"psyosphere"

A GPS Data Analysing Tool for the Behavioural Sciences

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Abstract

Positioning technologies (PT) such as GPS are widespread in society but are used only sparingly in behavioural science research. The current study attempts to unlock PT potential for behavioural science studies by developing a research tool to analyse GPS tracks, and by giving an overview of behavioural variables that can be studied with PTs. To test the research tool and to find more links between behavioural variables and PTs, we conducted two similar experiments. During the experiments, participants were placed in teams and carried cards with either a hostile or non-hostile task from a start to finish area. At the finish area the participants had to avoid guards, in order that their cards would not be confiscated. After each of three rounds the participants filled out a questionnaire to measure mental states related to hostile intent. The results show that the participants collectively changed their strategies on how to avoid guards, with each consecutive Round, and that mental states, such as fear, can be linked to changes in GPS variables, such as walking closer together. The current study demonstrates that behavioural experiments can be performed with GPS, outside of a laboratory setting.

Keywords: GPS, GIS, R, spatial movement, walking, psychology, hostile intent

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Positioning technologies (PTs) such as Global Positioning Systems (GPS), Glonass and Galileo can be used to determine the position on the globe and to record for instance the movement of planes, cars, and individuals (Hofmann-Wellenhof, Lichtenegger, & Wasle, 2007). PTs are now omnipresent in mobile devices such as smart phones, tablets, and laptops. It could for instance be used to identify people with early warnings signs for depression (Palmius et al., 2017; Saeb et al., 2015), partly or fully replace self-reported diaries in traffic research (Bohte & Maat, 2009; Schuessler & Axhausen, 2009; Stopher, Bullock, & Horst, 2002; J. Wolf, 2006), determine how populations behave after a disaster such as an earth quake (Bengtsson, Lu, Thorson, Garfield, & Von Schreeb, 2011), or to automatically detect active pickpockets in a shopping mall (Bouma et al., 2014). This omnipresence makes PTs potentially interesting to study behaviour in naturalistic settings. Surprisingly, behavioural scientists use PTs only to a small extent.

In this paper we argue that there are two reasons why PTs have largely been neglected in behavioural research. First, the data are too complex to analyse with software that traditionally were used in the social sciences, such as IBM SPSS Statistics (SPSS). Second, only a limited number of studies investigated the relationship between psychological variables and PT data. Consequently, little information is available which psychological variables could be studied with PTs. Therefore, the aim of this study is to develop a tool that enables behavioural scientists to make readily use of PTs to study movement and to give an overview of psychological variables that can be studied with PTs.

In current behavioural science research, the assessment of movement is often done via trained observers, interviewers, or self-reported diaries, and these methods have been of great use in the past (Axhausen, Zimmermann, Schönfelder, Rindsfüser, & Haupt, 2002; Doherty & Miller, 2000; Goodchild & Janelle, 1984; Janelle, Goodchild, & Klinkenberg, 1988; Shoval et al., 2010). These conventional methods to measure movement come with drawbacks that may be circumvented by using PTs instead. According to Shoval et al. (2010), the main obstacle is the information provided by participants. For example, people frequently underreport trips that are small, and people also underreport trips that do not start or end at home. Moreover, participants that drive a car underestimate their travel time whereas public transportation users overestimate their travel time (Ettema, Timmermans, & van Veghel, 1996; Stopher, 1992). Furthermore, participants can consciously omit information, for instance, if answers or not socially desirable. Finally, the interviewer could fail to prompt recall (interviewer error), or the participants could simply forget the information over time (recall bias; Anderson, 1971; Golledge, 1997; Vazquez-Prokopec et al., 2009). These limitations can be compensated by using PTs such as GPS (Bohte & Maat, 2009).

Benefits of PTs

Especially in traffic research, scientists compared PTs such as GPS with traditional methods of movement tracking and they pointed out several benefits of using PTs (Bohte & Maat, 2009; Schuessler & Axhausen, 2009; Stopher et al., 2002; J. Wolf, Schönfelder, Samaga, Oliveira, & Axhausen, 2004). Compared to self-reported diaries or interviews, (1) GPS loggers are less intrusive, as loggers may substantially reduce information that needs to be self-reported by participants or need to be asked by interviewers. (2) GPS loggers can reduce costs by reducing the interview duration. (3) The survey periods can be longer; smartphone apps tracking movement in the background allow for longer data-collection periods compared to when the participants self-report their trips. (4) The data quality can be improved since GPS loggers report small trips and travel times more accurately. (5) Finally, the sensors also have the benefit of recording additional data such as speed and acceleration which can be used for additional analysis (J. Wolf et al., 2004).

Next to these examples from traffic research, there are studies in other areas that employed PTs to replace or augment traditional methods of movement tracking. Particularly, research with target groups that are unable to maintain a self-reported diary and where observers would be especially expensive. For instance, for the mentally impaired, children and the elderly it may be difficult or even impossible to maintain a diary (Shoval et al., 2011). Traditionally, caretakers or family members were used to monitor those participants and noted the activities or filled in behavioural checklists for them (Shoval et al., 2011). Using caretakers or family members can be quite expensive, burdensome and biased. Moreover, Isaacson, Shoval, Wahl, Oswald, and Auslander (2016) argue that researchers may even avoid doing experiments with these target groups at all, because of these obstacles.

For groups that cannot maintain a diary, PTs such as GPS loggers can be an option to replace observers (Isaacson et al., 2016; Shoval et al., 2010; Shoval et al., 2008; Shoval et al., 2011). A critic could wonder whether a participant who is unable to fill in a diary would be able to handle the complex protocol for using sensors. Fortunately, research has shown that the mentally impaired and the elderly are indeed able to follow these protocols (Isaacson et al., 2016).

Additionally, as with many digital technologies, digital position recognition has some strengths compared to analogue data gathering (Brynjolfsson & McAfee, 2014). First of all, the analysis can be automated. For instance, an algorithm to detect pickpockets (Bouma et al., 2014) can be used again and again to detect this behaviour without the intervention of a researcher. Second, if the sensors are directly connected to a processor, the analysis can be real-time. The Global System for Mobile Communications (GSM) or Wi-Fi can often be directly connected to a processor, but this is not always possible with GPS loggers. Third, the analysis can be scaled up relatively easily. Therefore, it is possible to use the pickpocket classification algorithm on a larger airport by buying more sensors, for a fraction of the costs necessary to hire and train more security personnel. Fourth and finally, the analysis can be transferred easily. Once the technology is developed, it can be used on separate locations with a comparable small investment cost. For instance, installing new hardware and sensors can be cheaper than hiring and training new observers for a new location.

PT usage in past research

As mentioned before, PTs can be utilized to study a variety of subjects. For instance, research has shown that measures such as positive affect, extraversion or openness to experiences can predict the number of places someone visits over several days (Byrne & Byrne, 1993; Schwerdtfeger, Eberhardt, Chmitorz, & Schaller, 2010; P. S. A. Wolf, Figueredo, & Jacobs, 2013). Another example is risk-taking behaviour. GPS loggers can be used to detect risky driving behaviour such as speeding (Bolderdijk, Knockaert, Steg, & Verhoef, 2011). Table 1 gives a broad overview of research that employed PTs to study behaviour.

Table 1

PTs and Their Use in Past Research

Measures	Research
Anxiety, depression, or lifestyle (e.g. positive affect or extraversion)	Determining relationship between active versus sedentary lifestyle, social anxiety and depression, and number places visited with GPS (Huang et al., 2016; Saeb, Lattie, Schueller, Kording, & Mohr, 2016; P. S. A. Wolf et al., 2013).
Community specific routes description and visualisation	Measuring segregation in city communities with GPS (Davies et al., 2017; Whyatt et al., 2017).
Depression detection	Detecting depression from GPS movement data characteristics such as location variance, home stay, or mobility between favourite locations (Palmius et al., 2017; Saeb et al., 2015).
Environmental exposure	Measuring daily environmental exposure with GPS (Chaix et al., 2013; Phillips, Hall, Esmen, Lynch, & Johnson, 2001).
Following and leadership detection	Detecting leadership and followership with movement patterns (e.g. co-moving) with Wi-Fi data. (Kjargaard et al., 2013).
Information or disease spreading characteristics	Studying information spreading in face-to-face networks with Bluetooth, RFID and Wi-Fi (Isella, Romano, et al., 2011; Isella, Stehlé, et al., 2011; Madan, Moturu, Lazer, & Pentland, 2010).
Physical activity	Measuring physical activity of children, the elderly or other target groups with GPS (Elgethun, Fenske, Yost, & Palcisko, 2002; Fjørtoft, Kristoffersen, & Sageie, 2009; Isaacson, D'Ambrosio, Samanta, & Coughlin, 2015; Krenn, Titze, Oja, Jones, & Ogilvie, 2011; Maddison & Ni Mhurchu, 2009; Shoval et al., 2011).
Pickpocket detection	Detecting pickpockets with movement characteristics (e.g. walking speed) measured with security cameras (Bouma et al., 2014).
Population movement characteristics	Studying population behaviour after a disaster with GSM (Bengtsson et al., 2011).
Risk seeking	Measuring speeding as a form of risk seeking with GPS (Bolderdijk et al., 2011).
Travel characteristics such as travel mode, route choice or speed	Studying travel behaviour such as travel mode, route choice or speed with GPS (Bohte & Maat, 2009; Draijer, Kalfs, & Perdok, 2000; Murakami & Wagner, 1999; Necula, 2015; Schuessler & Axhausen, 2009; Stopher et al., 2002; J. Wolf, 2000, 2006; J. Wolf et al., 2004).
Virus transmission risk	Studying the spreading of disease with GPS (Vazquez-Prokopec et al., 2013; Vazquez-Prokopec et al., 2009).
Walking routes	Assessing tourist walking routes with GSM and GPS (Xia, Arrowsmith, Jackson, & Cartwright, 2008).

