuaalse käitumise vahel oli keskmise tugevusega seos. Eestis seletasid tegevusruumi suurus ja läbitud teepikkus üleriiklikul skaalal ~60% virtuaalse mobiilsuse muutusest alates COVID-19 algusest. Soomes seletas piiriülene käitumine ~50% virtuaalse mobiilsuse muutustest, olles seeläbi kõige olulisemaks teguriks. Nutitelefoni põhine andmete kogumise metoodika osutus usaldusväärseks lähenemiseks mõtestamaks ruumilise ja virtuaalse mobiilsuse omavahelist seost hargmaistel inimestel.

Keywords: Covid-19, hargmaised, ruumiline mobiilsus, virtuaalne mobiilsus, nutitelefonide jälgimine

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1 INTRODUCTION

Human mobility is known as movement through space in function of time. The movement in space-time is manifested not only for people but also elements such as objects, or information. The mobility paradigm affirms that all the world seems to be on the move (Sheller and Urry 2006). Following the interaction of elements in the space, the attraction between them is a fact and it is settled as a law in geography by the studies of Tobler (1970) who explains that closer elements in space has stronger attraction of those that falls apart in longer distances.

Castells (2000) explains that the contemporary society is made up of networks and it is defined as the network society in the information age. Then, these networks structure the financial transactions, communication, markets, information exchange, or personal interactions in the global level. The interlinkage between the elements in the network represents a "distance" which is shortened by communication technologies such as the mobile phone communication technology. Afterwards, Miller (2004) discusses the distance in the information age explaining that exits a "shrinking" of distances in the world. The idea of a society with no distances represents a society with no borders: physical, technological, or political. But borders still exist. van Houtum & van Naerssen (2002) debate about bordering and othering, explaining how borders no dot represents a fixed limit, rather they symbolize social practice of spatial differentiation. Borders regulate flows of mobility and reproduce places in space. Boesen & Schnuer (2016) remark that borders have not disappeared, but they have changed becoming more varied, mobile, and taking an important role in everyday life

The closeness in the information age is evident, the conceptualization of the "virtual space" by Kellerman (2016) breaks the borders in the world explaining that exists a non-physical mobility of elements and people (i.e., information, and tele-presence). Then, the virtual mobility in the world is a concept relatively recent and much remains unexplored and in need to be understood (Barbosa et al. 2018). The virtual mobility has emerged since daily human activities can be carried out in a virtual space well known as cyberspace (Janelle and Hodge 2000) such as work, education, leisure, purchasing, or financial transactions and can be understood as a simultaneous tele-presence of people in a common cyberspace but their physical presence remains in different locations. Barbosa et al (2018) explains that virtual environments can be accessed through devices such as smartphones and represent a space of interaction.

This virtual interaction and its effect in the physical/spatial mobility is a field that has not been explored so far representing a gap in human mobility studies, especially in transnational spaces. The phenomena studied in this present work refers to the linkage between spatial mobility vs virtual mobility, finding longitudinal changes caused by external factors such as the COVID-19 pandemic and how it limited the human mobility in cross-border regions.

Cross-border mobility can be understood in a macro-scale that unveils cultural approach, social integration, and market cohesion as it happens in the European Region (i.e., border between Finland and Estonia). In present cross-border commuting studies by Järv et al., (2021) and Silm et al. (2021) it is explained broadly how the maintenance of social practices between nations has transcended national borders and confirm the conceptualization of this social phenomena known as transnationalism.

The cross-border mobility is important to understand because it can bring benefits for the nations involved. Common improvements and coordination can be done in the maintenance of cross-border regulations that support the diversification in society, economy, communication, and spaces (Järv et al. 2021)

The studies in spatial behavior have demonstrated that variations in mobility are caused by external factors such as cultural backgrounds or habits of individuals (Järv et al. 2018), or time spent in activity locations (R. Ahas et al. 2010). Thanks to location-based technologies such as smartphones, it is possible to trace the displacement of individuals and analyze the variation of spatial mobility through time periods. The generation of such information has created the new concept of big spatiotemporal data (Yang et al. 2020) which can serve to reveal spatial mobility insights in a more precise way with the value of capturing the socio-spatial interaction of people (e.g. smartphone tracking data complemented with survey and virtual interaction) which is difficult to capture with traditional methods (Järv et al. 2021).

Nevertheless, the intersection between the physical space and the virtual space is a fact that needs to be reviewed in function of time. Miller (2004) explains that time is essential in spatial mobility but relative to virtual mobility. Virtual spaces let inter-relate elements in two different places at the same time whereas physical spaces only can inter-relate elements in one place at the same time. The time as a game-changer in geography has been approached by quantitative perspectives since the earlies ’70s when *Time*

Geography was founded by Hägerstrand (1970), the temporality in geographic studies has been used to identify changes in daily individual's spatial mobility

However, the time-geography framework was adapted to physical and virtual spaces with Yu & Shaw (2007) explaining that exists an intersection between the physical space and virtual space. This intersection confirms that individuals who access to virtual spaces through devices retrieve information that help them to make decisions and it may affect the activity patterns in physical space. In general, the rethinking of time-geography was argued because ICTs are loosening the traditional physical relation with time. The new reality involves virtual communication based on devices that naturally accommodate daily activity in cyberspace. (Couclelis, H. 2009).

Considering this link between spatial mobility and virtual mobility of people, it is decisive to consider how time and virtual activity as factors affect the spatial behavior of individuals in cross-border regions. The present thesis aims to fill this study gap by focusing on transnational people in the cross-border region between Finland and Estonia, and how their spatial mobility got biased by their virtual interaction through smartphones during COVID-19 pandemic.

To achieve this aim the next research questions were proposed:

a) How spatial behavior of transnational people is linked to their mobile phone virtual interaction?
b) How the global Covid-19 pandemic has influenced the spatial and virtual mobility of transnational people?
c) How feasible is the usage of data collected through smartphone for studying links between spatial and virtual mobility?

The first section of this master thesis is a literature review of spatial and virtual mobility addressing their metrics, and a complementary review of transnational mobility referring to the study case in the cross-border region of Finland-Estonia. Then, the second section describes the methods used for spatial and virtual mobility behavior measurement at transnational level highlighting the novelty of the metrics calculated using longitudinal smartphone data. Also, it includes the statistical analysis which reveals the linkage between spatial and virtual mobility with a spatial perspective. The third section is dedicated to the outcomes focused in the linkage of spatial and virtual mobility including spatial visualization. The last section gives a critical discussion about the main findings and followed by discussion and conclusion.

2 THEORETICAL OVERVIEW

2.1 Spatial mobility and activity space

Spatial mobility, as a human-centered topic, reflects the movement of individuals through time and space and it is conceptualized as human mobility. Humans have been linked with movements historically since the early migration patterns that were driven by factors such as climate change, inhospitable habitats, conflict, or food scarcity. In modern times, the factors have evolved due to contemporary development such as wage imbalance, differences in welfare and living conditions, and globalization. (Barbosa et al. 2018).

In early studies of human mobility, Stouffer (1940) approached the spatial mobility in function of distance, explaining that proximity is the main factor that influences mobility preferences of people. Simply, that distance influence the spatial behavior of people. The author defined an early *Law of Intervening Opportunities* which claims that trips between two locations are driven primarily by relative accessibility of socio-economic opportunities that lie between those two locations. Afterwards, with the *Quantitative Revolution of Geography*, the aim was to quantify human geography and promoted the statistical/spatial analysis that reveals human theoretical frameworks (Adams 2001). Then, time factor raised up relevance in spatial mobility spreading out a new wave known as *Time Geography*. The Swedish geographer Hägerstrand emphasized trajectories of individuals through space and time in a famous representation known as "space-time aquarium". The new ideas with time as factor in space pictured different constraints imposed by social life on individual's daily trajectories. (Barbosa et al. 2018). The framework of time geography in spatial mobility created concepts such as space-time path (daily route) and space-time prism (activity space), also included the definition of three constraints that may affect the daily travel behavior of people such as capability constraint (i.e., ability to drive a car), authority constraint (i.e., limited access to buildings), and coupling constraint (i.e., a meeting at city center at 3pm) (Yu and Shaw 2007).

The conceptualization in spatial mobility mentioned above promoted the research based in spatial patterns and factors/constraints that may affect it. A popular concept that is reviewed frequently is the activity space and how it fluctuates its size through space-time in daily activities (Buliung and Kanaroglou 2006).

The activity space was already conceptualized in early studies by Dijst (1999) as action space. Then, Schönfelder & Axhausen (2003) defined activity space as the two-dimensional form which is constituted by the spatial distribution of meaningful locations where the traveler has personal experience or social contact. The structure of activity space was already characterized in early studies by Golledge & Stimson (1997) with three determinants: home location, activity locations, and travels between these locations. In modern studies, Ahas et al. (2010) developed the anchor point model to detect meaningful locations in the activity space of individuals traced by mobile phone data. These anchor points (i.e., home location, work location) are key locations to study the mobility patterns and the structure/geometric shape of activity spaces.

In further studies, Schönfelder & Axhausen (2010) suggested that the best elements that structure the activity space are home location, time spent in home location, number of activity locations in the local neighborhood, trips within the neighborhood, mobility to and from frequently visited activity locations, and travels between and around the centers of daily life. As we mentioned before, the elements in the space move in function of time creating dynamics/relationships in space. This longitudinal dynamic is defined as activity-travel behavior, and it is conceptualized by Järv et al. (2014) as the construction of daily habitual, weekly, monthly, and seasonal routines together with strong variety-seeking behavior.

The activity-travel behavior can be influenced by external factors that reshape the activity space. Fan & Khattak (2008) reviewed how the urban form of the neighborhood influenced the chosen places they frequently visit, Calabrese et al. (2013) approached societal and environmental factors that influence mobility and serve urban planners for assessing urban sprawl and better neighborhood design.

Vich et al. (2017) explained how the socio-economic background may affect the suburban commuting in cities, same as Buliung & Kanaroglou (2006) who also mentioned that factors as age, gender and income affect the commuting behavior and suggested policy assessment dedicated to travel reduction strategies. Their main findings were that wealthier households are associated with larger activity spaces. In contrast, the smaller activity spaces are related to women, the young and elderly, and people with lower income.

The studies by Järv et al. (2014) demonstrated that seasonality, as a longitudinal factor, explains monthly variation in activity spaces in daily-travel behavior. The study

was done in Tallinn, Estonia, involving working-age users (ages 20-64) who showed variations up to 20% in their activity between Winter (February) and Summer (July). The variation was higher in July in comparison with the baseline (12-month average), with 35% more activity locations. In cross-border regions, the factors that may affect the activity space can be reviewed by both individual and institutional influence (Silm et al. 2021). Perkmann (2003) explains that the institutional factors influencing the mobility at crossing-border level are low tariffs in transportation, free movement of goods and people, single currency, when talking about institutional measures. The activity space in cross-border regions can be influenced also by individual's preferences such as culture interests, exchange studies, tourism, job opportunities, taxes, just to name a few (Decoville and Durand 2019).

Indeed, the understanding of the patterns of individual activity space at the local or regional level provides real-world solutions. As it is done in the present work, the understanding of transnational people in the cross-border region of Finland-Estonia is a key. The lifestyle and the mobility of transnational people is reviewed by their activity space. Thus, the conceptualization of activity space under the scope of travel behavior, brings an activity space structured by activity locations, and the external factors that influence mobility should be also considerations for spatial mobility research. The external factors that may have affected the spatial mobility in the mentioned cross-border region is addressed by the COVID-19 pandemic and its limitation of mobility and linked with their mobile phone virtual interaction. The activity space is one of the spatial mobility measurements that can be linked with virtual mobility.

2.2 Virtual mobility and cyberspace interaction

The "digitalization" of society is a topic that has been increasing attention in geographical science since the term *information society* was forged. Reggiani (2000) defines it as a society in which citizens intensively communicate by using contemporary Information and Communication Technology ICT (mobile phones, tv, or internet and pc). Clearly, it is a society driven by the exchange of information. Janelle & Hodge (2000) expressed that information lies in a continuum from raw facts to knowledge and can be seen as an outcome of manipulation of data that provide insights or real-world understanding. Then, Goodchild & Sheppard (2000) define the same term as *information age* and claim it as the age of globalization, a global village, and touch an interesting schema saying it is the age of liberation of human interaction from the tyranny of space.

By understanding the information society as a connected network where information is flowing (Castells 2000) one question remains to be answered. Where this flow happens? Kellerman (2016) explains that the closeness in the information age is evident and the ICTs are breaking the borders in the world by creating a non-physical movement of elements and people (i.e., information, and tele-presence) and a new concept of space emerge known as *cyberspace*.

Janelle & Hodge (2000) defines the cyberspace as the space that connects society virtually by Information and Communication Technologies and transmit information in more efficient way than in physical space. Ferreira & Vale (2021) explained the relevancy of cyberspace in geographic space explaining that it can be broadly understood as a cyberspatiality claiming it as a spatial-digital formation.

This cyberspace or virtual space let people carry on activities of daily life such as work, education, leisure, purchasing of products, or financial transactions. These daily activities carried on in virtual spaces is referred as virtual mobility (Barbosa et al. 2018). The virtual mobility is explained in two perspectives by Kellerman (2016) based on the purpose: 1) information, and 2) communication. The first one corresponds to the access of information and all the flows that are carried on in the cyberspace (e.g., internet) until it is consumed for users at worldwide level. And the second one, refers to users who communicate via various modes of communication (e.g., videocalls). Complementary, Barbosa et al (2018) explains two extra classes of virtual mobility based on interaction: 1) virtual spaces that recreates mobility such as game's environments, and 2) virtual spaceless environments that are accessed through devices such as smartphones. The first mentioned virtual mobility refers to virtual travel through internet understood also as virtual tourism (Larsen, Axhausen, and Urry 2006), and the second mentioned virtual mobility is considered a virtual interaction of people which is attached to behavioral pattern such as frequency of communication, online shopping, or GPS navigation usage while traveling.

The behavioral pattern of people in mobility is attached to their use of time in certain spaces or cyberspaces. A particular characteristic of the accessibility to cyberspace through ICTs is that it can happen "on the move". People can access to cyberspaces while they are using their mobile phones during traveling to workplace by bus, as an example. Critical examination about it can be seen in Ellegård & Vilhelmson (2004). Generally, people can use ICTs to become mobile, more or less home centered (such as teleworker

does), and spatially more or less extended. The influence of time spent in cyberspaces through ICTs is reviewed by Vilhelmson & Thulin (2008) explaining how physical and social interaction is affected by the virtual mobility. In fact, by spending extensive time in cyberspace people can become less sociable and home centered, but others can use cyberspace for communication and interaction with closer relatives at distance (E. Thulin and Vilhemson 2005). The present work is centered in reviewing how the spatial mobility of transnational people is linked with their usage of time in cyberspace accessed by their mobile phones. The importance of this review is relevant due to the external factors that can influence the spatial mobility pattern of transnational people such as the global COVID-19 pandemic.