As can be seen in Table 1, there are only a small number of studies investigating the link between The past research (see Table 1) contains only a small number of studies that investigated the link between PT data and psychological variables, such as personality or mental states (e.g., Palmius et al., 2017; Saeb et al., 2015). Therefore, we want to investigate if more psychological variables, than mentioned in Table 1, can be linked to PT data.

Laboratory studies have shown that behaviour may become overt as a result of psychological variables. For instance, sad, depressed and frightened people tend to walk slower than others, and joy and anger are linked to increased walking speed (Barliya, Omlor, Giese, Berthoz, & Flash, 2012; Gross, Crane, & Fredrickson, 2012; Michalak et al., 2009). Other research indicates that personality traits such as agreeableness are also linked to increased walking speed (Satchell et al., 2017).

Hostile intent and movement

Research outside of the laboratory has shown that motivation or conscious decisions such as pickpocketing corresponds with specific body movement (Bouma et al., 2014). Their algorithms to detect pickpockets based on variations in walking speed, orientation change or distance to other people were shown have a sensitivity up to 95.6% with 0.5% false alarms.

Researchers argue that other behaviours such as smuggling can also result in behavioural changes that can be detected (Wijn, Kleij, Kallen, Stekkinger, & de Vries, 2017). They conducted an experiment where the participants transported packages with supposedly illegal and legal contents. Participants were recorded on video and independent lay observers were asked to watch the videos and rate which participants were transporting an illegal package. According to the researchers the mental processes while transporting an illegal package lead to changes in the participants' behaviour that could be detected by the observers. However, the researchers did not discuss which cues could be used for the detection and further research is needed. Therefore, the current study will investigate if the mental processes can be linked to measurable changes in movement.

The mental processes of transporting an illegal package are linked to hostile intent. Wijn et al. (2017) define hostile intent "as an individual's intent to act in ways that imply or aim to inflict harm onto others." (p. 2). People with hostile intent try to hide it when they expect that others will try to prevent their actions (DePaulo et al., 2003; Ekman, Friesen, & O'sullivan, 1988; Koller, Wetter, & Hofer, 2016; Wijn et al., 2017).

Wijn et al. (2017) argue that persons with hostile intent have a heightened state of self-saliency and interpret cues in the surroundings as to be connected to them. A cue could, for instance, be a police guard looking in the direction of that person. This cue can cause a fear-related response pattern (e.g. fight or flight) and the person will try to supress the fear response in order not to attract the attention of the guard. In other words, a person with hostile intent will try to act normal. This suppression of fear-related responses is a cognitive effortful process and can be constrained, by other cognitive tasks (e.g. counting), or fatigue. Therefore, people with hostile intent should show more deviant behaviour if they have an increased cognitive load and get cues from the environment that they perceive as related to them (Wijn et al., 2017).

As an example, it could be argued that an unexpected route change by construction works at an airport could increase the cognitive load. When someone needs to reorient him- or herself in an unfamiliar environment it increases the cognitive load and therefore limits the person's ability to suppress fear related responses. Additionally, more security guards could act as a cue to trigger detectable behaviour changes (Wijn et al., 2017).

A PT research tool for behavioural scientists. As mentioned before, we argue that data from PTs are unsuitable to be analysed with the software that is traditionally used by behavioural scientists such as SPSS. SPSS is a specialised software to perform statistical analysis which is not suitable to handle geospatial data and analysis. Therefore, we developed a data analysis software with the aim to enable behavioural scientist to analyse movement data without the need of additional special expertise.

Out of the variety of PTs we decided to focus on GPS for our tool. GPS can be used all over the globe and does not depend on local GSM, Wi-Fi or other infrastructure. GPS is also omnipresent in smart phones or other devices, and dedicated GPS loggers are affordable. The data analysis software will work with longitude, latitude and timestamp data points that are typical for GPS loggers. The movement data from other PTs such as GSM and Wi-Fi data can be converted to be used with the same software once it is converted to longitude and latitude.

The tool will be a R package and is called “psyosphere” (Ziepert, Ufkes, & de Vries, 2018; see Appendix 3). R is an open-source programming language and data-analysis tool that is becoming more widespread (Muenchen, 2012). The choice for R has several benefits: since R is used by psychologists and computer scientists it could improve cooperation of interdisciplinary teams, the software is free of charge and therefore easier accessible than for instance SPSS, there are pre-existing packages for spherical calculations and handling of GPS data (e.g. Hijmans, Williams, & Vennes, 2015; Kahle & Wickham, 2013; Loecher & Ropkins, 2015; Wickham, 2016), and since R is open source the software can be improved upon by the research community.

The current study

For our current study we will focus on movement-descriptive variables such as speed, distance to peers or variations in the route. As mentioned before, there are several psychological variables that are linked to movement. For example, emotions such as happiness or fear are linked to walking speed (Barliya et al., 2012; Gross et al., 2012; Michalak et al., 2009). To find more psychological variables that are linked to movement, we want to determine whether mental states related to hostile intent result in changes in descriptive movement variables measured with GPS. Two experiments were conducted that were part of an undergraduate course for psychology students. During the experiments the participants would wear GPS loggers and were to transport cards with supposedly legal and illegal tasks from a start to finish area. In the finish area the participants had to avoid guards that could confiscate the cards. After each Round, the participants would fill in a questionnaire to measure the mental states.

Methods

Participants

We conducted two experiments as part of an undergraduate psychology course at the University of Twente. The first experiment took place in 2014 and the second in 2015. The experiments are similar to each other and we did not conduct an analysis between the experiments. In the first experiment 64 students participated, two were excluded from the analysis due to sensor failure, and 62 students (44 female and 18 male) remained. The average age was 21.61 (SD = 5.60) and ranged from 18 to 37. Furthermore, 30 students were Dutch and 32 were German. In the second experiment 93 students participated, 19 students were excluded from the analysis due to a lack of sensors or sensor failure, and 74 students (51 female and 23 male) remained. The average age was 22.41 (SD = 5.60) and ranged from 18 to 46. Moreover, 38 students were Dutch and 34 were German. The participants that acted as guards were excluded from analysis to limit the scope of the current study.

Procedure

The participants signed up for the experiment during an introductory lecture for an undergraduate course. The experiment was explained to the participants and they received written instructions. They had the possibility to ask questions and afterwards signed an informed consent form. The participants were randomly assigned into teams of five to six people or got an individual task. The participants received a GPS logger and were told to gather three hours later in a small park on the university campus.

Tasks. The teams (smugglers) had the tasks to transport supposed contraband during the experiment and the individual assignment for the other participants was to find the participants with contraband (guards). The contraband was a paper card with the size of a card game card. On the card was either an image of cocaine (illegal card) or flour (legal card) printed and with a text indicating the same. Both teams and guards could gain points by fulfilling their task and it was announced that the best team and best guard would win a price. The price was a voucher for a cinema and a bar of chocolate for each winning team member and guard.

Area. After arriving at the park, participants were directed to their assigned locations. The teams would go to a starting point that was behind a mount and out of sight of the guards. The guards were waiting at the finish in an about two-metre-wide and 20-metre-wide strip that had to be crossed by the teams later. The finish area was marked with barrier tape on the ground. A group of 17 tall trees were standing inside and around the finish area. A visual inspection of the data did not reveal signal distortions by the trees. The distance from the starting area to the finish area was 150 metres. The mound was in the middle between start and the finish and the teams and guards could see each other when the teams walked over the mound. The mound had a semi-circular shape and the guards were positioned in the centre of the semi-circle in a distance of about 75 metres. See Figure 1 for an illustration of the area.

Figure 1. Experiment area with participant tracks and GPS polygons. The tracks of six team members in Experiment 2 are plotted in black (illegal card) and yellow (legal card). The tracks begin in the start polygon (A), enter the line of sight for guards' polygon (B) and end before the finish polygon (C).

Contraband. The teams would receive the legal and illegal cards at the starting area, they had to distribute it and each participant had to carry exactly one. The cards stated that the teams would win ten points for each illegal card they transported and one point for each legal card. The legal card also stated that the guards would lose a point if they took a legal card from a team member. Before starting the teams had to write a number on the card that was matched to their GPS logger and the starting time.

Round. The teams were instructed to walk from the starting area, across the park and through the finish area. The guards could confiscate the team members card by tapping them on their shoulder. The team member would give their card to the guard and the guard would note a number on the card which was assigned to the guard. The team members had to avoid being checked by the guards. This could be done by for instance distracting them by sending the team members with legal cards first or walking with a wide distance among each other therefore it would be difficult for the guards to reach all team members before they crossed the finish area. The guards were not allowed to leave the finish area and had to wear safety vests to enable the team members to spot them easily. Each time after crossing the finish area the team members would drop the remaining cards they had into a box and fill in a questionnaire. After this they would walk back to the start position for another Round.

Experiment 1. Between the experiments were some differences on how the experiments were conducted. In Experiment 1, five participants had the task to be a guard and the other participants were assigned into teams between three and six members with an average of 4.85. Before the start of the first experiment the participants filled in an additional trait questionnaire. Further, participants were instructed not to run, and four rounds were conducted. Additionally, all teams were wearing a card with their team number on their chest, and a team of five participants was wearing stress sensors around their wrist that measured their skin conductivity. At the starting area each team got two illegal cards and the rest were legal cards. Afterwards, between four and five teams with an average of 21.08 participants would start at the same time and the ratio between guard's participants was 0.24 when the participants approached the finish area. After each Round the teams would fill in a Dutch version of the State questionnaire.

Experiment 2. In Experiment 2, three participants had the task to be guards and the other participants were assigned into teams between four and seven team members with an average of 5.69. Furthermore, the instruction not to run was omitted, and the participants were not wearing any stress sensors or team numbers. At the starting area the teams could choose freely the ratio of illegal and legal cards and they were asked to write down which strategy they wanted to use. Afterwards, each team would start separately, and when approaching the finish area, the ratio between participants and guards was 0.54. Additionally, the finish area in Experiment 2 was larger than in Experiment 1 and enabled the guards to walk more freely. At the end of each Round, the team members would write down their points and could see the total points of the other teams. Finally, they would only fill in an English version of the State questionnaire. Some questions were removed and added in the State questionnaire (see Appendix 1) and additionally the teams were asked to rank how they perceived every team member as a leader and how they could improve their strategy as a team in the next Round. The guards were frequently told how many points each guard had.

Measures

State questionnaire. The mental states of the participants were measured with a questionnaire based on the research by Wijn et al. (2017) and Stekkinger (2012) to measure hostile intent and related constructs. Some questions have changed to fit the current study and two questions were added to measure self-observed behaviour changes. For instance, whether the participants changed their pace after seeing the guards. Table 2 contains all questions, and the Cronbach's alpha or Pearson's *R* for the state questionnaire constructs when applicable. The reliability for each scale where we calculated Cronbach's alpha, the index was above .78 (see Table 2). All State questions used a 7-point Likert scale from 1 “Not at all” to 7 “Very much”. Appendix 1 contains the full questionnaire.

Two items checked whether participants felt that they had hostile intentions (Hostile Intent; Stekkinger, 2012; Wijn et al., 2017). Five items measured the participants alertness to threats from the guards (Alertness to Being Target of Guards; Galbraith, Manktelow, & Morris, 2008; Stekkinger, 2012; Wijn et al., 2017). Five items checked the inhibitory and activation control (Cognitive Self-Regulation; Stekkinger, 2012; Wijn et al., 2017). Four items measured the self-focus of the participants (Situational Self Awareness; Govern & Marsch, 2001; Stekkinger, 2012; Wijn et al., 2017). Four items assessed the feelings of fright that the participants felt through the presence of the guards (Frightened by Presence of Guards; Stekkinger, 2012; Wijn et al., 2017). Five items checked the impulses that were suppressed by the participants (Suppressed Impulses to Change Movement; Stekkinger, 2012). Three items measured the extent that participants questioned themselves (Contemplation of Hostile Intent; Stekkinger, 2012; Wijn et al., 2017). Finally, two items are added to the questionnaire and assessed the self-observed behaviour changes (Awareness Movement Change in Presence of Guards; Stekkinger, 2012). For a detailed explanation of the mental processes and their function see Wijn et al. (2017).

GPS data. Every participant carried an i-gotU GT-600 GPS logger. The logger received location signals from GPS satellites and saved them every second in a data point. The logger saved the time, latitude, longitude and elevation. From the GPS data Speed, Speed Variation, Intra-Team Distance, Route Deviation and Variation Route Deviation were calculated. Speed was measured as the mean kilometres per hour between each data point. Speed Variation was calculated as the standard deviation of the kilometres per hour between each data point. Intra-Team Distance is the mean distance from one team member to the other team members in metres. Route Deviation is the distance in metres between a data point and the shortest route from start to finish. Variation Route Deviation is the standard deviation of the Route Deviation for each data point.

Analysis

GPS data preparation. The data from the GPS loggers were exported and analysed with the R package “psyosphere”, which was developed for the current study (Ziepert et al., 2018). The software created a track for each Round of each participant, and plotted the tracks on a map, which was retrieved from google maps (Google LLC, 2018). See Figure 1 for the tracks and map. A track began in the starting area that was determined by a polygon of GPS coordinates (A) and ended when the participants crossed a GPS based finish line behind the finish area (B). The R package also marked automatically from which point the teams and guards could see each other based on a polygon of GPS coordinates (C). Before the point of visibility, the teams followed generally a straight line and started to change their movement mostly after seeing the guards. Therefore, the analysis included only the data from when the teams were visible to the guards, until the members crossed the finish line. Within line of sight of the guards 31,113 coordinates were recorded in Experiment 1, for four rounds, and 17,172 in Experiment 2, for three rounds. Based on this data, the R package calculated the GPS variables that are mentioned above.

The R package detected two types of faulty data. First, if the speed exceeded a maximum of 40 km/h then the data were marked as missing values and excluded from analysis. An unrealistic speed can be for instance recorded due to signal loss from the GPS satellites. This occurred 16 times (0.05%) in Experiment 1 and 8 times (0.05%) in Experiment 2. Second, if the time difference between coordinates exceeded one second then the Speed, Speed Variation and Distance between the coordinates were marked as missing values and excluded from analysis. Three coordinates (0.01%) in Experiment 1 and 152 coordinates (0.89%) in Experiment 2 were excluded because of a time difference larger than one second.

State PCA. We analysed the State questions that were used in both experiments with a principal component analysis (PCA). In total, we conducted six explorative PCAs, one for each of the three rounds in the two experiments. Afterwards, we compared the PCAs and counted how often items shared a component. A model with eight components emerged and we testes this model with a confirmatory PCA. For the confirmatory analysis, the data of the six rounds over the two experiments were analysed together.

Relationships between State and GPS variables. Descriptive statistics and correlations, for the State components and GPS variables, were calculated for each experiment separately. Finally, we conducted a multi-level analysis with the GPS variables as dependent variables, and the State components and rounds as the predictors. In total we created ten models, five for each experiment. The multi-level analysis tested for consistent changes per Round (e.g. increasing Intra-Team Distance per Round) and the impact of grouping in teams. Three random effect models did not converge, and two of these models, were models with a maximum random effects structure based on the experimental design. Moreover, According to Barr, Levy, Scheepers, and Tily (2013), a maximum random effects model should be prioritized when conducting a multilevel analysis. For our current study, a maximum random effects model included random slopes per Round and a static intercept per team and participant. To improve the model convergence rate, Barr et al. (2013) suggest to remove outliers, and therefore, data have been removed from the GPS variables, except Intra-Team Distance, when the data were outside of the Inter Quartile Range times 1.5 (Hoaglin, 2003). 15 outliers have been removed from Speed, 9 from Speed Variation, 5 from Route Deviation, and 14 from Variation Route Deviation. After removing the outliers, all models with a maximum random effects structure converged and two models did not converge. Intra-Team Distance was excluded from the outlier removal since this increased the model convergence rate.

Exclusions. Only the first three rounds of both experiments were used since the participants did not complete the State questionnaire after the fourth Round of Experiment 1. The stress sensor data was not used due to faulty data; answers to strategy, leadership and motivation questions were not analysed to limit the scope of the current study and could be analysed in a follow up study.

Results

Factor Analysis

We conducted an exploratory principal component analysis (PCA) for 30 items of the state questionnaire (see Appendix 1) for each experiment and for each of the first three rounds. This resulted in six PCAs and each PCA used an oblique rotation (oblimin). Afterwards we compared the PCAs by counting how often items were grouped together within a component. We used the resulting model with eight components for a confirmative PCA over the data of both experiments and their first three rounds. The Kaiser-Meyer-Olkin (KMO) measure for the confirmative PCA verified the sampling adequacy for the analysis. The KMO of .90 is above the minimum of .50 (Kaiser, 1974). The Bartlett's test of sphericity, χ^2 (435) = 8198, $p < .001$, illustrated that the correlations between the items were large enough for a PCA. The eight components explained 22% of the variance. Seven items had an eigenvalue higher than 1.00 and the eighth component had an eigenvalue of 0.88. As already mentioned, the model that we derived from the first six PCAs indicated eight components and not seven. Therefore, we decided to retain eight components for the confirmative PCA that was conducted for all data combined.