Living a transnational lifestyle requires certain patterns of communication. The reason is that transnational people move in physical space, but their relatives and friends stay static. Thus, trips are often related with its purpose such as being in contact with other people or being present at the working place. This study is limited to study the time spent in mobile phone cyberspace and its linkage with spatial mobility metrics during transnational moves.

The nodes of virtual interaction are a link between the physical space and virtual space (Vilhelmson and Thulin 2008). Homes for example are a node because the time spent in virtual space can affect the spatial pattern of mobility if the purpose is being home centered. Other nodes such as the workplace located in the neighbor country can affect clearly the spatial mobility pattern and the virtual interaction with relatives. In a nutshell, the linkage between spatial mobility and virtual mobility remains unexplored in transnational spaces and it is the aim of this study to clarify how this smartphone virtual interaction and external factors has influenced the space of transnational people in the study period.

3 CASE STUDY: Transnational Estonians in Finland

The transnationalism is defined as a phenomenon in which people cross geographical, cultural or political borders with specific economic or social purposes while having close ties with mentioned countries (Basch, Schiller, and Blanc 1994). The transnational people are characterized by "being" in more than one nation. The way of being is measured and understood based on the different activities they do. Commonly, transnational people have spatial mobility such as trips between countries to visit friends and family, also communication activities through ICTs such as phone calls or emails, and a deterministic activity of being transnational is the economic activity such a better income or investments. The mention ways of "being" in different nations are explained by Levitt & Schiller (2004), and the authors clarify that those activities are measurable. On the other hand, authors explained that transnational people also have ways of "belonging" which are not measurable. Belonging to a nation (or nations) refers to the sense of membership of the society as a result of memories or traditions, cultural activities and feeling to places. R. Ahas et al., (2017) defined the transnationalism in parameters of time and trips. They consider transnationals to people who spend at least 25% of the days in a year (92 days) in home country as well as in a foreign country and makes 5 to 52 trips in a year to mentioned country.

In cross-border context, Silm et al., (2021) explain that the increasing mobility between nations enhances the functional ties between them and this will generate an intense connection known as a cross-border region. The particularity in cross-border regions is that mobility can be permanent or temporary. Permanent for those who move to other country with settlement purpose (migration). On the contrary, the practice of temporary mobility is increasing between neighbor countries creating an extensive transnational mobility and lifestyle (Levitt and Schiller 2004). Due to the challenge of measuring temporary mobility, this study suggested as one of the research questions to evaluate the feasibility of data collected through mobile phone to measure spatial and virtual mobility with a spatial perspective.

The cross-border region between Finland and Estonia has been increasing after the Estonian independence on 1991. The visits between the two countries grew from 5.500 visits to 13.100 visits (on average per day) from 1993 until 1999 when crossing border became visa-free, in 2016 the visits increased significantly to 23.200 visits on average per day by ferry (Port of Tallin, 2019). The permanent mobility (migration) between the two

countries is unbalanced, Finns living in Estonia constitute the 0.45% of 2022 Estonian population (Statistics Estonia, 2021), meanwhile Estonians living in Finland represents the 3.5% of Estonian population (Statistics Finland, 2021). Silm et al., (2021) explain that permanent mobility of Estonian population to Finland is greater, than vice versa, because Finland is substantially wealthier. This review of volumes and temporal pattern of transnational people during 2015, revealed that crossing-border movements with touristic purpose is greater from Finland to Estonia (99%) than Estonia to Finland (94%). Nevertheless, the other type of visit from Estonia to Finland is considered as transnational people (5.2%), commuters (0.6%), and long-term stayers (0.5%). The visits from Estonia to Finland last 5 days on average and the duration relates to weekly rhythm of working days while they are coming back to Estonia on weekends. It is mentioned as well, that during 2020, the Finnish labor market had a shortage of personnel in construction and other services, giving to Estonians the chance to access to better salaries at cost of transnational lifestyle.

As we observe, the cross-border region between Estonia and Finland is dynamic. Cultural differences are seen based on the purpose of the movements from one country to another. Finns tend to move mostly for touristic purposes to Estonia on the contrary to Estonians that move with work related purposes to Finland. The measurement of changes of this temporary spatial mobility is addressed in this study at longitudinal level, including its linkage with smartphone virtual activity of the transnational group. It is well known, that the COVID-19 pandemic caused limitation to cross-border travels since the Spring 2020 and it is important to include it as external factor affecting spatial mobility. The incoming international travels were temporary banned and it affected people whose life involved crossing national borders (Järv et al. 2021).

3.1 Quantifying Human Mobility and Virtual interaction

The quantification of human mobility brings a variety of methods for measuring the daily movements of people and their virtual mobility through ICTs. Well known classical methods for spatial movements are travel diaries and surveys of mobility. A travel diary collects the time-space movement of respondent in their daily life. The information is later digitized and expressed in sections such as individual trips, time-space organization, transport behavior, and useful socio-economic parameters of individuals. The drawback of this method is the poor-quality information it gives about the daily trips (Kraft et al. 2020). Another classical method is the survey approach, and it measures the travel

patterns and personal profile, and they are filled in with different time range for example the University Community Mobility Habits Survey at the UAB (Barcelona – Spain) every two years. The main outcome of the surveys is to obtain the residence and work location as nodes in commuting traveling (Vich, Marquet, and Miralles-Guasch 2017).

As novel and modern methods, the approaches have come with specific kinds of data such as mobile phone detail records (CDR), social media data, or GPS tracks collected through loggers or phone apps. CDR data is a log stored in the antennas of network mobile phone operator and support the measurement of movements based of calling activity. There are vast applications of this data for human mobility studies including disaggregated individual level. CDR is able to cover large areas and long time periods but it has limited socio-economic variables information due to privacy policy (Järv, Ahas, and Witlox 2014). Complementary, social media data with geotag has supported the understanding of global movement patterns. The social media data is rather supportive for measuring mobility with mobility rates or diversity of destinations, but the results require validation with comparison of ground truth or official statistics (Hawelka et al. 2014).

Furthermore, the GPS tracking data collection has been efficient since the instrument to collection is a personal use app instead of a device that can be battery expensive. Prior to the consent of the users the GPS data collection approach is truly longitudinal, and it supports the understanding of spatial behavior over time and provides spatial-temporal data with good quality (Järv et al. 2021). The usage of this data in human mobility field has been applied in a variety of topics at different scale such as suburban commuting (Vich, Marquet, and Miralles-Guasch 2017), neighborhood walkability (Rundle et al. 2016), structural changes in cities (Calafiore et al. 2021), just to name a few. In order to enrich the mobility information, the GPS tracks are enriched with surveys that provide socio-economic background, types of activities, duration of activities, etc. The present study is focused on the usage of GPS tracks collected through mobile phone and its validation as an efficient data source for measuring transnational movement of people.

Regarding virtual mobility, the measurements are related mostly to activity or time duration which are carried on virtual spaces. Järv et al (2021) measured the virtual interaction expressed as daily communication activity and daily communication partners. The authors calculated the ingoing and outgoing call activity and text messages, then they

reviewed the diversity of partner communication-interaction splitting the country of communication such as Finland and Estonia. Another approach is calculating the time spent in virtual spaces accessed through ICTs. for example, Vilhelmson & Thulin (2008) measured the virtual access with time spent in computer and telephone usage and media related access like a TV understanding how people's daily life can be home-centered. Then, Thulin & Vilhelmson (2012) examined a group of youth people in Sweden using time-space diaries and interviews explaining how the spatial and virtual communication is integrated. The types of practices found were based on: home-oriented with heavy internet use, physically mobile with heavy mobile phone use, physically mobile with heavy internet and mobile use, and home-oriented, rarely mobile physically and virtual. Same as Lee-Gosselin & Miranda-Moreno (2009) that examined out-of-home activities and its relation with internet and mobile phone use. Authors found that mobile phone use was associated with active trips.

It is Indeed, it is a need the measurement of virtual interaction because it can influence the physical space of individuals. I can relate that probably it is harder to reach an unknown restaurant location without the option of navigational routing in personal smartphones. Thanks to the access to virtual spaces individuals are decreasing the time spent in physical traveling and probably decreasing the social interaction.

3.1.1 Activity space

The concept of activity space usually refers to the geographic extent where an individual carries out daily activities, and where meaningful places are located (Schönfelder and Axhausen 2003). Thus, the measurement of activity space is approached geometrically to both visualize and analyze the individual's spatial behavior. There are two options to measure activity space: using a certain distance/radius from the meaningful nodes or individual's trajectory or measuring the geographical area by various measuring techniques.

In a different view this extensity is also expressed as convex hull polygon, standard deviational ellipse (SDE), or buffering the representative daily path between meaningful activity locations (Vich, Marquet, and Miralles-Guasch 2017). The chosen measurement technique depends on the type of data used. Pappalardo et al. (2016) used Call Detailed Records (CDR) and measured activity space as the spatial spread of the cell towers visited from the individual's nodes. Vich et al. (2017) used convex hull polygon in daily path and deviational ellipse (SDE) with nodes. Järv et al (2014) in a deep analysis explain that

SDE measures the smallest possible area in which activity locations are found with a probability of 95%. In a longitudinal view, the author calculated the SDE monthly and daily based with monthly and daily activity locations respectively to describe the spatial behavior. In addition, this SDE calculation is agreed by Buliung & Kanaroglou (2006), explaining that it summarizes the overall dispersion and orientation of daily activities excluding the effect of outliers (Yuill 1971) and underlies the home and workplace location. Thus, the SDE provides a reliable understanding of the extensity of activity space whereas the convex hull has no statistical connotation.

Nevertheless, referring to GPS records, buffering the daily path is described as the more realistic calculation because it represents the actual route followed by individuals (Vich et al, 2017). In this metric, it is necessary to take into account the buffer radius. Vich et al (2017) used a buffer with 500m radio from the line that connected the entire route between the activity locations. This buffer was chosen based on the maximum accuracy error recorded by GPS signals. The radio chosen fell into the range 200m – 1000m used in previous health accessibility studies done by Sherman et al., (2005), Zenk et al., (2011), and Hirsch et al. (2014). In the context of transnational spaces the radio used is 200m for the representation of activity space, adding the particularity that overlapped geometries must be dissolved (Järv et al. 2021).

3.1.2 Daily travelled distance

The distance traveled in spatial mobility is measured by the length of the route created between the locations captured as moves, when talking about mobile phone GPS tracks. The distance traveled can be expressed with temporal rhythms such as daily distance traveled is it have seen in studies by Järv et al., (2021) at transnational level and Kraft et al (2020) at local level. The distance traveled explains the need of individuals to travel from point A to point B. These movement happen between locations where individuals do meaningful activities for their daily lives and are defined as stops (Ahas et al, 2010). It is considered a stop when certain amount of time is spent per location and refers to a specific purpose in the daily life of the individual (Bazzani et al. 2010).

The distance traveled at local level can be calculated in the urban-street network. Palominos & Smith (2020) define daily travels as an active travel corridor which is calculated with network analysis between the stops. The objective of studying the displacement of individuals is to understand the spatial behavior. Fan & Khattak (2008) reviewed the spatial behavior at neighborhood level and demonstrated that shorter daily-

traveled distances are related to land use mixture. Same as Bahadure & Kotharkar (2015) the authors revealed that neighborhoods with high land-use mixture have efficient distances to essential activity locations. Efficient distances are understood as shorter and in some cases pleasant.

The daily travel behavior of individuals is anchored to the their most meaningful locations: home and work (Ahas et al, 2010). But clearly, when the study area become larger such as transnational spaces are, then the anchor points gives transnational movement pattern. Silm et al (2021) reviewed temporal patterns explaining how transnational people make often trips between Finland and Estonia at weekly rhythm for work purpose. The study of the changes in spatial mobility allows authorities to provide better decision making based on factors that shape mobility at local, national, or transnational level such as improvements in transpotation system (Tenkanen and Toivonen 2020) or cross-border communities (Gerber 2012). In the present study, the daily travelled distance may help to understand the movement pattern of individuals at transnational level. The variation of the travelled distance reveals the longitudinal travel pattern affected by external factors, also it is used to find how the spatial behavior is linked with the smarphone virtual interaction.

3.1.3 Daily time of smartphone usage

The time spent on smartphone screen can be considered as metric to indicate the engagement to the virtual space. The interaction between the user and the smartphone (ICT) creates access to a virtual space where the user practices daily life activities. Most of youth carry on virtual daily activities like communication with friends and family or leisure time like videogames (E. Thulin and Vilhemson 2005), adults carry on activities based on their lifestyle such as remote working either at home or cybercafes, also online shopping of groceries or goods, financial activities such as bank transfers and payments that avoid physical moves to the bank, remote studies, and communication and leisure activities as well. (Barbosa et al. 2018)

In studies from Deng et al., (2019) the authors studied the smartphone usage pattern from fifty people during one week and showed that on average the users spent 2 hours and 39 minutes per day using the smartphone. By using sophisticated and granular analysis, the preference of the smartphone's app usage started with social networking, followed by media maps such as netflix, then web surfing apps, and finally communication apps such as emails.

The pattern of the smartphone usage is influenced by the demographic group of the user and its preferences. For instance, Linnhoff & Smith (2017) demonstrated that on average men spend 3.2 hours/day meanwhile women spend 4.8 hours/day. Womens tend to use personal apps for productivity and social networking in comparison with men that use more apps related to sports and food. Generally, the preferences or needs of each user influence the time spend in smartphone. If part of the work of a user is to maintain digital marketing from social network in its personal phone, then they may have more hours spent in social network. The key factor, is based on the purpose of the usage of smartphone. When users are moving at local or transnational level, the habits of smartphone usage can influence their traveling. As an example, transnational workers may decrease their smartphone usage at the working city because they have little time to spend on it. On the contrary, during the trip they may be using social network, reading books on phone, or simply calling or chatting. This assumption is done in order to explain how the smartphone usage habits of the user can influence the spatial travel behavior. Based on the idea mentioned above, the present work was dedicated to understand the linkage of the smartphone usage habits and its influence in the spatial mobility at transnational level. The consideration of external factors such as the COVID-19 pandemic and the spatialization of the virtual interaction at transnational level are included.