Table 2 shows the factor loadings after rotation in the pattern matrix. The coefficients in the pattern matrix indicate the unique contribution of a component to an item while controlling for other components. Table 3 shows the structure matrix of the PCA. The coefficients in the structure matrix indicate the relationship strength between the item and the component while ignoring other components. The clustering of the items show that the items load on the components as intended. The constructs in order are Alertness to Being Target of Guards, Cognitive Self-Regulation, Situational Self Awareness, Frightened by Presence of Guards, Suppressed Impulses to Change Movement, Contemplation of Hostile Intent, Awareness Movement Change in Presence of Guards and Hostile Intent.

Table 2

PCA Pattern Matrix for the State Questionnaire

Item	Alertness to Being Target of Guards	Cognitive Self-Regulation	Situational Self Awareness	Fright	Suppressed Impulses to Change Movement	Contemplation of Hostile Intent	Awareness Movement Change in Presence of Guards	Hostile Intent
I thought I had attracted the border guards' attention	**.89**	-.02	.02	-.04	-.00	.01	-.01	.01
I had the feeling the border guard(s) targeted me	**.89**	.04	-.02	-.03	.03	.03	-.01	-.07
I felt like I was the one being addressed by the border guard(s)	**.87**	-.01	-.01	.01	.04	.03	-.02	.04
I had a feeling that I was going to be stopped	**.79**	.07	.04	.05	.09	-.02	-.04	-.02
I had the idea that the others were paying attention to me	**.70**	-.07	.04	.10	-.13	-.07	.19	.08
During this round I have tried to hide my nerves	.07	**.88**	-.00	.09	-.03	-.04	.01	.03
During this round I have tried to hide my tension	.06	**.86**	.03	.03	-.06	-.03	-.02	.04
During this round I have tried to hide my emotions	.06	**.84**	-.01	.03	.02	.00	.03	.00
During this round I have tried not to attract attention	-.13	**.79**	-.03	-.10	.05	.11	.04	-.06
During this round I have tried to act as normal as possible	-.14	**.62**	.14	-.07	.09	-.09	.02	.08
During this round I was aware of the way I presented myself	.00	-.02	**.88**	-.02	-.04	.02	.01	.05
During this round I was aware of how I looked	-.02	.07	**.86**	.01	-.03	-.05	-.03	-.05
During this round I was aware of my inner feelings	.05	.04	**.77**	.06	.00	.05	-.11	.07
During this round I was aware of everything in my direct surroundings	.02	-.08	**.74**	-.02	.08	.03	.10	-.04
I was startled by the border guards' presence	.00	-.04	.07	**.81**	.05	-.14	.08	.10
The border guards' presence made me feel stressed	.06	.08	-.02	**.79**	.06	.14	-.11	.02
I was startled when I first noticed the border guards	.03	.03	-.02	**.79**	.05	-.17	.10	.10
The border guards' presence made me feel tense	-.01	.08	.04	**.77**	.01	.27	-.00	-.09
I would rather have chosen a different route	.19	.01	-.02	-.13	**.77**	.02	-.07	.06
I would rather have taken a detour to avoid the border guards	.03	.02	.06	.02	**.77**	.10	.05	-.07
I would rather have hidden myself	-.07	.03	.02	.15	**.72**	.11	.03	-.06
I would rather have turned around	.02	-.00	-.06	.16	**.71**	-.08	.00	.14
I would rather have run away from the border guards	.02	.02	.05	.10	**.52**	-.23	.24	.20
I was thinking about what I had to hide from the border guards	.02	.03	.12	-.03	.07	**.75**	.14	.13
I was wondering whether I looked suspicious to the border guards	.05	.07	.08	.22	.07	**.61**	.14	-.12
I was wondering whether I was doing something that I was not allowed to do	.03	.03	.02	-.00	.07	**.60**	.01	**.43**
During this round I have increased my pace as soon as I saw the border guards	-.00	.03	-.06	.05	-.06	.05	**.85**	.13
During this round I have changed my course as soon as I saw the border guards	.04	.06	.08	-.03	.13	.07	**.78**	-.16
During this round I felt I was doing something illegal	.02	.15	.04	.06	.09	.14	-.06	**.74**
During this round I felt I had hostile intentions	.02	.01	.09	.11	.03	.01	.12	**.73**
Eigenvalues	3.70	3.52	2.92	3.08	2.96	1.79	1.74	1.77
% of variance	.12	.12	.10	.10	.10	.06	.06	.06
α (*R*)	.90	.87	.84	.88	.83	.78	(.53)	(.64)

Note. Component loadings that are higher than or equal to .40 are in bold. Data of all experiments and rounds are analysed together.

Table 3

PCA Structure Matrix for the State Questionnaire

Item	Alertness to Being Target of Guards	Cognitive Self-Regulation	Situational Self Awareness	Frightened by Presence of Guards	Suppressed Impulses to Change Movement	Contemplation of Hostile Intent	Awareness Movement Change in Presence of Guards	Hostile Intent
I felt like I was the one being addressed by the border guard(s)	**.89**	.13	.19	.26	.38	.10	.11	.20
I thought I had attracted the border guards' attention	**.88**	.11	.20	.20	.32	.07	.09	.15
I had the feeling the border guard(s) targeted me	**.88**	.15	.17	.20	.35	.09	.10	.09
I had a feeling that I was going to be stopped	**.85**	.22	.24	.31	**.42**	.09	.12	.18
I had the idea that the others were paying attention to me	**.71**	.08	.21	.30	.22	-.00	.28	.23
During this round I have tried to hide my nerves	.21	**.91**	.34	**.41**	.26	.22	.20	.27
During this round I have tried to hide my tension	.18	**.87**	.35	.34	.20	.21	.15	.25
During this round I have tried to hide my emotions	.20	**.87**	.32	.36	.28	.25	.20	.24
During this round I have tried not to attract attention	-.03	**.77**	.24	.17	.18	.31	.15	.10
During this round I have tried to act as normal as possible	.01	**.65**	.33	.20	.20	.14	.15	.23
During this round I was aware of the way I presented myself	.18	.30	**.88**	.17	.12	.26	.20	.23
During this round I was aware of how I looked	.15	.34	**.85**	.16	.09	.18	.15	.15
During this round I was aware of my inner feelings	.23	.35	**.81**	.24	.18	.28	.12	.27
During this round I was aware of everything in my direct surroundings	.20	.22	**.75**	.17	.21	.24	.27	.16
I was startled by the border guards' presence	.27	.29	.24	**.88**	.40	.02	.36	**.41**
I was startled when I first noticed the border guards	.28	.31	.17	**.87**	.39	-.02	.36	**.41**
The border guards' presence made me feel stressed	.30	.40	.22	**.85**	**.43**	.26	.20	.36
The border guards' presence made me feel tense	.22	**.42**	.28	**.81**	.38	.39	.29	.27
I would rather have taken a detour to avoid the border guards	.34	.27	.22	.35	**.82**	.31	.29	.19
I would rather have chosen a different route	**.45**	.19	.13	.23	**.79**	.19	.14	.24
I would rather have turned around	.33	.23	.10	**.47**	**.79**	.11	.25	.36
I would rather have hidden myself	.25	.29	.19	**.43**	**.78**	.31	.28	.21
I would rather have run away from the border guards	.31	.24	.20	**.45**	**.65**	.00	**.43**	**.40**
I was thinking about what I had to hide from the border guards	.16	.35	**.41**	.23	.35	**.85**	.34	.32
I was wondering whether I looked suspicious to the border guards	.21	.37	.35	.38	.36	**.70**	.34	.15
I was wondering whether I was doing something that I was not allowed to do	.18	.33	.32	.29	.35	**.70**	.22	**.57**
During this round I have increased my pace as soon as I saw the border guards	.11	.21	.18	.34	.23	.20	**.87**	.29
During this round I have changed my course as soon as I saw the border guards	.18	.24	.29	.27	.35	.25	**.82**	.07
During this round I felt I was doing something illegal	.23	**.41**	.31	**.43**	.38	.32	.18	**.84**
During this round I felt I had hostile intentions	.23	.29	.33	**.46**	.33	.20	.33	**.83**

Note. Component loadings that are higher than or equal to .40 are in bold. Data of all experiments and rounds are analysed together.

Descriptive Statistics

Table 4 displays preliminary descriptive statistics such as the mean, standard deviation and correlation coefficients for the State and GPS variables per experiment. For example, more participants carried an illegal card (Illegal Card Selection) in Experiment 2 than in

Experiment 1 (M_1 = 0.41, M_2 = 0.88). In Experiment 1 each team had only two illegal cards to distribute, and in Experiment 2 the teams could choose a free ratio of cards and chose on average more illegal cards than in Experiment 1. Also, Hostile Intent was higher in Experiment 2 than in Experiment 1 (M_1 = 2.36 M_2 = 3.02). To determine the relationship between Illegal Card Selection and Hostile Intent an independent *t* test was conducted. The test results show that there was a significant difference in Hostile Intent for Experiment 1 when the illegal card was chosen (M_1 = 3.07, SD_1 = 1.87) than when the legal card was chosen (M_1 = 1.88, SD_1 = 1.07) with t_1 (112) = -5.11, $p_1 < .001$, and Cohen's d_1 = 0.83. Similarly, there was also a significant difference in Hostile Intent for Experiment 2 when the illegal card was chosen (M_2 = 3.10, SD_2 = 1.64) than when the legal card was chosen (M_2 = 2.46, SD_2 = 1.31) with t_2 (49.04) = -2.60, p_2 = .012, and Cohen's d_2 = 0.41. The results of both experiments demonstrate that participants who chose an illegal card reported a higher feeling of hostile intent than participants who chose a legal card, and this relationship was stronger in Experiment 1 than in Experiment 2. A reason for the stronger relationship in Experiment 1 could be that, in Experiment 1, each team had fewer illegal cards to distribute. The illegal cards scored ten points for the team and the legal cards scored one point, therefore, the illegal cards were important to become the team with the highest score. Since the illegal cards were limited in Experiment 1, it was important to carry the illegal cards successfully, that is, without being checked by the guards, to achieve the highest score. By comparison, in Experiment 2, there were unlimited illegal cards which created overall higher self-reported feelings of Hostile Intent but put less stress on the individual that carried an illegal card.

Differences between experiments. The descriptive statistics illustrate some differences between the experiments. For instance, in the first experiment, participants were warned not to run to prevent them from harming themselves. The warning was not given in the second experiment. Consequently, in Experiment 1 the Speed was 4.59 kilometres per hour and 6.01 kilometres per hour in Experiment 2. Additionally, the Speed Variation was 1.43 in Experiment 1 and 4.04 in Experiment 2. It appears that, the warning not to run in Experiment 1 led to a decreased Speed and Speed Variation, compared to Experiment 2.

Other difference between the experiments are the Intra-Team Distance, Route Deviation, and Variation Route Deviation. During Experiment 1 the participants walked closer together than in Experiment 2 (M_1 = 9.59, M_2 = 12.65). Additionally, the Route Deviation was larger in Experiment 2 than in Experiment 1 (M_1 = 7.53, M_2 = 11.39), and also, the Variation Route Deviation was larger in Experiment 2 (M_1 = 3.15, M_2 = 4.77). A likely explanation for the differences, in Intra-Team Distance, Route Deviation, and Variation Route Deviation, could be that the participants in Experiment 2 had to avoid the guards more than in Experiment 1, since there were more guards per participant at the finish area in Experiment 2. Specifically, the ratio between guards and participants was 0.24 in Experiment 1 and 0.54 in Experiment 2.

Correlations. Table 4 illustrates that the State variables frequently correlate with each other significantly, and the GPS variables correlate only partly with each other or with the State variables. GPS variables that correlate with each other in both experiments are for instance Variation Route Deviation and Intra-Team Distance (R_1 = .19, p_1 = .012, R_2 = .15, p_2 = .030), and this means that teams which varied more in their route also had a longer distance to their team members. A reason could be that some participants avoided the guards by changing their route, other team members did not do so, and therefore the distance between the participants increased. Additionally, Speed and Speed Variation (R_1 = -.48, p_1 < .001, R_2 = .53, p_2 < .001), and Route Deviation and Variation Route Deviation (R_1 = .58, p_1 < .001, R_2 = .62, p_2 < .001) correlated with each other. In both pairs, the relationships could be expected since they are caused by the underlying mathematical relationship of the variables. Specifically, the variables are the average and standard deviation of the same measurement. For instance, a continuously increasing distance to the shortest path leads to a higher average distance (Route Deviation) and a higher standard deviation of the distance (Variation Route Deviation).

Table 4

Mean, SD and Correlation Coefficients of State Variables

Experiment	Variable	Mean	SD	01 *R* (*p*)	02 *R* (*p*)	03 *R* (*p*)	04 *R* (*p*)	05 *R* (*p*)	06 *R* (*p*)	07 *R* (*p*)	08 *R* (*p*)	09 *R* (*p*)	10 *R* (*p*)	11 *R* (*p*)	12 *R* (*p*)	13 *R* (*p*)	14 *R* (*p*)
1	01 Illegal Card Selection	0.41	0.49	1.00													
2	01 Illegal Card Selection	0.88	0.33	1.00													
1	02 Hostile Intent	2.36	1.56	**.38 (< .001)**	1.00												
2	02 Hostile Intent	3.02	1.61	**.13 (.028)**	1.00												
1	03 Alertness to Being Target of Guards	3.71	1.72	-.01 (.874)	**.21 (.003)**	1.00											
2	03 Alertness to Being Target of Guards	4.05	1.81	.08 (.209)	**.30 (< .001)**	1.00											
1	04 Cognitive Self-Regulation	3.50	1.75	**.36 (< .001)**	**.41 (< .001)**	.11 (.126)	1.00										
2	04 Cognitive Self-Regulation	3.91	1.39	**.24 (< .001)**	**.39 (< .001)**	**.19 (.001)**	1.00										
1	05 Situational Self Awareness	4.07	1.59	.08 (.248)	**.36 (< .001)**	**.24 (.001)**	**.45 (< .001)**	1.00									
2	05 Situational Self Awareness	4.01	1.36	-.06 (.358)	**.41 (< .001)**	**.28 (< .001)**	**.35 (< .001)**	1.00									
1	06 Frightened by Presence of Guards	2.73	1.42	**.33 (< .001)**	**.62 (< .001)**	**.23 (.003)**	**.48 (< .001)**	**.29 (< .001)**	1.00								
2	06 Frightened by Presence of Guards	3.32	1.55	**.16 (.010)**	**.48 (< .001)**	**.39 (< .001)**	**.38 (< .001)**	**.28 (< .001)**	1.00								
1	07 Suppressed Impulses to Change Movement	2.76	1.45	**.21 (.004)**	**.65 (< .001)**	**.33 (< .001)**	**.44 (< .001)**	**.33 (< .001)**	**.65 (< .001)**	1.00							
2	07 Suppressed Impulses to Change Movement	2.96	1.46	.06 (.329)	**.36 (< .001)**	**.55 (< .001)**	**.22 (< .001)**	**.17 (.005)**	**.50 (< .001)**	1.00							
1	08 Contemplation of Hostile Intent	3.40	1.50	**.16 (.023)**	**.49 (< .001)**	**.16 (.026)**	**.47 (< .001)**	**.54 (< .001)**	**.46 (< .001)**	**.55 (< .001)**	1.00						
2	08 Contemplation of Hostile Intent	3.32	1.54	.01 (.917)	**.55 (< .001)**	**.31 (< .001)**	**.43 (< .001)**	**.37 (< .001)**	**.41 (< .001)**	**.41 (< .001)**	1.00						
1	09 Awareness Movement Change in Presence of Guards	3.26	1.82	.04 (.612)	**.32 (< .001)**	.01 (.875)	**.30 (< .001)**	**.32 (< .001)**	**.40 (< .001)**	**.37 (< .001)**	**.40 (< .001)**	1.00					
2	09 Awareness Movement Change in Presence of Guards	3.49	1.61	.05 (.368)	**.33 (< .001)**	**.34 (< .001)**	**.23 (< .001)**	**.25 (< .001)**	**.40 (< .001)**	**.43 (< .001)**	**.43 (< .001)**	1.00					
1	10 Speed	4.59	0.43	-.10 (.169)	.06 (.468)	-.15 (.050)	-.10 (.202)	.06 (.436)	-.04 (.619)	-.10 (.211)	.04 (.561)	**.27 (< .001)**	1.00				
2	10 Speed	6.01	0.84	.04 (.577)	**-.16 (.018)**	-.06 (.383)	-.05 (.474)	-.10 (.138)	-.05 (.442)	-.10 (.161)	-.08 (.227)	.00 (.982)	1.00				
1	11 Speed Variation	1.43	0.39	.09 (.212)	**.15 (.046)**	**.39 (< .001)**	.01 (.877)	.15 (.054)	.07 (.390)	**.27 (< .001)**	.04 (.596)	-.09 (.260)	**-.48 (< .001)**	1.00			
2	11 Speed Variation	4.04	0.96	.00 (.976)	-.11 (.115)	.12 (.089)	-.03 (.651)	-.04 (.602)	.06 (.387)	.10 (.138)	-.04 (.547)	.00 (.975)	**.53 (< .001)**	1.00			
1	12 Intra-Team Distance	9.59	5.59	-.05 (.468)	.08 (.278)	**.18 (.017)**	-.03 (.659)	.08 (.289)	-.07 (.375)	.06 (.392)	.05 (.475)	.09 (.245)	**.31 (< .001)**	-.01 (.850)	1.00		
2	12 Intra-Team Distance	12.65	4.60	.08 (.261)	.05 (.437)	.06 (.346)	-.03 (.645)	.08 (.217)	-.02 (.729)	.01 (.833)	-.01 (.845)	-.04 (.522)	.04 (.535)	**.17 (.011)**	1.00		
1	13 Route Deviation	7.47	4.06	-.12 (.115)	.04 (.631)	.02 (.759)	-.03 (.728)	.04 (.562)	-.07 (.375)	.11 (.151)	.00 (.977)	.14 (.058)	.08 (.279)	.10 (.197)	.12 (.102)	1.00	
2	13 Route Deviation	11.39	5.88	-.06 (.371)	.02 (.745)	**.20 (.004)**	.06 (.354)	.07 (.328)	.03 (.647)	.12 (.084)	-.01 (.927)	.11 (.122)	.05 (.431)	.01 (.877)	**.16 (.020)**	1.00	
1	14 Variation Route Deviation	3.06	1.97	-.04 (.582)	**.16 (.030)**	-.04 (.561)	.01 (.944)	.12 (.110)	.06 (.441)	**.19 (.011)**	**.15 (.046)**	**.30 (< .001)**	**.24 (.001)**	.05 (.490)	**.19 (.012)**	**.58 (< .001)**	1.00
2	14 Variation Route Deviation	4.77	2.39	-.11 (.120)	-.01 (.836)	**.25 (< .001)**	.01 (.874)	.00 (.965)	-.04 (.596)	**.20 (.004)**	-.02 (.775)	.06 (.398)	.07 (.295)	**.15 (.027)**	**.15 (.030)**	**.62 (< .001)**	1.00