4 DATA AND METHODS

4.1 Data and sample

The Mobility Lab of the University of Tartu (UT) has collected smartphone data since 2013. For collecting the smartphone data an Android application called MobilityLog is used, which is designed for long-term mobility tracking and social-network-related experiments. The application has been jointly developed by the Computer Laboratory of the University of Cambridge and the Mobility Lab, UT since 2010. The sample for this study includes 45 anonymous users that have been traced in Estonia and Finland since August of 2019 (before COVID-19) until November 2021, covering a total period of 28 months. The MobilityLog app collects a variety of data such as GPS locations, call activity, surveys of socio-economic background, and phone usage information. For the present study the datasets used were: spatial data (GPS coordinates, timestamps); Phone use (screen events, timestamps).

The GPS dataset collected contains ~49.7 million of locations (data points) that enables to discover the spatial travel behavior of the transnational users. The trajectory of their travels was created and it supported the accurate calculation of metrics such as daily travelled distance and daily activity space. On the other hand, the dataset of phone use contained in total ~2.03 million records with usage event attributes such as screen-on events and screen-off events. Only the screen-on events (~29 thousand records) were used as an indicator for a virtual interaction and its duration was calculated by the change (from off to on) in chronological order. This enables to understand the longitudinal virtual behavior at daily level and was used for a spatial enrichment process to find the locations of daily virtual activity.

The Mobility Lab supplements the smartphone-based data with quantitative interviews (pre-interviews and post-interviews). The pre-interview aims to gather semantic information about the activity locations (place of residence, place of work/school, leisure time activity sites, etc.), members of social network (type of connection, communication channels used, frequency of communication by different channels) and socio-demographic background of the participant. The post-interview is conducted at the end of the smartphone tracking period and is based on the information collected by the smartphone. The interview information was not used in this study.

The encrypted smartphone data was uploaded via mobile internet or WiFi from the mobile phones to the server of the Mobility Lab, UT. The data provided with surveys are

automatically linked with MobilityLog data by a unique ID which is given to each respondent for privacy purposes. The data from MobilityLog and surveys are stored in a secure database in the server of the Mobility Lab, UT.

4.2 Study area

The transnational space of this study was considered by the two independent administrative boundaries of Finland (capital city Helsinki) and Estonia (capital city Tallinn) (Figure 1). The exploration of the movement dataset showed that some users were travelling to other countries different that Finland and Estonia. Thus, all moves outside the study area were not considered for the calculation of the metrics. The specification about removing unnecessary data and its transformations are explained in the following sections.

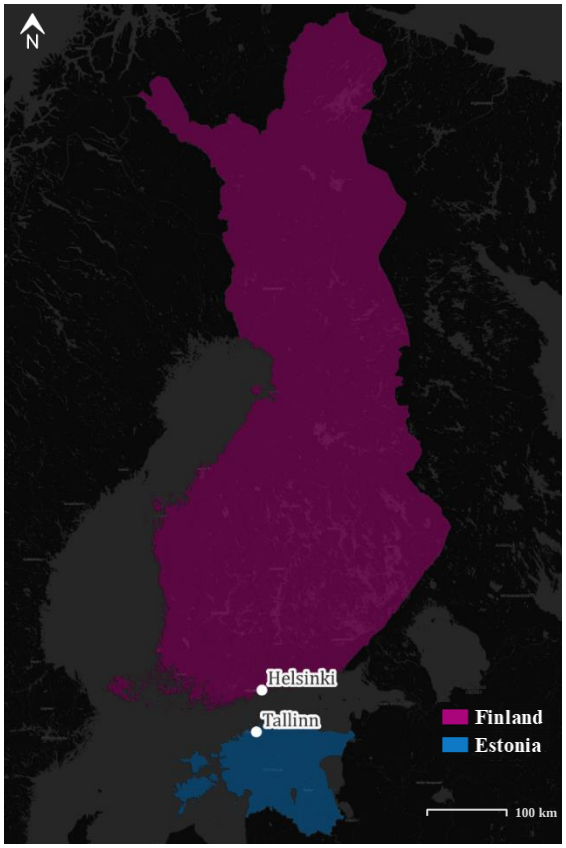

Figure 1. Study area: Independent Administrative boundaries of Finland and Estonia. Basemap Darkmatter CartoDB CC-BY-3.0

4.3 The global Covid-19 pandemic

The COVID-19 in the last years was an external factor that has affected considerably the spatial/virtual mobility around the world. The present study is considering how the Covid-19 pandemics effected in the spatial and virtual mobility of

transnational people. The way the Covid-19 pandemics is aligned in this study is by splitting the longitudinal indicators in periods. Thus, it helps to visualize how the Covid-19 situation changed in comparison to what it is called the baseline (pre Covid-19 seven months in 2020) until the last month sampled in 2021. The periods were taken from Järv et al. (2021) a study of Covid-19 affection in spatial mobility and communication activity between Finland and Estonia, then complemented with new period taken like the second lock-down restrictions in Finland during March 2021 (ERR News, 2021). The periods were generalized by month in the transnational space formed by Estonia and Finland. The longitudinal view can be seen in Figure 2.

As a comment, the period called "Restrictions" during February and March of 2021 refers to a month where restaurants and bars closed to avoid gathering of people. The periods are representative in a general way in Estonia and Finland.

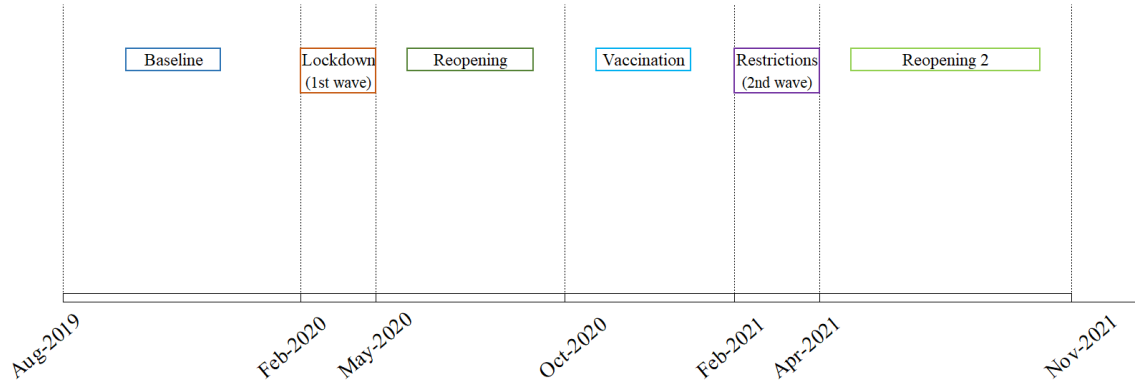

Figure 2. The division of the study period regarding the Covid-19 context.

4.4 Data preprocessing

The processing of a large dataset is challenging due to time consuming steps. The best way to see the progress during the steps was running a Python programming workflow in loop for each transnational user. Then, all the results were gathered or used together as loop again in order to keep adding attributes to the moves or calculating indicators. For spatial metrics, it is understood as move the trajectory (LineString) created sequentially with its locations and timestamps. Most of the users had records outside Estonia and Finland and they were removed in order to have an accurate measurement at daily and transnational level. Also, the time interval between sequential records longer than one day were removed. The total dataset decreased 9.93% after both filters were applied. With this clean data as an input, the transnational metric was calculated counting the crossing-border of users at daily level considering the direction of commuting. Graser

(2021) explains that movement data must cover the spatial extent required, in this case the extent of Finland and Estonia understood as a study area. Also emphasizes that it is proper to evaluate and understand the movement dataset so there is no misleading to wrong conclusion or metrics.

For virtual interaction metrics, the dataset of screen-on events user's smartphone was prepared with no spatial attributes but only timestamps at daily level. Then, it was used to enrich the moves (LineString) of transnational users matching the day attribute. The geometry used in moves changed from the daily trajectory (LineString) to its last location in the day (Point). This spatial enrichment helped to disseminate the virtual behavior at daily level with transnational attribute. The counties of Estonia and Finland were used as spatial units for aggregation of daily virtual interaction to show the spatial distribution of the daily screen-on events. The processes of preparation, transformation, aggregation, and calculation were documented as workflows in the following sections.

4.4.1 Movement data preparation

The moves dataset preparation consists in the transformation of GPS locations with Point geometry to trajectories with LineString geometry. The process was handled with the Python library Movingpandas for movement datasets. Once the moves trajectory dataset was ready it was needed to pass two filters: 1) Sampling-temporal outliers, and 2) Spatial outliers. The sampling time is the duration between each pair of GPS records in chronological order and it consistency shows how heterogeneous is the dataset. The main idea was to keep the dataset at daily temporal quality so all the sampling times over 86.400 seconds (1 day) were removed.

Once the sampling-temporal outliers were removed the new dataset contained on average 29 seconds as sampling time with its median value equal to 1 second. This process of sampling heterogeneity gave a good temporal quality to the dataset and makes it reliable to calculations. This workflow can be seen in Figure 3. The GPS raw data contained a Well Known binary (WKB) geometry format that required to be transformed to Well Know Text (WKT) which is the format used for GeoDataFrames in Python.

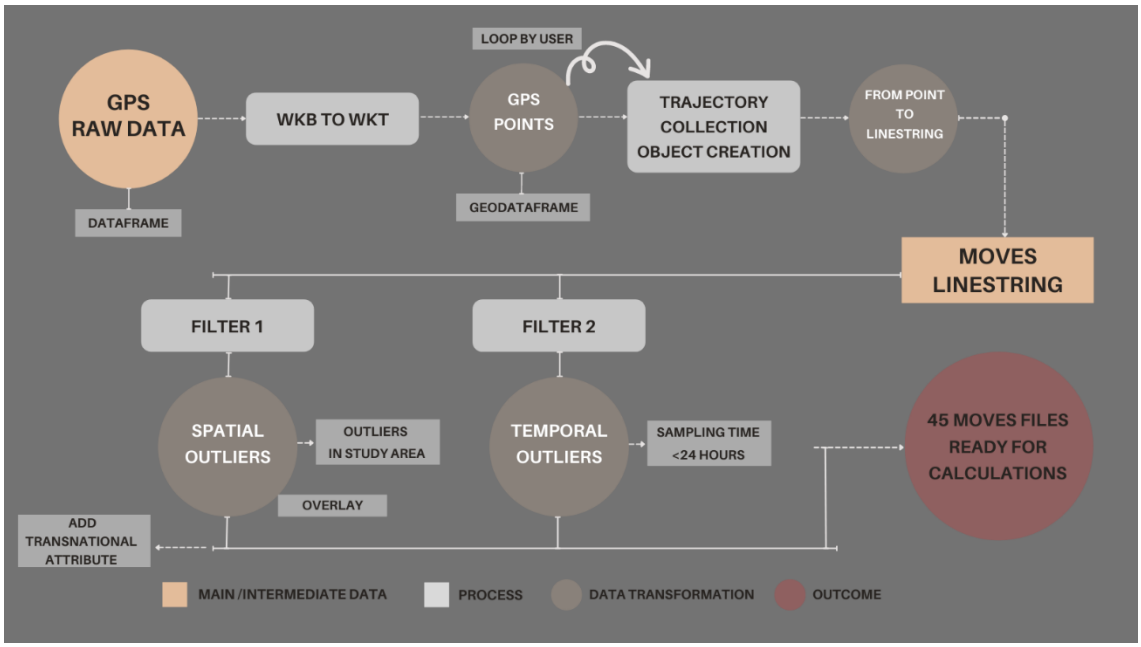

Figure 3. Workflow of data preparation: From GPS to Moves file

Furthermore, the moves dataset requires evaluation at spatial context. All the moves that occurred outside the study area (each administrative boundary of Finland and Estonia) were removed and the ones inside attributed with its country of move. The spatial outliers were removed once GPS locations were transformed to trajectories to keep precision in further distance calculations. The Figure 4 shows the moves files of the data sample. Once, the moves dataset was prepared the workflow moved forward to the calculation of daily indicators.

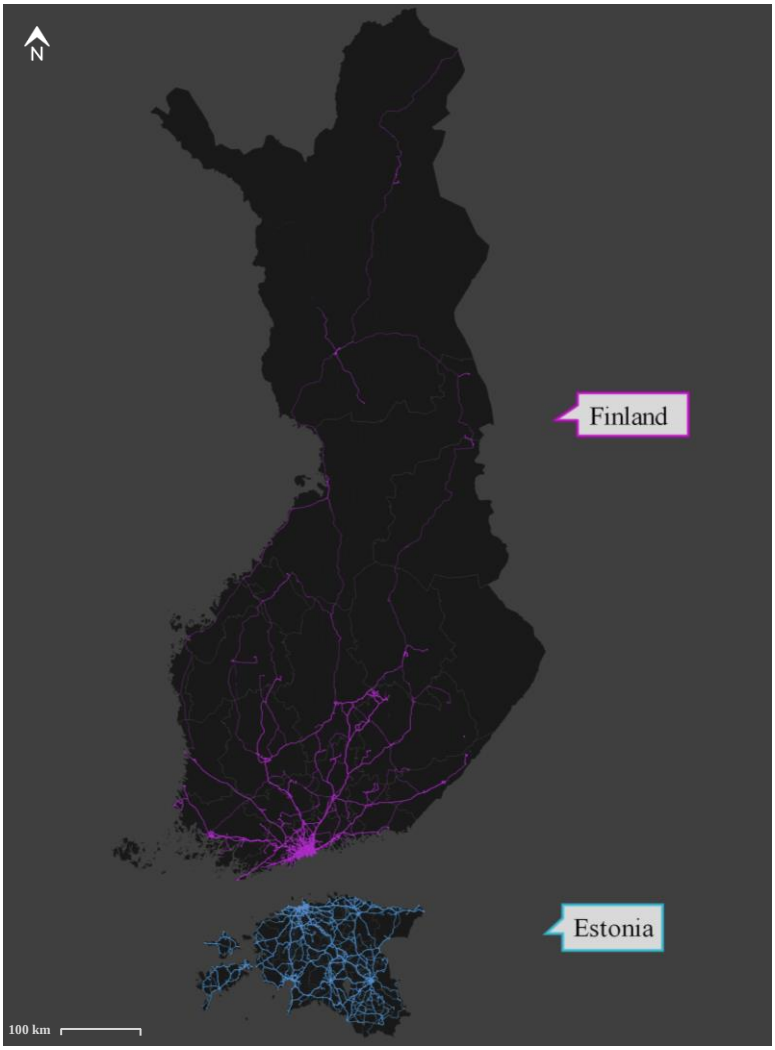

Figure 4. The overall mobility of the sample distinguished by Finland and Estonia

4.5 Calculating metrics for analysis

Once the moves were prepared, they were used to calculate the needed metrics that helped to understand the spatial and virtual travel behavior. The workflow was done in order to study various metrics: 1) Spatial behavior, 2) Cross-border behavior and 3) Virtual interaction.

4.5.1 Measuring transnational spatial behavior

The moves dataset was aggregated at daily level and by each user for the calculation of both spatial indicators: 1) Monthly travelled distance, and 2) Monthly activity space. The calculation attributed transnationalism in its travels. At daily level, the average traveled distance was normalized by the number of users in its specific day. Once all days were calculated the monthly value was normalized by the number of days when the user

was active. So, the calculation represents the average daily traveled distance in each month. Same process was done for the activity space and it is explained in Figure 5.

Both spatial indicators were attributed its country of move so we can understand better the transnational pattern and differences. The traveled distance was calculated in Mercator projection (EPSG: 3857). The daily activity space was calculated with 200 meters' buffer in each daily trajectory. All the overlapped activity spaces were dissolved to prevent repetitive and erroneous calculation. The spatial process of activity space was accelerated by simplifying the trajectory at 100 meters' tolerance which gave still an accurate calculation but light in geometries. Surface calculations were done in Mercator projection as well.

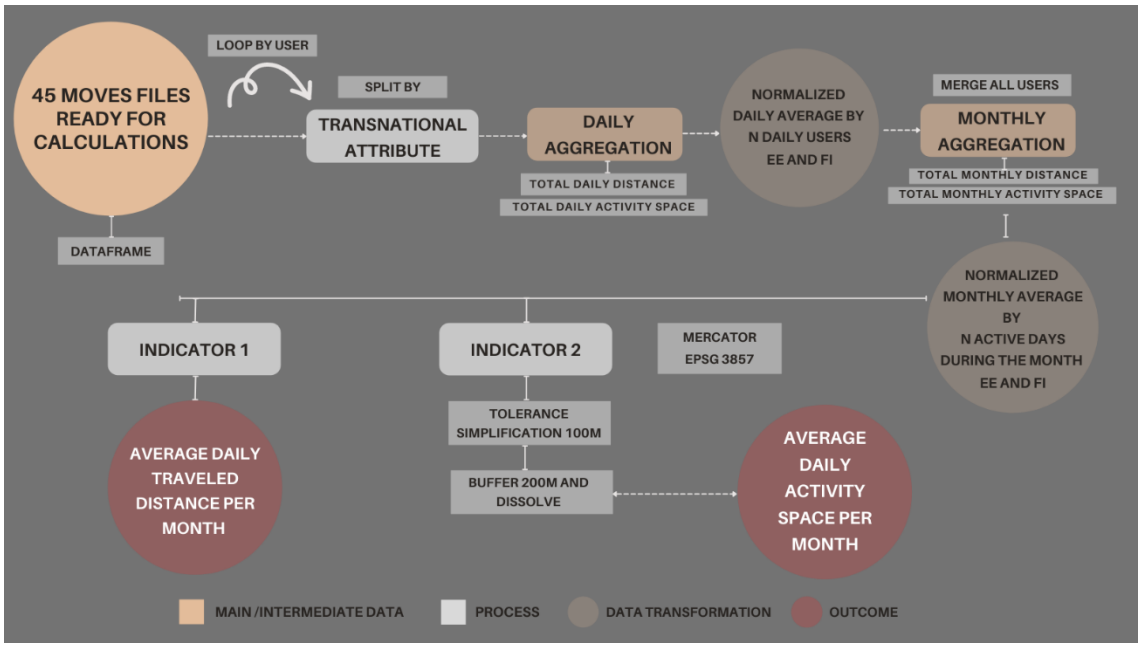

Figure 5. Workflow of Spatial behavior indicators

4.5.2 Measuring cross border behavior

Each segment of the transnational trajectory has a country attribute where the move happened. So, with this attribute in chronological order it is possible to know when the next move occurred in a different country. A code was assigned to moves from Estonia to Finland and a different code to moves from Finland to Estonia. Then, codes were counted independently at daily level giving the number of crossing border every day. This value helped to calculate the average normalized by the number of users in the same day. In order to get an indicator that explains the monthly average was calculated considering the length of each month were daily values were counted. The overview of the workflow can be seen in the

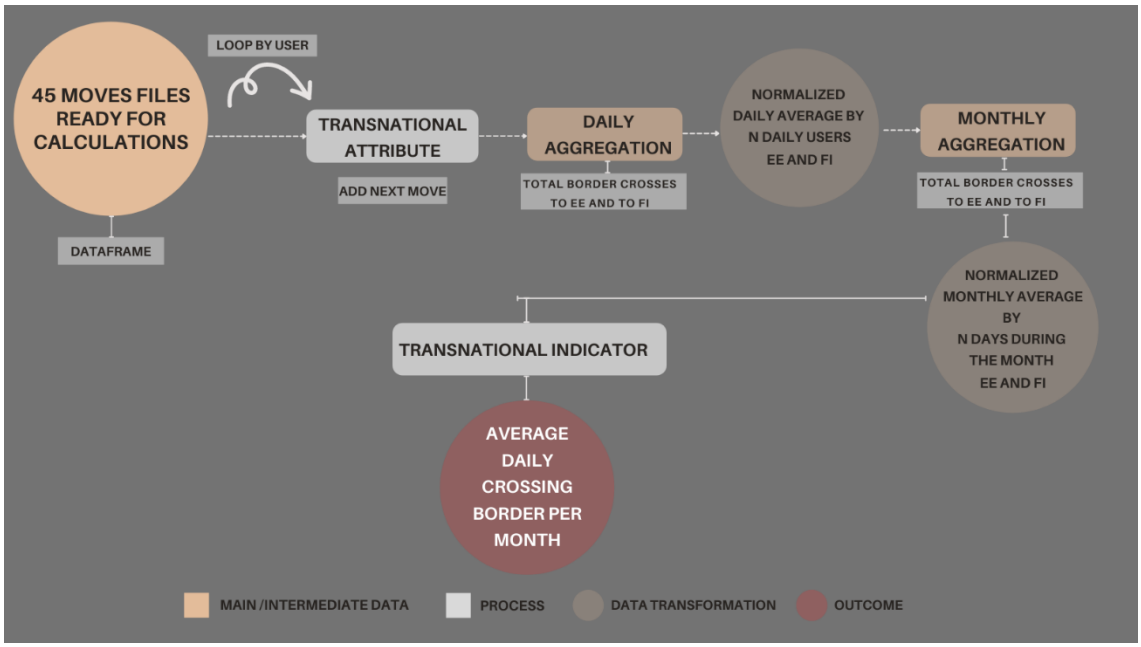

Figure 6. Workflow of Cross-border behavior indicator

4.5.3 Measuring virtual Interaction

The events of the phone usage dataset were sorted chronologically and it showed a logical order switching from screen-on to screen-off and screen-off to screen-on. Then, the screen-on event duration was calculated by the difference with the timestamp of its next event, and so on with all the events. Once the duration was calculated for all events only the screen-on events duration was kept for being used in further processes.

The screen-on events duration has a median of ~1 minute of screen-on considering the whole data sample. The distribution of frequency of the screen-on events duration can be seen in the Figure 7 which includes its median value as red dashed vertical line. Generally, the screen-on event duration seems to be lower than 1 hour with few exceptions considered outliers.

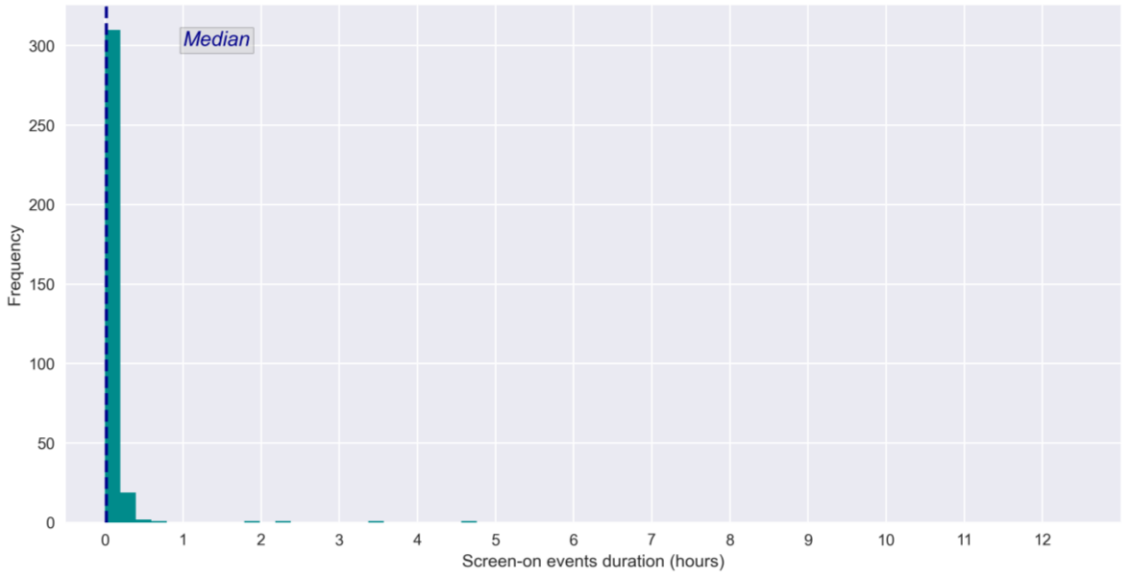

Figure 7. Screen-on events duration distribution of frequency

Once the screen on duration was calculated the dataset was aggregated at daily level having a total duration by day by each user dataset. The daily distribution has a median of ~3 hours. This daily dataset still does not contain any spatial attribute so the dissemination by transnational country is not possible at the moment. Then, in order to enrich this daily screen on duration the day attribute was matched with a daily move. To achieve this matching, the moves of each user was geometrically aggregated at daily level as a LineString and then transformed as a single point attributed by the last location of its daily trajectory. Finally, by attributing transnational daily moves to screen on duration it is possible to proceed to virtual interaction indicators at transnational level. The Figure 8 shows the overall spatial distribution of daily screen on duration of all the data sample. The daily outliers of screen on events were removed only for visual purpose. Logically, the daily screen on duration cannot be greater than 1440 minutes (24 hours).

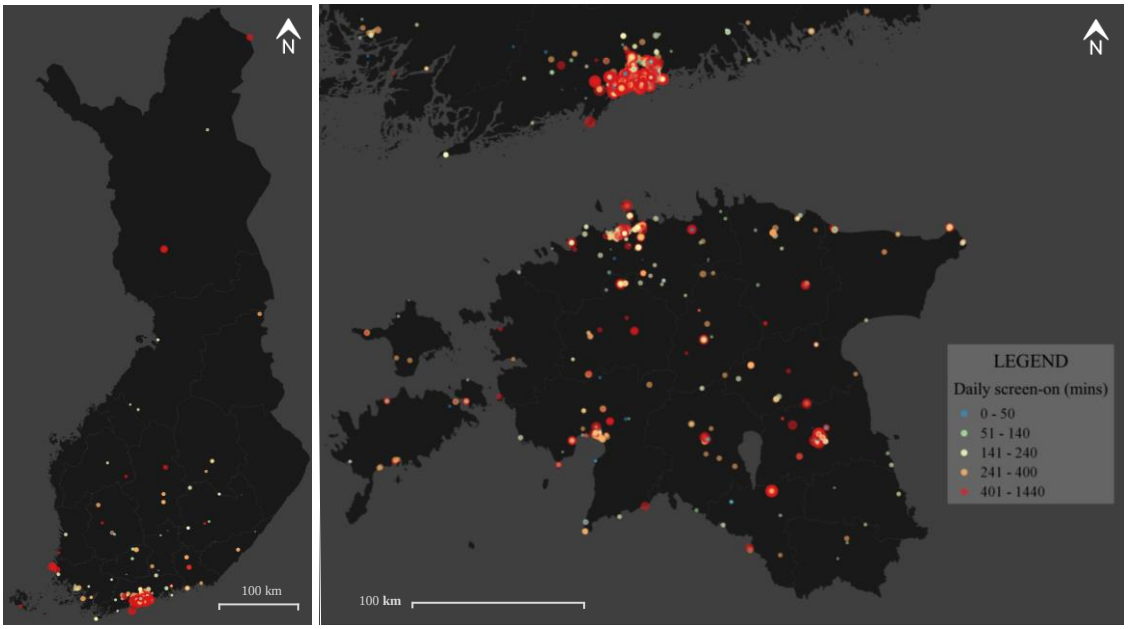

Figure 8. The overall spatial distribution of daily screen-on duration. Classification as 5 quantiles

The daily screen on event duration of the data sample was aggregated at daily level. It gave the daily average normalized by the number of users in the same day. Then, the aggregation at monthly level gave the average normalized by the number of days when screen-on was active. Additionally, by each month, outliers were removed depending on the number of days. For example, if a user was active during five days in Finland in a selected month then the daily values over 120 hours were not considered (24 hours during 5 days) and so on with other months in order to get a logical threshold.