Note. *p*-values less than .050 are in bold.

Regression Analysis

Per experiment and for each of the five GPS-based outcome variables we conducted regression analyses with the state constructs as predictors. We tested these ten regression models for random effects per participant, team, and Round. Testing for random effects is necessary since the measurements for each participant are not independent but depend on the Round that is measured and the team a participant is in. For instance, a team with fast walking members could have motivated a slow walking member to walk faster. To test the random effects, we created six random effect models which are displayed in Table 5 (see Model 1.1 – 6.1). The models are sorted by complexity with the lowest complexity in the beginning and the highest complexity at the end. The first model is a baseline model (Model 1.1) with a GPS outcome variable and 1 as predictor, and afterwards the random effects are added to the baseline model. Additionally, in Model 5.1 and 6.1 the predictor 1 is replaced with Round. For each Round, we assumed that the items varied together (covariance) and the time between measurements is equally spaced. Therefore, we used a first-order autoregressive covariance structure to model the covariance (Field, Miles, & Field, 2012).

To select a random effects model, a model fit indicator, such as the Akaike information criterion (AIC; Akaike, 1974), or the Bayesian information criterion (BIC; Schwarz, 1978), can be used. However, Barr et al. (2013) suggest it would preferable to select a random effects model based on the experimental design instead of selecting a model based on the model fit. For our current study, a maximum random effects model included random slopes per round and a static intercept per team and participant, and therefore Model 6.1 was selected. Finally, for the current study, we were interested in the effect of all state variables on the GPS outcome variable, and consequently, we added the State variables as predictors to the regression model (Model 6.2).

Table 5

Random Effect Models

Model	Random Intercept	Random Slope	Outcome variable	Predictor
1.1	None		GPS variable	1
2.1	Participant		GPS variable	1
3.1	Team		GPS variable	1
4.1	Team and participant		GPS variable	1
5.1	Participant	Round	GPS variable	Round
6.1	Team and participant	Round	GPS variable	Round
6.2	Team and participant	Round	GPS variable	Round and State variables

Model for Speed. We calculated Model 6.2 with Speed as outcome variable and Table 6 displays the results per estimate. As Table 6 highlights, Awareness Movement Change in Presence of Guards was a significant and positive predictor for Speed in Experiment 1 and the same relationship was not significant in Experiment 2 ($b_1 = 0.08$, $p_1 < .001$, $b_2 = 0.05$, $p_2 = .241$). Thus, when the participants reported a speed or route change after seeing the guards, the participants walked faster. An apparent explanation could be that the participants increased their speed, in an attempt, to outpace the guards.

Additionally, in Experiment 1 Suppressed Impulses to Change Movement is a significant and negative predictor for Speed and the same relationship was not significant in Experiment 2 ($b_1 = -0.09$, $p_1 = .008$, $b_2 = -0.07$, $p_2 = .195$). This means that, people which suppressed their impulses walked slower, and an explanation could be that participants walked slower in order not to attract the attention of the guards. An alternative explanation could be that participants were uncertain which route would be the best to avoid the guards and therefore slowed their pace.

Table 6

Regression Model for Speed: Statistics per Estimate

	Experiment 1			Experiment 2		
Estimate	*b*	*SE*	*p*	*b*	*SE*	*p*
Round	0.05	0.04	.232	0.11	0.07	.116
Illegal Card Selection	-0.03	0.07	.636	0.04	0.18	.819
Alertness to Being Target of Guards	-0.03	0.02	.166	-0.01	0.04	.721
Cognitive Self-Regulation	-0.02	0.02	.395	0.01	0.05	.832
Situational Self Awareness	-0.01	0.03	.687	-0.05	0.05	.339
Frightened by Presence of Guards	0.03	0.03	.290	-0.00	0.05	.951
Suppressed Impulses to Change Movement	**-0.09**	0.03	**.008**	-0.07	0.05	.195
Contemplation of Hostile Intent	0.02	0.03	.527	-0.03	0.05	.537
Awareness Movement Change in Presence of Guards	**0.08**	0.02	**< .001**	0.05	0.04	.241

Note. *p*-values less than .050 are in bold.

Model for Speed Variation. We calculated Model 6.2 with Speed Variation as outcome variable and Table 7 displays the results per estimate. The table shows that, Suppressed Impulses to Change Movement was a significant a positive predictor in Experiment 1 but not in Experiment 2 (b_1 = 0.12, p_1 < .001, b_2 = 0.03, p_2 = .575). This means, when the participants had suppressed impulses then they varied more in their walking pace. A simple explanation could be that participants failed in suppressing their impulses and therefore varied more. However, as Table 6 shows, participants reduced their pace when they had suppressed impulses (b_1 = -0.09, p_1 = .008, b_2 = -0.07, p_2 = .195) and if participants had failed in suppressing their impulses, one would suspect that their overall pace increased and not decreased. Hence, an alternative explanation could be that Suppressed Impulses to Change Movement measures the uncertainty of the participants on how to avoid the guards and not the suppressed impulses. Accordingly, the uncertainty could have caused the participants to slowdown, in order to orient themselves, and then to follow the new path with an increased pace.

Furthermore, Round is a positive and significant predictor for Speed Variation in Experiment 1 and the same relationship is not significant in Experiment 2 (b_1 = 0.08, p_1 < .031, b_2 = 0.05, p_2 = .575). Consequently, with each consecutive Round the participants varied more in their pace, and the variation could have helped the participants to avoid the guards better.

Additionally, Alertness to Being Target of Guards is a positive and significant predictor for Speed Variation, and the same relationship was not significant in Experiment 2 (b_1 = 0.05, p_1 = .008, b_2 = 0.07, p_2 = .139). Namely, when participants were targeted by the guards, then they would vary more in their speed. A likely explanation is that participants tried to avoid the guards by changing their walking pace.

Finally, Awareness Movement Change in Presence of Guards was a significant and negative predictor for Speed Variation in Experiment 1 but not in Experiment 2 (b_1 = -0.06, p_1 = .002, b_2 = 0.00, p_2 = .993). This means, when participants were aware that they changed their route or speed after seeing the guards, then they varied less in their walking pace. A reason could be, that participants had chosen a route, after seeing the guards, that avoided the guards successfully and therefore the participants could keep their pace. Because of the lower guard ratio in Experiment 1 it was easier to avoid the guards.

Table 7

Regression T, P and Beta Values for Speed Variation as Dependent Variable

	Experiment 1			Experiment 2		
Estimate	*b*	*SE*	*p*	*b*	*SE*	*p*
Round	**0.08**	0.04	**.031**	0.05	0.09	.575
Illegal Card Selection	0.11	0.06	.088	-0.16	0.22	.449
Alertness to Being Target of Guards	**0.05**	0.02	**.008**	0.07	0.04	.139
Cognitive Self-Regulation	-0.03	0.02	.217	0.07	0.06	.285
Situational Self Awareness	0.04	0.02	.117	-0.11	0.06	.069
Frightened by Presence of Guards	-0.03	0.03	.207	-0.01	0.06	.885
Suppressed Impulses to Change Movement	**0.12**	0.03	**< .001**	0.03	0.06	.575
Contemplation of Hostile Intent	-0.05	0.03	.065	-0.04	0.06	.468
Awareness Movement Change in Presence of Guards	**-0.06**	0.02	**.002**	0.00	0.05	.933

Note. *p*-values less than .050 are in bold.