Finally, the daily average of screen-on duration calculated by month at transnational level gives the option to obtain a second indicator of transnationalism. The ratio (proportion) of screen-on duration between Finland and Estonia was added to find out how virtual interaction is linked with spatial mobility. This additional indicator will support findings and give more spatial and virtual perspective about the transnational people. A detailed workflow of the calculation of transnational indicators can be seen in Figure 9

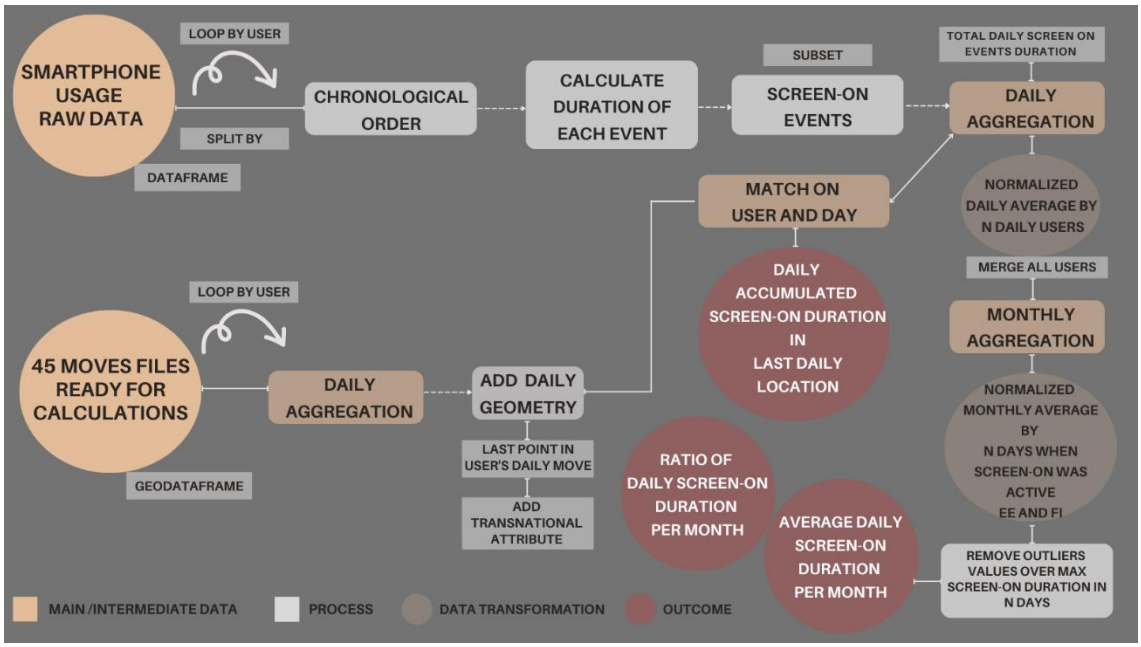

Figure 9. Workflow of Virtual interaction indicators

4.6 Data analysis

The main purpose of analyzing given metrics was to understand the variation regarding both spatial and virtual mobility during Covid-19 periods in comparison with a baseline period (from 2019-08-01 until 2020-03-01). Baseline period characterizes the normal daily life before COVID-19 pandemic started. For each spatial measure examined, the monthly average was calculated with daily averages while considering daily sample sizes (Figure 5). For the cross-border measure, the monthly average was calculated with daily averages while considering daily sample sizes (Figure 6). For each virtual measure, the monthly average considering monthly sample size in days was calculated with daily averages considering daily sample sizes (Figure 9).

In total, 9 metrics were analyzed, as follows:

1) The daily travelled distance in Estonia
2) The daily travelled distance in Finland
3) The extent of a daily activity space in Estonia
4) The extent of a daily activity space in Finland
5) The cross-border mobility to Estonia
6) The cross-border mobility to Finland
7) The duration of virtual interaction in Estonia
8) The duration of virtual interaction in Finland
9) The proportion of virtual interaction in Finland compared to Estonia

First, a descriptive analysis is conducted by measuring the proportional difference from the baseline for each month to understand the change from a common pattern of spatial behavior. The measurements were plotted in figures to give perspective about the influence of the COVID-19 on the spatial behavior.

Second, the linkage between the spatial mobility and virtual mobility was statistically examined with Ordinary Least Squares Regression (OLS). The OLS method is a linear regression equation which describe the relationship between one dependent variable (Y) and one independent variable (X). The coefficient of determination (R^2) tells how much percentage of variation the dependent variable can be explained by the independent variable and range between 0 and 1. For this analysis, the OLS model was run in correlation pairs at transnational level considering the virtual interaction indicators as dependent variables. In total, 72 OLS models were run: 6 correlation pairs of screen-on indicator during 6 periods, and 6 correlation pairs of proportion of virtual interaction during 6 periods.

The OLS model was run by each Covid-19 period in accumulative approach. So, for the baseline OLS was run with series of 7 months corresponding to its time range. Then, the months corresponding to the first lockdown were added and the OLS was run with series of 9 months. The same accumulative approach was done for the next period and so on. The linkage between the dependent variable (Virtual interaction) and the independent variable (Spatial mobility) is explained by the statistical significance (P-value) and the coefficient of determination. This statistical power of influence between spatial mobility and virtual interaction supports finding how strong was the influence of the mobility restrictions during Covid-19 in the virtual interactions of transnational people.

5 RESULTS

5.1 Changes in spatial mobility

The spatial behavior analysis revealed that transnational users reduced their spatial mobility during the Lockdown 1st wave in ~75%, as it is shown in Figure 10 during March and April, of 2020. In both First Reopening and Second Reopening the traveled distance increased in both countries. The relative difference is that in Finland (~75%) the mobility increase is higher than in Estonia (~50%). I say relative because in median absolute values the daily traveled distance in Estonia is ~103 km meanwhile in Finland is 22.7km. This changes in the reopening explain that transnational people moved more than normal in Finland after lockdowns.

A second strong decrease of mobility is seen during the Restrictions 2nd wave on March of 2021 when the gathering in public places was forbidden specially in restaurants and bard but people was able to move in green spaces. Something interesting to note, is that during vaccination people remained calmed and no changes of mobility were seen but during Spring of 2021 transnationals seems to prefer movement in Estonia.

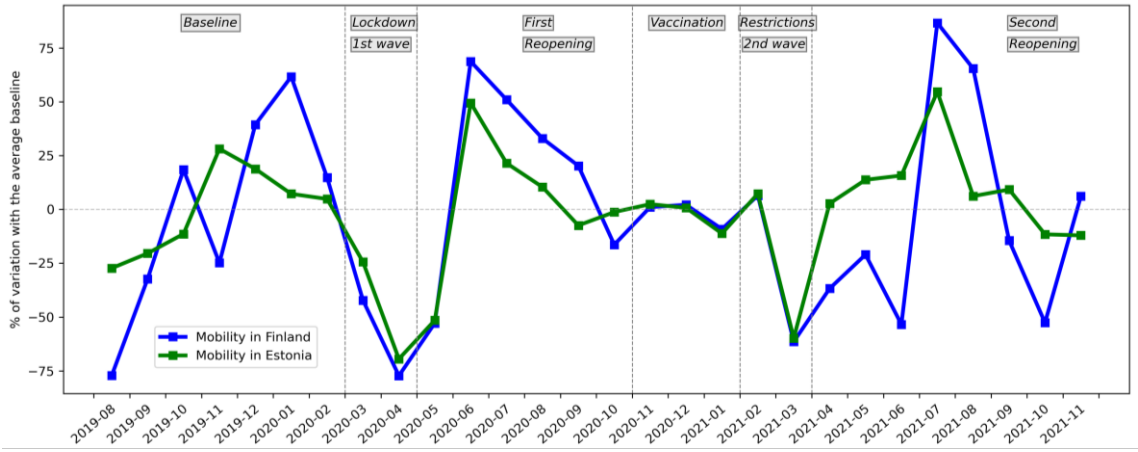

Figure 10. Monthly variation in daily average distance traveled compared to Baseline

In general terms, the spatial mobility of transnational people is higher in Estonia than in Finland. There is an increase during summer months in First and Second Reopening and the decrease during Lockdown and Restrictions is evident. On the other hand, the activity space showed a correlated pattern which is logic. Transnational people move long traveled distance that gives bigger activity spaces. A decrease in activity space can be seen again in the Lockdown 1st wave and in Restrictions 2nd wave as the Figure 11 shows. The increase of mobility in both Reopening has a significant difference in Finland. The Second Reopening shows higher increase at ~75% and it suggest that transnational

people took longer trips in Summer of 2021 than in Summer of 2020. In absolute terms the median activity space in Estonia is 25.8 km^2 and in Finland 5.4 km^2. This value can explain that transnationals move wider in Estonia and locally in Finland.

Figure 11. Monthly variation in daily average activity space compared to Baseline

5.2 Changes in cross-border mobility

Transnational people were moving back and forward crossing border between Estonia and Finland. The mobility restrictions of entering to another country during Covid-19 brought a decrease of travels. The reflect of these restrictions can be seen in the transnational space between Finland and Estonia during the Lockdown 1st wave and the Restrictions 2nd wave in the next Figure 12. The cross-border mobility decreases at ~100% in transnationals crossing to Finland and in ~75% crossing to Estonia. This suggest that people traveled more times to Estonia than to Finland. The monthly average during the lockdown was 4 times crosses to Estonia and 1 time cross to Finland.

The First Reopening showed a fast increase in crossing border and what it is good to highlight is how the crosses had a decreasing tendency until the Restrictions 2nd wave. Another anomaly can be seen in Vaccination period when transnationals traveled more to Estonia in December 2020. Surprisingly, after the 2nd wave the crossing border seems to find a balance in a lower average (~25%) than baseline. This phenomenon can be attributed to the preference of working remotely as it happened to many people after lockdowns. On monthly median values transnational people cross border ~11 times to Estonia and ~12 times to Finland.

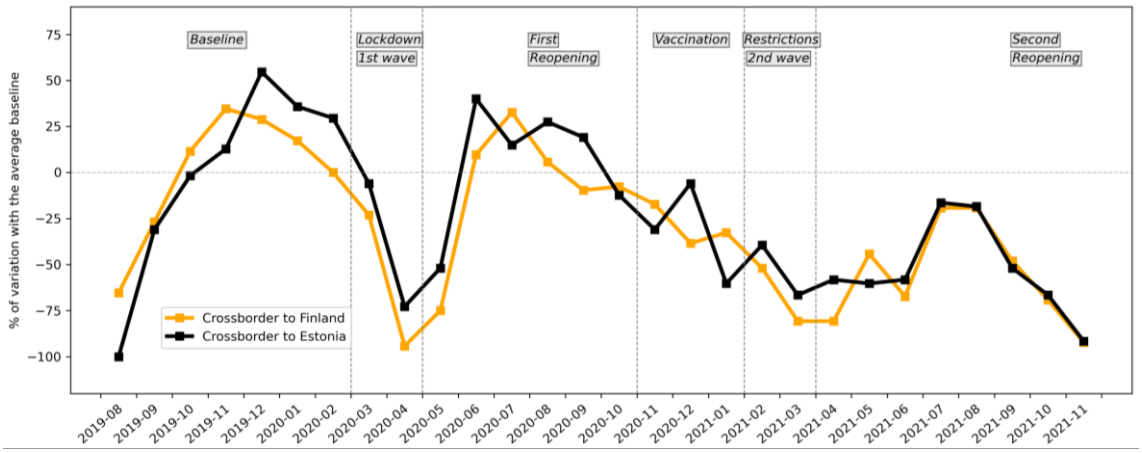

Figure 12. Monthly variation in daily average cross-border mobility

5.3 Changes in virtual mobility

The virtual mobility of transnational users had a very strong anomaly during Lockdown 1st wave. The Figure 13 shows how the virtual interaction increased in almost 200% but particularly only in Finland. On other hand, in the same period the virtual interaction decreased ~50% in Estonia. Clearly, the dataset shows the extensive usage of smartphones during the lockdown and seems that transnational people decided to spend the lockdown in Finland.

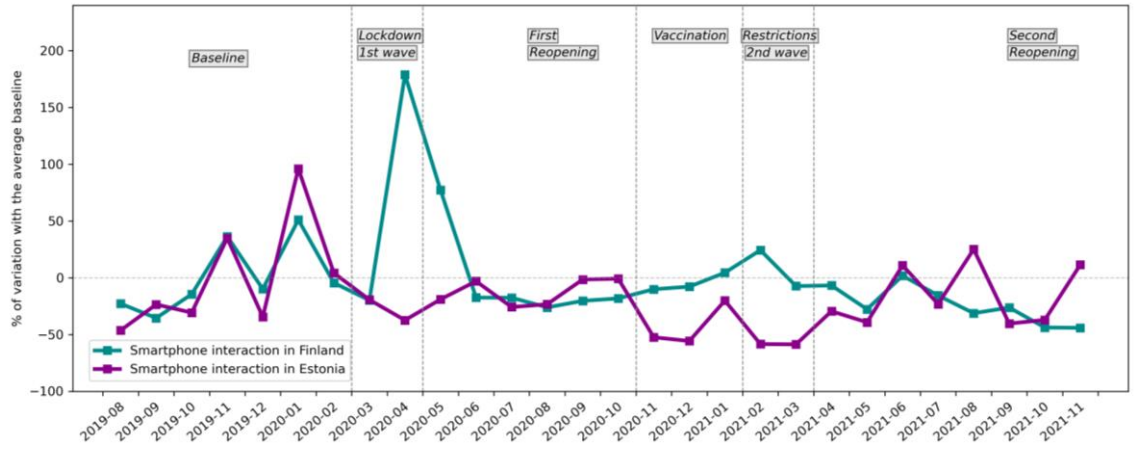

Figure 13. Monthly variation in daily average of virtual interaction compared to Baseline

In general, the virtual behavior seems balanced in normality with peaks during the baseline. The anomalies in baseline can be attributed to communication pattern of holidays. Also, there is an inverse anomaly during Vaccination and Restrictions 2nd wave where the virtual interaction in Estonia is reduced in ~50% but in Finland increased ~25%. As an assumption, seems that transnationals preferred to spent vaccination period

and Restrictions 2nd wave in Finland. The daily average median of virtual interaction in Estonia was ~5 hours meanwhile in Finland was 7,5 hours.

Comparing the virtual interaction proportion (ratio) between Finland and Estonia can explain in which period anomalies are present. The main anomaly was found in the Lockdown 1st wave when virtual interaction was 5 times bigger than in Estonia, as it can be seen in the Figure 14. Also, the ratio in the Vaccination period and in Restrictions 2nd wave shows an increase in 2 times and 3 times, respectively. The anomalies can reveal that transnational people had more virtual interaction with smartphone while they stayed in Finland. Their preference of being physically in Finland during Vaccination it still questionable because it can depend of their preferred place of vaccination. But, seems that they preferred to spend physically more in Finland most probably because of working activity.

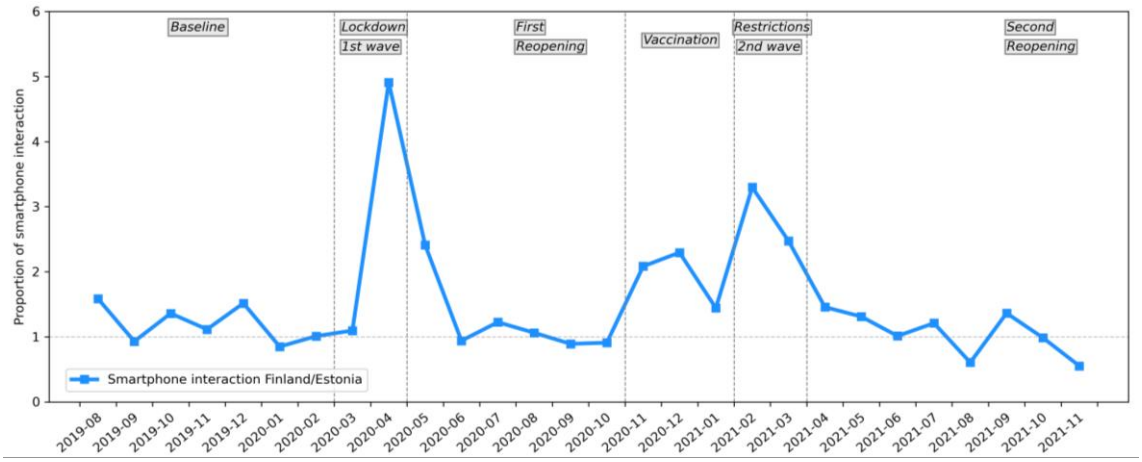

Figure 14. Monthly variation of virtual interaction ratio between Finland and Estonia

5.4 The nexus between spatial and virtual mobility

Some interesting insights about the spatial and virtual behavior at transnational level have seen so far. But still an important question needs to be answered. How is the space linked with virtual interaction?