Model for Intra-Team Distance. We calculated Model 6.2 with Intra-Team Distance as outcome variable and Table 8 displays the results per estimate. The table shows that Round was a positive and significant predictor for Intra-Team Distance in Experiment 1 and the same relationship was close to significant in Experiment 2 ($b_1 = 2.24$, $p_1 < .003$, $b_2 = 0.85$, $p_2 = .067$). This means that the distance to other team members increased with each Round, and the increasing distance could be a strategy, by the participants, that emerged to better avoid the guards.

Furthermore, Frightened by Presence of Guards was a significant and negative predictor for Intra-Team Distance in Experiment 1 and the same relationship was not significant in Experiment 2 ($b_1 = -0.62$, $p_1 = .023$, $b_2 = -0.20$, $p_2 = .242$). Therefore, when participants had feelings of fright because of the guards then they walked closer together, possible to compensate for the fear.

Additionally, Contemplation of Hostile Intent was a significant and positive predictor for Intra-Team Distance in Experiment 1 and the same relationship was not significant in Experiment 2 ($b_1 = 0.52$, $p_1 = .034$, $b_2 = 0.09$, $p_2 = .580$). This means, when participants were questioning the legality of their actions or whether they have to hide something, they would walk further apart from their fellow team members. It is possible, the participants had conflicting emotions about their hostile intentions and therefore did not want to affiliate with their team members.

Table 8

Regression T, P and Beta Values for Intra-Team Distance as Dependent Variable

	Experiment 1			Experiment 2		
Estimate	*b*	*SE*	*p*	*b*	*SE*	*p*
Round	**2.24**	0.73	**.003**	0.85	0.46	.067
Illegal Card Selection	0.17	0.58	.770	0.08	0.70	.906
Alertness to Being Target of Guards	0.18	0.18	.323	0.16	0.14	.262
Cognitive Self-Regulation	0.13	0.19	.497	0.27	0.18	.129
Situational Self Awareness	-0.32	0.20	.119	-0.06	0.18	.719
Frightened by Presence of Guards	**-0.62**	0.27	**.023**	-0.20	0.17	.242
Suppressed Impulses to Change Movement	0.19	0.27	.479	-0.01	0.18	.953
Contemplation of Hostile Intent	**0.52**	0.24	**.034**	0.09	0.15	.580
Awareness Movement Change in Presence of Guards	-0.07	0.16	.665	-0.13	0.15	.413

Note. *p*-values less than .050 are in bold.

Model for Route Deviation. We calculated Model 6.2 with Route Deviation as outcome variable and Table 9 displays the results per estimate. As the table shows, Alertness to Being Target of Guards is a significant and positive predictor for Route Deviation in Experiment 2 and a close to significant and negative predictor in Experiment 1 (b_1 = -0.32, p_1 = .068, b_2 = 0.62, p_2 = .031). Therefore, in Experiment 1, participants that perceived themselves as a target by the guards kept a shorter distance to the shortest route, and in Experiment 2, participants did the opposite. The difference could be explained by the change in the guard ratio. In Experiment 1, the guard had to be selective and participants why thought to be a target could try to act as normal as possible by deviation less from the shortest route. In Experiment 2, the guards could stop all participants if they were fast enough, and therefore, when participants would feel themselves a target would need to actively avoid the guards by outwalking them.

Additionally, Round is a significant and positive predictor for Route Deviation in Experiment 1, and the same relationship is not significant in Experiment 2 (b_1 = 2.14, p_1 < .001, b_2 = 0.18, p_2 = .738). This means that, the participants walked in increasingly greater distances to the shortest route each Round, and a reason could be, that a higher route deviation helped in avoiding the guards. Additionally, the higher guard ratio in Experiment 2 made it easier to pursue participants and therefore in Route Deviation was from the start greater in Experiment 2 than in Experiment 1, and consequently, could not be increased as much as in Experiment 1.

Finally, Suppressed Impulses to Change Movement is a significant and positive predictor for Route Deviation in Experiment 1 and the same relationship was not significant in Experiment 2 (b_1 = 0.63, p_1 = .028, b_2 = 0.28, p_2 = .484). Therefore, participants who reported suppressed impulses also deviated more from the shortest route. An explanation could be that participants were uncertain about their route and therefore deviated more from the shortest route.

Table 9

Regression T, P and Beta Values for Route Deviation as Dependent Variable

	Experiment 1			Experiment 2		
Estimate	*b*	*SE*	*p*	*b*	*SE*	*p*
Round	**2.14**	0.52	**< .001**	0.18	0.53	.738
Illegal Card Selection	-0.26	0.58	.656	-1.89	1.32	.155
Alertness to Being Target of Guards	-0.32	0.17	.068	**0.62**	0.28	**.031**
Cognitive Self-Regulation	-0.26	0.21	.226	0.42	0.39	.279
Situational Self Awareness	0.11	0.22	.624	-0.10	0.37	.778
Frightened by Presence of Guards	-0.27	0.28	.335	-0.06	0.36	.875
Suppressed Impulses to Change Movement	**0.63**	0.28	**.028**	0.28	0.39	.484
Contemplation of Hostile Intent	0.01	0.26	.958	-0.52	0.35	.138
Awareness Movement Change in Presence of Guards	-0.04	0.18	.825	0.25	0.31	.415

Note. *p*-values less than .050 are in bold.

Model for Variation Route Deviation. We calculated Model 6.2 with Variation Route Deviation as outcome variable and Table 10 displays the results per estimate. As the table shows, Suppressed Impulses to Change Movement is a significant predictor for Variation Route Deviation in Experiment 1 and Experiment 2 (b_1 = 0.34, p_1 = .033, b_2 = 0.37, p_2 = .017). This means, when participants reported more suppressed feelings then they also changed their route more often. A reason could be that the participants were uncertain about the route to avoid the guards and therefore changed it more often.

Additionally, Round is a negative and significant predictor for Variation Route Deviation in Experiment 2 and the opposite relationship is not significant in Experiment 1 (b_1 = 0.10, p_1 = .773, b_2 = -1.05, p_2 = .049). Thus, when participants selected an illegal card in Experiment 2 then they changed their route less often. An explanation is the small number of participants that carried a legal card in Experiment 2 and which were used by the teams to distract the guards by changing their route more often.

Furthermore, Illegal Card Selection is a negative and significant predictor for Variation Route Deviation in Experiment 2 and the opposite relationship is not significant in

Experiment 2 (b_1 = 0.12, p_1 = .721, b_2 = -1.10, p_2 = .045). Therefore, when participants chose an illegal card in Experiment 2 they changed their route less often. An explanation could be that, participants with a legal card changed their route more often to attract the attention of the guards and that participant with an illegal card did the opposite. This strategy could have been more important in Experiment 2 since the area, where the guards were allowed to walk, was larger in Experiment 2. Consequently, when a participant got the attention from the guard, the guard had to walk further away from other participants.

Moreover, Alertness to Being Target of Guards is a positive and significant predictor for Variation Route Deviation in Experiment 2 and the opposite relationship is not significant in Experiment 1 (b_1 = -0.14, p_1 = .164, b_2 = 0.29, p_2 = .009). This means that, when the participants perceived themselves as a target by the guards then the participants would change their route more often in Experiment 2 and the opposite happened in Experiment 1. The reason could be that in Experiment 2 every participant could be checked and when the participants perceived themselves as a target they actively avoided the guards by changing their route more often. In Experiment 1, in contrary, not all participants could be checked, and the participants could try to act normal to reduce guard suspicion.

Finally, Awareness Movement Change in Presence of Guards is a positive and significant predictor for Variation Route Deviation in Experiment 2 and the same relationship is not significant in Experiment 1 (b_1 = 0.23, p_1 = .024, b_2 = 0.08, p_2 = .529). Thus, when the participants were aware that they changed their route or speed after seeing the guards, then they also changed their route more often. A reason could be that the participants attempted to outmaneuver the guards by changing the route after seeing them.

Table 10

Regression T, P and Beta Values for Variation Route Deviation as Dependent Variable

	Experiment 1			Experiment 2		
Estimate	*b*	*SE*	*p*	*b*	*SE*	*p*
Round	**0.82**	0.26	**.002**	0.08	0.22	.734
Illegal Card Selection	0.10	0.33	.773	**-1.05**	0.53	**.049**
Alertness to Being Target of Guards	-0.14	0.10	.164	**0.29**	0.11	**.009**
Cognitive Self-Regulation	-0.19	0.12	.118	0.24	0.15	.119
Situational Self Awareness	0.12	0.13	.368	-0.19	0.15	.188
Frightened by Presence of Guards	-0.20	0.16	.207	-0.21	0.14	.150
Suppressed Impulses to Change Movement	**0.34**	0.16	**.033**	**0.37**	0.15	**.017**
Contemplation of Hostile Intent	0.01	0.15	.944	-0.23	0.14	.093
Awareness Movement Change in Presence of Guards	**0.23**	0.10	**.024**	0.08	0.12	.529

Note. *p*-values less than .050 are in bold.