So far the spatial distribution of the daily virtual interaction of transnational people was seen in the Figure 8. The virtual interaction seems to be scattered and it is not giving a clear message about its link with space. In another perspective, the virtual interaction can be seen aggregated into counties in order to understand the spatial concentration and in which administrative units exist more virtual interaction. The spatial concentration of the virtual interaction at County level can be seen in the Figure 15.

As it was already mentioned, the virtual interaction seems to be scattered in Estonia and concentrated in Finland. Finland contains most of the virtual interaction into its capital region Helsinki-Uusimaa with the 78% of total concentration. On the other hand, Estonia concentrates virtual interaction in its counties with greater urban areas Tallinn (in Harju county) and Tartu (in Tartu county), with ~5% and ~10% of total, respectively.

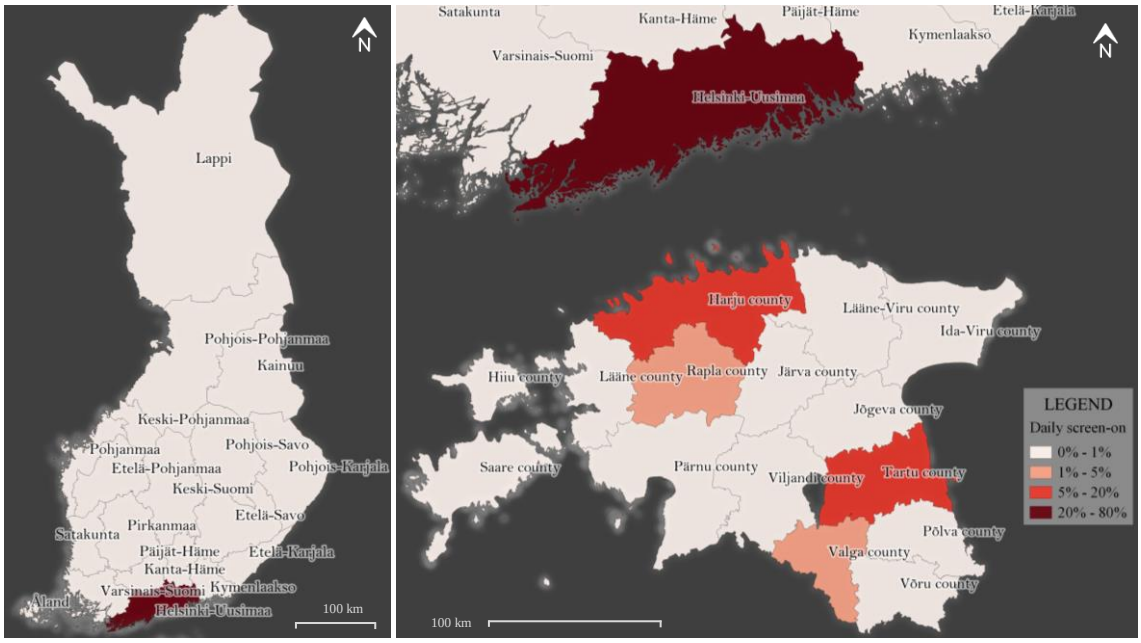

Figure 15. Concentration of daily virtual interaction at County level. Natural Breaks with 4 classes

Then, to comprehend in a more meaningful way this linkage, the coefficient of determination of the regression model (OLS) can explain how strongly is the virtual interaction affected by the changes in spatial mobility. The Figure 16 represents how strongly is affected the virtual interaction by the changes in spatial behavior in Estonia. The most significant influence was found in the Restrictions 2nd wave period. The activity space and the crossing border explained the 20% and 10% of the changes in virtual interaction at 95% confidence level. During Lockdown 1st wave period the activity space had a strong influence in the changes of virtual interactions with nearly 35%. Lockdowns in general had the strongest affection by activity space and cross border mobility.

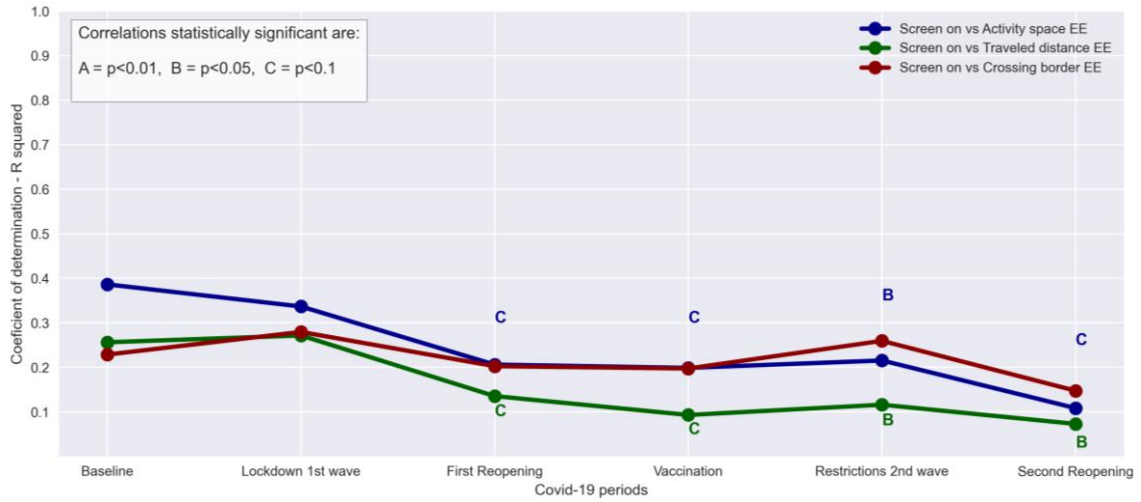

Figure 16. OLS between virtual interaction and spatial behavior - Estonia

In Finland, the virtual interaction changes are explained at 30%, ~28%, and 20% by the changes in cross border mobility. Especially during the First Reopening, Vaccination, and Restrictions 2nd wave as the Figure 17 shows. Generally, in Estonia the virtual interaction changes are explained mostly by the activity space and cross border behavior and in Finland mostly by the cross border behavior. For those values that are not statistically significant can be due to insufficient evidence to conclude that a relationship exists.

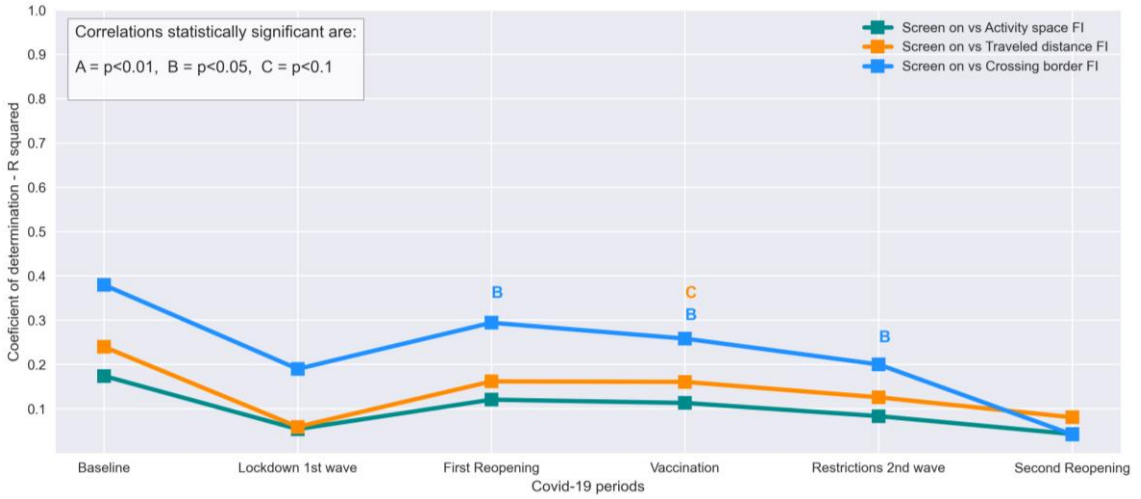

Figure 17. OLS between virtual interaction and spatial behavior – Finland

On the other hand, the proportion of virtual interaction seems to give a clearer message. In Estonia, the activity space and the traveled distance seems to be influencing strongly the changes in virtual interaction. A significant influence is found in Lockdown 1st wave with nearly 60%, then in First Reopening and Vaccination with 50%. The Figure 18 is explaining that during the 1st wave the change in activity space and traveled distance

affected considerably the changes in virtual interaction. Same reflection is seen in next period with lower influence most probably because people started moving more and being less dependent of virtual interaction through smartphone. Cross border mobility also had the same pattern of influence in virtual interaction but in lower probability nearly 30%.

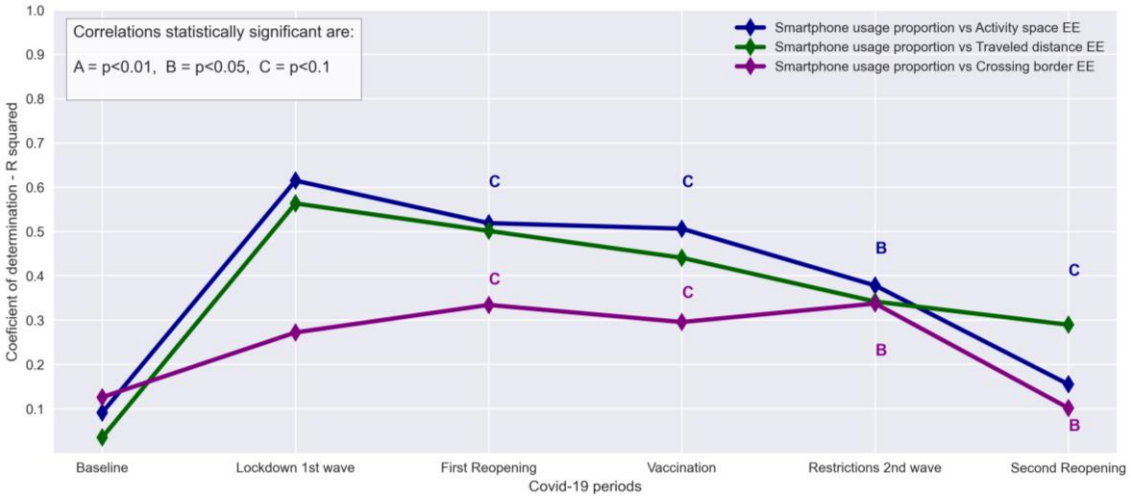

Figure 18. OLS between virtual interaction ratio and spatial behavior – Estonia

In Finland, the proportion of virtual interaction changes seems to be affected mostly by the cross border mobility in nearly 50% during all the periods but not in Baseline and Second Reopening. Clearly, the cross border mobility is a variable that can explain the changes in virtual mobility. Transnational people preferred to move locally Finland so that is why the activity space and the traveled distance are not affecting considerably the virtual interaction with nearly 30%.

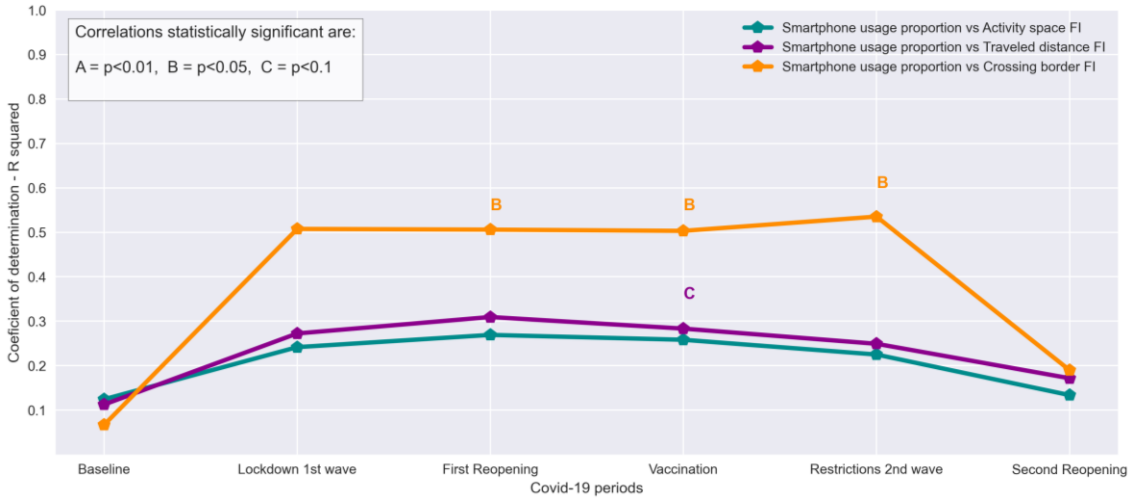

Figure 19.. OLS between virtual interaction ratio and spatial behavior – Finland

6 DISCUSSION

6.1 Link in spatial and virtual behavior

The results have shown evidence in an existing link between the spatial and virtual behavior. The transnational Estonians living in Finland showed particularities in its linkage. A good breaking point to notice is the scale of mobility. The spatial and virtual review showed that transnationals move extensively in Estonia around the main urban centers like Tartu and Tallinn meanwhile in Finland mostly in the capital region of Helsinki. As the present study is using the smartphone screen interaction as proxy of virtual mobility it is understood that virtual space is accessed through mobile device.

A moderate link has been found on specific variables that influence the changes in the virtual interaction. In Estonia, the changes in virtual interaction are explained in nearly 60% by the daily traveled distance and the activity space. On the other hand, in Finland nearly 50% of the changes in virtual behavior are explained by the cross-border mobility. This mobile phone usage in transnational trips is certainly frequent evidence found also in studies by Lee-Gosselin (2009). The author explained that people with high access to virtual spaces with mobile phone use are frequent travelers. This reflection is understood as a transnational lifestyle where moving back and forward from Finland to Estonia is common. Same evidence was found by Thulin & Vilhelmson (2012) but in a youth group. What have not been said in previous studies is that specifically the crossing-border behavior has the strongest influence in the usage of smartphone, as it has been revealed in this present study.

The present thesis contributes the understanding of transnational people daily lives. It explains how transnationals are connected in virtual space through mobile phone and how this usage is spatially distributed. The dissemination of virtual interaction by countries is valuable because it helps to understand how transnational people access virtual spaces and how it is linked with their physical space.

6.2 Changes in spatial and virtual behavior due to COVID-19 pandemic

The present study considered the transitions of Covid-19 pandemic since the first lockdown that started in March 2020, the time periods can be seen detailed in Figure 2. The metrics were calculated at daily level and aggregated at monthly level due to the length of the study period. For smaller study periods more granular changes can be found and explained at daily level. In similar studies by Järv et al. (2021), weekly periods were

used and the same pattern in changes was found. The results showed the expected pattern due to Covid-19 mobility restrictions. In Lockdown 1st wave the spatial mobility decreased and virtual interaction increased. Same as Restrictions 2nd wave but with the virtual interaction only increased approximately 25% in Finland. The First Reopening and Second Reopening showed increase especially in summer months in both countries. Vaccination period shows a small decrease but the pattern is aligned to Baseline (pre Covid-19 period).

Sharp changes were found especially at the beginning of the COVID-19 pandemic in the Lockdown 1st wave. The spatial mobility variables such as traveled distance and activity space decreased in -75% when Covid-19 started. Despite the mobility restrictions it was difficult to reduce it in the totality. Some spatial mobility still happened like short trips for grocery shopping. Nations forbid the entering of international people and this was reflected in the cross-border metric. The cross-border moves decreased in -100% specifically in direction to Finland. The metrics disseminated by Estonia and Finland helped to understand the role of each country in the mobility of transnationals. The virtual mobility metric analyzed showed the highest change. The time spent with smartphone screen-on increased almost 200% during Lockdown 1st wave only in Finland. Additionally, transnationals showed no smartphone interaction in Estonia during lockdown. The assumption is that transnationals spent the lockdown in Finland and that is why it reflects no trips to Finland and high smartphone interaction.

6.3 Smartphone data for spatial and virtual mobility research

The quality and accuracy of the location data collected through smartphone is feasible for spatial mobility research. The temporal sampling with a median of 1 second helped to calculate indicators at daily level. Also, most the trajectories generated matched the road networks giving a clear view that the dataset gets locations with good accuracy. What may require more critical evaluation is the outlier consideration. Sample contained temporal gaps probably by the phone turned off and it caused inconsistency in the trajectory generation. As it was done in this study, it is recommended to remove mentioned outliers and be aware of having a clean trajectory to avoid wrong calculations.

For virtual mobility research the screen events dataset is reliable, but it requires adjustments. The time of the screen events sampling is heterogeneous and it can cause confusion at the moment of interpreting results. Also, the data contains more classes than screen-on and screen-off that disturb the chronological order of the screen events and

gives information not required. I recommend for future studies to write a proper metadata explaining how the dataset is generated by the phone usage. Also, to remove unnecessary classes different than screen-on and screen-off events directly from system generation.

A relevant point of discussion I suggest in future reviews is to have a well-defined outlier. It is difficult to consider what it really is an outlier in the dataset of screen events. The outlier removal in the present study worked well and I would recommend using same approach with a threshold at monthly level. Nevertheless, the dataset gave the expected understanding of transnational lifestyle. It can be used for future projects that require spatial and virtual mobility measurements for policy review.

7 CONCLUSION

The spatial and the virtual mobility of the 45 transnational users reviewed in the present study were analyzed transversally with COVID-19 pandemic transition. The mobility restrictions implemented by the spread of COVID-19 virus biased the spatial and virtual behavior of transnational people in the cross-border region between Estonia and Finland. The results of this thesis explained that the linkage between spatial and virtual mobility is evident and got affected by the COVID-19 transition as external factor. The main findings provide insights and empirical evidence about how the virtual behavior is biased by changes in spatial behavior in the cross-border region between Finland and Estonia.

The spatial mobility has a moderate link with the virtual interaction in specific behaviors. In Estonia, the changes of virtual behavior were explained by the activity space and the traveled distance. In Finland, the changes in virtual behavior are mostly explained by the cross-border mobility. The COVID-19 transition affected as a milestone the mobility of people. The changes in the monthly rhythms of transnationals disseminated by nation revealed the transnational lifestyle. The results showed a highly decrease in the spatial behavior at the beginning of the COVID-19 pandemic. Cross-border mobility decrease totally during the lockdowns. The virtual interaction with smartphone got compromised and increased considerably only during the first lockdown. The linkage revealed that transnationals were highly active in cyberspace through smartphone when they decreased their spatial mobility.

The present study has provided insights that serve as evidence of spatial and virtual mobility anomalies. The methodology was structured in a geospatial Python workflow that can be reused with the same mobile phone datasets. Thus, serve to researchers and institutions dedicated to enforcing cross-border regions, and those who are focused in mobility not only of people but also of social and technological goods that support the development in transnational spaces.

SUMMARY

The spatial mobility of transnationals Estonians living in Finland got affected by the mobility restrictions due to the Covid-19 pandemics. As many others, the daily life pattern of transnationals changed during the Covid-19 transitions specially for the purpose of their travels related to work, family, leisure, services, and socializing. However, the consequences of restrictions in spatial mobility at local and transnational scale brought together different adaptations to their daily activities such as remote work in virtual environments, food delivery, communication with family and friends, and leisure time spent in web surfing. This phenomenon of accessing virtual environments through ICTs devices to perform daily activities such as working or shopping is known as virtual mobility. Based on this scope, the aim of this present thesis is to examine the link between spatial and virtual behavior and how it changes during the Covid-19 pandemic.

The spatial behavior of transnationals was measured with a longitudinal GPS tracking dataset obtained through smartphone application. The locations were recorded at 1 second sampling interval covering a total study period of 28 months from August 2019 until November 2021. In addition, their virtual behavior was reviewed with a unique complementary dataset that recorded the interaction between the transnationals and their smartphone. The measurement of virtual interaction was done based on the timestamp differences of screen on/off events. The subject of analysis was the relationship between the changes of spatial and virtual behavior during Covid-19 transition periods. The transnationals selected for this examination were in total 45 Estonians who were primary living in Finland and supported their anonymized data collection.

The indicators were calculated by Estonia and Finland for spatial and virtual behavior. The spatial mobility metrics were the daily traveled distance, daily activity space, and the daily cross-border moves. The virtual mobility metrics were the daily duration of screen-on interaction, and the proportion of daily screen-on duration in Finland compared to Estonia. Afterwards, the evaluation of the spatial and virtual pattern of the transnational people was done by comparing their daily average by each month with the pre-covid period. Then, the linkage was analyzed with Ordinary Least Squares (OLS) Regression model between correlation pairs in each accumulated Covid-19 transition period. The models considered the spatial mobility indicators as independent variables and the dependent variables as the virtual mobility indicators.

The results revealed a decline in spatial mobility in both nations at the beginning of Covid-19 pandemics. On the contrary, the virtual mobility arises but only in the main home country of transnational people. The main findings at transnational scale showed that the daily average of virtual interaction is concentrated at local level in Helsinki Region in 78% at their main home country. On the other hand, the virtual behavior in Estonia seems to be scattered but the nodes of concentration are the main urban centers such as Tallinn and Tartu. The spatial and virtual mobility seems to be moderate linked in two transnational scales. At national level in Estonia the traveled distance and the activity space metrics explains the changes in virtual interaction at nearly 60% probability in the beginning of Covid-19 pandemics. Meanwhile, at local level in Finland the cross-border behavior is the main predictor of the changes in virtual interaction at nearly 50% probability during the entire Covid-19 transition. Curiously, the cross-border behavior seems to influence the changes in virtual interaction at local level in their main home country but not in the second home country where they have more broad spatial behavior. The use of smartphone tracking methodology proved to be a reliable approach for better understanding spatial and virtual mobility of transnational people.

Ruumilise käitumise ja virtuaalse suhtlemise omavaheline seos nutitelefoni andmetel: Soomes elavate hargmaiste eestlaste näide COVID-19 pandeemia ajal

Bryan Rodrigo Vallejo Vega

Kokkuvõte

Covid-19 pandeemiast tingitud mobiilsuspiirangud mõjutasid Soomes elavate hargmaiste eestlaste ruumilist mobiilsust. Nagu paljud teised näitajad, muutusid ka hargmaiste inimeste olulisemad igapäevaelu mustrid Covid-19 pandeemia ajal seonduvalt töö, pere, vaba aja veetmise, teenuste tarbimise ja sotsialiseerumisega. Kehtestatud liikumispiirangute tagajärjel tekkisid muutused erinevates igapevaelulistes tegevustes nii kohalikul kui rahvusvahelisel tasandil, nagu kaugtöö virtuaalkeskkondades, toidu tellimine koju, pere ja sõpradega suhtlemine ning vaba aja veetmine veebis surfates. Nähtust, kus läbi IKT-seadmete saadakse juurdepääs virtuaalsetele keskkondadele, et teha igapäevaseid tegevusi nagu töötamine või poodlemine, nimetatakse virtuaalseks mobiilsuseks. Uurimistöö eesmärk on uurida ruumilise ja virtuaalse käitumise seost ja selle muutust Covd-19 pandeemia ajal.

Hargmaiste inimeste ruumilist käitumist mõõdeti longituudsete GPS andmete salvestamisega kasutades nutitelefoni rakendust. Uuritavate asukohti salvestati ühesekundilise intervalliga 28 kuu jooksul 2019. aasta augustist kuni 2021. aasta novembrini. Lisaks kasutati virtuaalse käitumise mõistmiseks unikaalset täiendavat andmekogu, mis salvestas hargmaiste inimeste telefonikasutusega seonduvat informatsiooni. Virtuaalse suhtluse mõõdikuna arvutati telefoni ekraani seesoleku aeg lähtudes ekraani sisse- ja välja lülitamise ajamärkidest. Uurimistöö analüüs keskendus ruumilise ja virtuaalse käitumise omavahelisele seosele Covid-19 perioodidel. Valim koosnes 45 hargmaisest eestlasest, kelle peamine elukoht oli Soomes ja kes olid nõus oma andmete kogumisega.

Ruumilise ja virtuaalse käitumise mõõdikud arvutati nii Eestis kui Soomes veedetud aja kohta. Ruumilise mobiilsuse mõõdikuteks olid päevane läbitud teekond, päevane tegevusruumi suurus ja päevane piiriületuste arv. Virtuaalse mobiilsuse mõõdikud olid ekraani sisselülitatud oleku päevast kestust ja ekraani sisselülitatud oleku kestuse osakaal Soomes võrdluses Eestiga. Mõõdikute leidmiseks võrreldi vastava mõõdiku päevast keskmist iga kuu lõikes covidi-eelse perioodiga. Hargmaiste inimeste ruumiliste ja

virtuaalsete käitumismustrite omavahelise seose uurimiseks kasutati lineaarseid regressioonimudeleid korrelatsioonipaaride vahel Covid-19 perioodide jooksul. Mudelites kasutati sõltumatute tunnustena ruumilise mobiilsuse mõõdikuid ja sõltuvate tunnustena virtuaalse mobiilsuse mõõdikuid.

Tulemused näitasid, et mõlemas riigis toimus Covid-19 pandeemia alguses ruumilise mobiilsuse langus. Virtuaalne mobiilsus kasvas üksnes hargmaiste peamise elukoha riigis. Uuritavad tegid keskmiselt 78% oma virtuaalsetest interaktsioonidest paiknedes samal ajal Suur-Helsingis. Virtuaalne käitumine Eestis oli jaotunud ruumiliselt hajusamalt, kuid kontsentreerus eelkõige peamistes keskustes nagu Tallinn ja Tartu. Ruumilise ja virtuaalse mobiilsuse vahel on keskmise tugevusega seos. Uuritavate Eestis paiknemise ajal kogutud andmete põhjal kirjeldasid läbitud teepikkus ja tegevusruum ligi 60% virtuaalsete interaktsioonide muutustest Covid-19 pandeemia alguses. Uuritavate Soomes paiknemise ajal oli mudelite alusel riigipiiride ületamiste arv virtuaalsete interaktsioonide hulka ennustavaks teguriks, selgitades 50% varieeruvusest. Seega paistab piiriületuste arv mõjutavat hargmaiste inimeste virtuaalsete interaktsioonide hulka kohalikul tasandil enim riigis, kus inimesed veedavad suurema osa oma ajast, samas kui nende teises koduriigis on neil ruumiline käitumine laiaulatuslikum. Nutitelefoni põhine andmekogumise metoodika osutus usaldusväärseks lähenemiseks mõtestamaks ruumilise ja virtuaalse mobiilsuse omavahelist seost hargmaistel inimestel.

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REFERENCES

Adams, John S. 2001. "The Quantitative Revolution in Urban Geography." *Urban Geography* 22 (6): 530–39. https://doi.org/10.2747/0272-3638.22.6.530.

Ahas, R., Silm, S., Tiru, M. 2017. "Tracking Trans-Nationalism with Mobile Telephone Data." https://2017.inimareng.ee/en/open-to-the-world/tracking-trans-nationalism-with-mobile-telephone-data//

Ahas, Rein, Siiri Silm, Olle Järv, Erki Saluveer, and Margus Tiru. 2010. "Using Mobile Positioning Data to Model Locations Meaningful to Users of Mobile Phones." *Journal of Urban Technology* 17 (1): 3–27. https://doi.org/10.1080/10630731003597306.

Bahadure, Sarika, and Rajashree Kotharkar. 2015. "Assessing Sustainability of Mixed Use Neighbourhoods through Residents' Travel Behaviour and Perception: The Case of Nagpur, India." *Sustainability (Switzerland)* 7 (9): 12164–89. https://doi.org/10.3390/su70912164.

Barbosa, Hugo, Marc Barthelemy, Gourab Ghoshal, Charlotte R. James, Maxime Lenormand, Thomas Louail, Ronaldo Menezes, José J. Ramasco, Filippo Simini, and Marcello Tomasini. 2018. "Human Mobility: Models and Applications." *Physics Reports* 734: 1–74. https://doi.org/10.1016/j.physrep.2018.01.001.

Basch, L., N. Schiller, and C. Blanc. 1994. "Transnational Projects, Postcolonial Predicaments, and Deterritorialized Nation-States." ISBN 9782881246302

Bazzani, Armando, Bruno Giorgini, Sandro Rambaldi, Riccardo Gallotti, and Luca Giovannini. 2010. "Statistical Laws in Urban Mobility from Microscopic GPS Data in the Area of Florence." *Journal of Statistical Mechanics: Theory and Experiment* 2010 (5). https://doi.org/10.1088/1742-5468/2010/05/P05001.

Boesen, E, and G Schnuer. 2016. "European Borderlands Living with Barriers and Bridges." https://doi.org/https://doi.org/10.4324/9781315580852.

Buliung, Ronald N., and Pavlos S. Kanaroglou. 2006. "A GIS Toolkit for Exploring Geographies of Household Activity/Travel Behavior." *Journal of Transport Geography* 14 (1): 35–51. https://doi.org/10.1016/j.jtrangeo.2004.10.008.

Calabrese, Francesco, Mi Diao, Giusy di Lorenzo, Joseph Ferreira, and Carlo Ratti. 2013. "Understanding Individual Mobility Patterns from Urban Sensing Data: A Mobile

Phone Trace Example." *Transportation Research Part C: Emerging Technologies* 26: 301–13. https://doi.org/10.1016/j.trc.2012.09.009.

Calafiore, Alessia, Nombuyiselo Murage, Andrea Nasuto, and Francisco Rowe. 2021. "UC Santa Barbara Spatial Data Science Symposium 2021 Short Paper Proceedings Title Deriving Spatio-Temporal Geographies of Human Mobility from GPS Traces." https://doi.org/10.25436/E26K5F.

Castells, Manuel. 2000. "Toward a Sociology of the Network Society." *Contemporary Sociology* 29 (5): 693–99. https://doi.org/10.2307/2655234.

Couclelis, Helen. 2009. "Rethinking Time Geography in the Information Age." *Environment and Planning A* 41 (7): 1556–75. https://doi.org/10.1068/a4151.

Decoville, Antoine, and Frédéric Durand. 2019. "Exploring Cross-Border Integration in Europe: How Do Populations Cross Borders and Perceive Their Neighbours?" *European Urban and Regional Studies* 26 (2): 134–57. https://doi.org/10.1177/0969776418756934.

Deng, Tao, Shaheen Kanthawala, Jingbo Meng, Wei Peng, Anastasia Kononova, Qi Hao, Qinhao Zhang, and Prabu David. 2019. "Measuring Smartphone Usage and Task Switching with Log Tracking and Self-Reports." *Mobile Media and Communication* 7 (1): 3–23. https://doi.org/10.1177/2050157918761491.

Dijst, Martin. 1999. "Two-Earner Families and Their Action Spaces: A Case Study of Two Dutch Communities." *GeoJournal* 48 (3): 195–206. https://doi.org/10.1023/A:1007031809319.

Ellegård, K, and B Vilhelmson. 2004. "Home as a Pocket of Local Order: Everyday Activities and the Friction of Distance." https://doi.org/10.1111/j.0435-3684.2004.00168.x

ERR News, 2021. Finland going to lock-down in March. https://news.err.ee/1608121795/finland-going-on-lock-down-in-march

Fan, Yingling, and Asad J. Khattak. 2008. "Urban Form, Individual Spatial Footprints, and Travel Examination of Space-Use Behavior." *Transportation Research Record*, no. 2082: 98–106. https://doi.org/10.3141/2082-12.

Ferreira, Daniela, and Mário Vale. 2021. "From Cyberspace to Cyberspatialities?" *Fennia - International Journal of Geography*, no. April. https://doi.org/10.11143/fennia.100343.

Gerber, Philippe. 2012. “Advancement in Conceptualizing Cross-Border Daily Mobility: The Benelux Context in the European Union.” *European Journal of Transport and Infrastructure Research* 12 (2): 178–97. https://doi.org/10.18757/ejtir.2012.12.3.2980.

Golledge, Reginald G., and R. J. (Robert John) Stimson. 1997. *Spatial Behavior : A Geographic Perspective*. ISBN 9781572300507

Goodchild, M., and E. Sheppard. 2000. “Forewords at Information, Place, and Cyberspace.” ISBN 3540674926 9783540674924 3642086926 9783642086922

Graser, A. 2021. “An Exploratory Data Analysis Protocol for Identifying Problems in Continuous Movement Data.” *Journal of Location Based Services* 15 (2): 89–117. https://doi.org/10.1080/17489725.2021.1900612.

Hägerstrand, Torsten. 1970. “What about People in Regional Science?” *Papers in Regional Science* 66: 1–6. https://doi.org/10.1007/BF01936872.

Hawelka, Bartosz, Izabela Sitko, Euro Beinat, Stanislav Sobolevsky, Pavlos Kazakopoulos, and Carlo Ratti. 2014. “Geo-Located Twitter as Proxy for Global Mobility Patterns.” *Cartography and Geographic Information Science* 41 (3): 260–71. https://doi.org/10.1080/15230406.2014.890072.

Hirsch, Jana A., Meghan Winters, Philippa Clarke, and Heather McKay. 2014. “Generating GPS Activity Spaces That Shed Light upon the Mobility Habits of Older Adults: A Descriptive Analysis.” *International Journal of Health Geographics* 13 (1): 1–14. https://doi.org/10.1186/1476-072X-13-51.

Houtum, Henk van, and Ton van Naerssen. 2002. “Bordering, Ordering and Othering.” *Tijdschrift Voor Economische En Sociale Geografie* 93 (2): 125–36. https://doi.org/10.1111/1467-9663.00189.

Janelle, Donald G., and David C. Hodge. 2000. *Information, Place, Cyberspace, and Accessibility*. https://doi.org/10.1007/978-3-662-04027-0_1.

Järv, Olle, Rein Ahas, and Frank Witlox. 2014. “Understanding Monthly Variability in Human Activity Spaces: A Twelve-Month Study Using Mobile Phone Call Detail Records.” *Transportation Research Part C: Emerging Technologies* 38: 122–35. https://doi.org/10.1016/j.trc.2013.11.003.

Järv, Olle, Henrikki Tenkanen, Maria Salonen, Rein Ahas, and Tuuli Toivonen. 2018. “Dynamic Cities: Location-Based Accessibility Modelling as a Function of Time.”

Applied Geography 95 (February): 101–10. https://doi.org/10.1016/j.apgeog.2018.04.009.

Järv, Olle, Ago Tominga, Kerli Müürisepp, and Siiri Silm. 2021. "The Impact of COVID-19 on Daily Lives of Transnational People Based on Smartphone Data: Estonians in Finland." *Journal of Location Based Services* 00 (00): 1–29. https://doi.org/10.1080/17489725.2021.1887526.

Kellerman, Aharon. 2012. "Daily Spatial Mobilities: Physical and Virtual." *Daily Spatial Mobilities: Physical and Virtual*, 1–238. https://doi.org/10.1080/00750778.2013.778138.

Kraft, Stanislav, Tomáš Květoň, Vojtěch Blažek, Lukáš Pojsl, and Jiří Rypl. 2020. "Travel Diaries, GPS Loggers and Smartphone Applications in Mapping the Daily Mobility Patterns of Students in an Urban Environment." *Moravian Geographical Reports* 28 (4): 259–68. https://doi.org/10.2478/mgr-2020-0019.

Larsen, Jonas, Kay W. Axhausen, and John Urry. 2006. "Geographies of Social Networks: Meetings, Travel and Communications." *Mobilities* 1 (2): 261–83. https://doi.org/10.1080/17450100600726654.

Lee-Gosselin, Martin, and Luis F. Miranda-Moreno. 2009. "What Is Different about Urban Activities of Those with Access to ICTs? Some Early Evidence from Québec, Canada." *Journal of Transport Geography* 17 (2): 104–14. https://doi.org/10.1016/j.jtrangeo.2008.11.009.

Levitt, Peggy, and Nina Glick Schiller. 2004. "Conceptualizing Simultaneity: A Transnational Social Field Perspective on Society'." https://doi.org/doi:10.1111/j.1747-7379.2004.tb00227.x.

Linnhoff, Stefan, and Katherine Taken Smith. 2017. "An Examination of Mobile App Usage and the User's Life Satisfaction." *Journal of Strategic Marketing* 25 (7): 581–617. https://doi.org/10.1080/0965254X.2016.1195857.

Miller, Harvey J. 2004. "Tobler's First Law and Spatial Analysis." *Annals of the Association of American Geographers* 94 (2): 284–89. https://doi.org/10.1111/j.1467-8306.2004.09402005.x.

Palominos, Nicolas, and Duncan A Smith. 2020. "Identifying and Characterising Active Travel Corridors for London in Response to COVID-19 Using Shortest Path and Streetspace Analysis." *UCL Working Papers Series* 44: 1–20. www.casa.ucl.ac.uk.

Pappalardo, Luca, Maarten Vanhoof, Lorenzo Gabrielli, Zbigniew Smoreda, Dino Pedreschi, and Fosca Giannotti. 2016. “An Analytical Framework to Nowcast Well-Being Using Mobile Phone Data.” *International Journal of Data Science and Analytics* 2 (1–2): 75–92. https://doi.org/10.1007/s41060-016-0013-2.

Perkmann, Markus. 2003. “Cross-Border Regions in Europe: Significance and Drivers of Regional Cross-Border Co-Operation.” *European Urban and Regional Studies* 10 (2): 153–71. https://doi.org/10.1177/0969776403010002004.

Reggiani, A. Janic, M. 2000. “Information Society and Behavioral Issues” 26 (3): 212–25. https://doi.org/http://www.jstor.org/stable/23288401 Accessed:

Rundle, Andrew G., Daniel M. Sheehan, James W. Quinn, Katherine Bartley, Donna Eisenhower, Michael M.D. Bader, Gina S. Lovasi, and Kathryn M. Neckerman. 2016. “Using GPS Data to Study Neighborhood Walkability and Physical Activity.” *American Journal of Preventive Medicine* 50 (3): e65–72 . https://doi.org/10.1016/j.amepre.2015.07.033.

Schönfelder, Stefan, and Kay W. Axhausen. 2003. “Activity Spaces: Measures of Social Exclusion?” *Transport Policy* 10 (4): 273–86. https://doi.org/10.1016/j.tranpol.2003.07.002.

Schönfelder, Stefan, and Kay W. Axhausen. 2010. “Urban Rhythms and Travel Behavior: Spatial and Temporal Phenomena of Daily Travel.” 6688: 1–230. https://doi.org/10.1080/14616688.2011.575076.

Sheller, Mimi, and John Urry. 2006. “The New Mobilities Paradigm.” *Environment and Planning A* 38 (2): 207–26. https://doi.org/10.1068/a37268.

Sherman, Jill E., John Spencer, John S. Preisser, Wilbert M. Gesler, and Thomas A. Arcury. 2005. “A Suite of Methods for Representing Activity Space in a Healthcare Accessibility Study.” *International Journal of Health Geographics* 4: 1–21. https://doi.org/10.1186/1476-072X-4-24.

Silm, Siiri, Jussi S. Jauhiainen, Janika Raun, and Margus Tiru. 2021. “Temporary Population Mobilities between Estonia and Finland Based on Mobile Phone Data and the Emergence of a Cross-Border Region.” *European Planning Studies* 29 (4): 699–719. https://doi.org/10.1080/09654313.2020.1774514.

Statistics Estonia. 2021. “RV069: Population by Country of Birth/Citizenship, County, Sex and AgeGroup.” https://andmed.stat.ee/en/stat

Statistics Finland. 2021. “Country of Birth According to Sex by Municipality, 1990–2021.” http://pxnet2.stat.fi/PXWeb/pxweb/en/StatFin/.

Stouffer, S. 1940. “Sociological Relating Mobility and Distance *” 5 (6): 845–67. https://doi.org/doi:10.2307/2084520.

Tenkanen, Henrikki, and Tuuli Toivonen. 2020. “Longitudinal Spatial Dataset on Travel Times and Distances by Different Travel Modes in Helsinki Region.” *Scientific Data* 7 (1): 1–15. https://doi.org/10.1038/s41597-020-0413-y.

Thulin, E., and B Vilhemson. 2005. “Virtual Mobility of Urban Youth ICT Based Communication in Sweden” 96 (5): 477–87. https://doi.org/DOI:10.1111/j.1467-9663.2005.00480.x.

Thulin, Eva, and Bertil Vilhelmson. 2012. “The Virtualization of Urban Young People’s Mobility Practices: A Time Geographic Typology.” https://doi.org/10.1111/geob.12005

Tobler, W. 1970. “A Computer Movie Simulating Urban Growth in the Detroit Region.” *Economic Geography* 46: 234–40. https://doi.org/10.1126/science.11.277.620.

Vich, Guillem, Oriol Marquet, and Carme Miralles-Guasch. 2017. “Suburban Commuting and Activity Spaces: Using Smartphone Tracking Data to Understand the Spatial Extent of Travel Behaviour.” *Geographical Journal* 183 (4): 426–39. https://doi.org/10.1111/geoj.12220.

Vilhelmson, Bertil, and Eva Thulin. 2008. “Virtual Mobility, Time Use and the Place of the Home.” *Tijdschrift Voor Economische En Sociale Geografie* 99 (5): 602–18. https://doi.org/10.1111/j.1467-9663.2008.00494.x.

Yang, Chaowei, Keith Clarke, Shashi Shekhar, and C. Vincent Tao. 2020. “Big Spatiotemporal Data Analytics: A Research and Innovation Frontier.” *International Journal of Geographical Information Science* 34 (6): 1075–88. https://doi.org/10.1080/13658816.2019.1698743.

Yu, Hongbo, and Shih Lung Shaw. 2007. “Revisiting Hägerstrand’s Time-Geographic Framework for Individual Activities in the Age of Instant Access.” *GeoJournal Library* 88: 103–18. https://doi.org/10.1007/1-4020-5427-0_7.

Yuill, Robert S. 1971. “The Standard Deviational Ellipse; An Updated Tool for Spatial Description.” *Geografiska Annaler. Series B, Human Geography* 53 (1): 28. https://doi.org/10.2307/490885.

Zenk, Shannon N., Amy J. Schulz, Stephen A. Matthews, Angela Odoms-Young, Jo Ellen Wilbur, Lani Wegrzyn, Kevin Gibbs, Carol Braunschweig, and Carmen Stokes. 2011. “Activity Space Environment and Dietary and Physical Activity Behaviors: A Pilot Study.” *Health and Place* 17 (5): 1150–61. https://doi.org/10.1016/j.healthplace.2011.05.001.

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