Summary

In summary, the results show that the participants used strategies to avoid the guards. For instance, the participants changed their behaviour with each consecutive Round, by increasing the distance to team members, by accelerating and decelerating more often, by taking longer routes, and by changing the route more often. These changes indicate a collective strategy by the participants to become better in avoiding the guards. Additionally, teams made use of a distraction strategy. For that purpose, participants chose to carry a legal card and distracted the guards, in order to improve the chances of their team members, that have an illegal card, to avoid the guards.

Participants were presumably uncertain about the best route to avoid the guards, and the uncertainty, reduced pace, increased changes in pace, increased the route length, and increased changes in direction. Additionally, participants stayed closer to team members when they had feelings of fear and kept a greater distance if they had the feeling that they had to hide something. Furthermore, participants attempted to avoid guards by, changing the pace more often when targeted, by increasing the pace after seeing the guards, and by changing the route more often after seeing the guards.

In Experiment 1 the participants had two illegal cards per team and in Experiment 2 the participants could choose a free ratio of legal and illegal cards. Therefore, the increased availability of illegal cards presumably reduced the relationship between the selection of an illegal card and feeling of hostile intent. Another difference between the experiments was the ratio of guards and participants. Specifically, in Experiment 2 were more guards per participant than in Experiment 1 and that made it more difficult for the participants to avoid the guards in Experiment 2. Consequently, when participants perceived themselves as target by the guards, the participants in Experiment 1 took a more direct path and made less changes to their direction in order not to attract further attention by the guards. Moreover, the participants in Experiment 2 did the opposite, in an attempt, to outmanoeuvre the guards and took a longer route and made more changes to their route. Finally, in Experiment 1, when participants saw the guards they reduced their speed in order not to attract any attention and a similar effect could not be found in Experiment 2.

Discussion

The aim of the current study was to develop a research tool that enables behavioural scientists to more easily use Positional Technologies (PTs), such as GPS, for psychological experiments, and to give an overview which psychological variables can be studied with PTs. Additionally, we conducted two experiments to find new variables that can be linked to GPS movement data and to test the new research tool.

Psyosphere

Therefore, we developed the R package “psyosphere” (Ziepert et al., 2018) to analyse GPS data by transforming GPS tracks into descriptive variables, such as speed, direction or distance, that can be analysed with linear regression methods. Our “psyosphere” builds on existing R packages (e.g. Hijmans et al., 2015; Kahle & Wickham, 2013; Loecher & Ropkins, 2015; Wickham, 2016) and is optimized to handle multiple tracks simultaneously and to make comparisons between these tracks. This is done, because comparisons between multiple participants with linear regression methods is a typical technique of conducting studies in behavioural science. To give a simplified example, the speed of multiple car drivers for a given route could be compared, to investigate if speed warnings reduce risky driving behaviour. Furthermore, the package supports data preparation through cleaning up the data by marking coordinates with unrealistic speeds as missing values or by detecting measuring gaps. Additionally, sub-tracks can be selected by providing start and finish areas. The package also supports the visualization of tracks. For that purpose, tracks and polygons can be plotted on maps, tracks can be coloured based on grouping variables, and tracks can be plotted per participant or team (see Figure 1).

Psychological variables

To illustrate which type of variables could be studied with PTs and “psyosphere”, we gave an overview of variables that were used in past research (see Table 1). Additionally, we conducted two experiments to study the relationship between feelings of hostile intent and movement data measured with GPS loggers. During the experiments, teams of participants would smuggle supposedly illegal and legal cards, while crossing a park, and were instructed to avoid being stopped by guards that were looking for the illegal cards.

The two experiments have illustrated that mental states related to hostile intent can influence the movement of participants. For instance, we found that when participants were fearful then they walked closer together. This finding is in line with past research, that has demonstrated that people stay closer together when confronted with an outside threat

(Brady & Walker, 1978; Feshbach & Feshbach, 1963; Schachter, 1959). Past research has also demonstrated that feelings of fright were related to a slower pace (Barliya et al., 2012). With the current study we could not reproduce this effect and a reason could be that participants did consider a slower pace as suspicious behaviour and feared that this would attract the attention of the guards, and therefore, suppressed the urge to walk slower.

Additionally, we found that when participants were contemplating whether they were doing something illegal and whether they had to hide something, they would keep a larger distance to their team members. This finding is in accordance with past research. For instance, participants in uncertain situations with a threat to personal self-esteem have been shown to keep a larger interpersonal distance (Brady & Walker, 1978; Schachter, 1959). For the current research, the threat to the personal self-esteem was the question whether participants believe that they were doing something illegal and the uncertainty could be whether participants will be intercepted by the guards.

Furthermore, we found that the participants developed evasive strategies, over the three rounds, to avoid the guards. In detail, the participants spread out more, took longer routes and changed their route and pace more often. We assume that the evasive strategies gave the guards fewer opportunities to stop participants and check whether they had illegal cards. Similarly, the second experiment illustrates that teams used distraction strategies to improve the overall team score. To distract the guards, one or two team members would carry a legal card, would walk ahead of the team members, with illegal cards, and would show an erratic movement such as changing the route more often to attract the attention of the guards. In a related pen-and-paper experiment, researchers asked participants to draw a route from a starting position to a designated target, without giving away their final destination (Jian, Matsuka, & Nickerson, 2006). The experiments showed that participants would take a longer route with erratic movement, such as changing direction more often, to hide their intended target. The findings of Jian et al. (2006) are comparable with the evasion strategies but not with distraction strategies, that we found in the current study. We argue that this seeming discrepancy can be explained by the beliefs of participants about what observers would characterize as normal behaviour, in the current situation. Thus, participants will use evasive strategies if they judge their behaviour as normal movement, compared to other people around them. Furthermore, participants can use evasive movement that exceeds perceived normal movement to purposefully create suspicion.

Finally, we found that when participants presumably were uncertain about their route, they showed erratic movement, such as changing the route more often, taking longer routes, changing the pace more often and overall walking slower. To test whether participants were actually uncertain, a future study could ask participants for instance “I felt uncertain which route I should take”. An alternative explanation could be that participants felt regret about the route they chose because they got caught. This could be assessed by, in a future study, asking the participants if they got stopped by the guards and whether they felt regret about the route they have taken.

Limitations

Arguably, the ratio between participants and guards influenced the relationship between the self-reported mental states and the measured GPS variables. Specifically, when the participants were carrying illegal cards, we assumed, that they would try to hide this fact before the guards and would try to act normal. To act normal, the participants had to suppress fear-related responses, such as running away. Furthermore, the suppression of fear-related responses takes effort, and cues from the surroundings, such as encountering a guard or being targeted by a guard, could limit the ability of participants to act normal. Therefore, we measured whether the participants changed their movement when they encountered the guards. In the second experiment it was much more likely that participants would be stopped than in the first experiment. As a consequence, the guards were much less selective in stopping participants in the second experiment, and therefore, participants opted more for openly evading guards then trying to act normal. Thus, we believe that the high ratio between guards and participants was the reason that we found a smaller number of significant relationships, between mental states and GPS variables, in the second experiment compared to the first experiment. We still found meaningful relationships that were present in both experiments, and we advise that future research should limit the amount of guards in order that not all participants can be checked.

Another limitation of the current study is that we tested for 90 regression estimates, which renders the probability of finding statistical significant relationships merely by chance (Type I error inflation) rather high. It is possible to correct for this chance by reducing the significance level with, for instance, a Bonferroni correction (Holm, 1979), and it is a matter of scientific discussion when and how to adjust the significance level (e.g. Cabin & Mitchell, 2000; Fisher, 1956). For the current study we chose not to correct the significance level since we were interested in exploring the data and finding new relationships while accepting a higher risk of false positives (Wigboldus & Dotsch, 2016). Additionally, to partly reduce the probability of finding statistical significant results by chance, we compared if a statistical significant relationship in one experiment could also be found in the other experiment. We believe that a follow-up study should include hypothesis testing and an experimental design, to confirm the findings of the current study and to ensure ecological validity.

Finally, we reason that the self-reported measure Suppressed Impulses to Change Movement only partly measured the intended mental state. The measure was meant to assess in how far participants suppressed impulses and tried to act normal in order not to attract the attention of the guards. Questions asked were for instance: “I would rather have chosen a different route” or “I would rather have run away from the guards”. The participants that scored high on Suppressed Impulses to Change Movement walked slower, changed their pace more often, walked a longer route, and changed their route more often, and we believe these erratic changes in movement would increase suspicion in the guards instead of reducing them. Additionally, especially in the second experiment we observed that a small group of participants ran away from the guards and chose a different route to avoid the guards. Therefore, a more reasonable description for the Suppressed Impulses to Change Movement measure would be that the questions measured the participants’ uncertainty of which route they should have chosen, or a regret about their route choice. The questions for the Suppressed Impulses to Change Movement measure were adopted from research by Wijn et al. (2017) and in their study, the participants had to follow a predetermined path. Therefore, the participants did not run away from the guards and additionally, the guards did not interact with the participants, which could have triggered a flight response. Consequently, for future research we advise to formulate new questions to assess the suppression of impulses to change movement.

Future development

Past research has shown that detecting movement patterns is dependent on the sensor accuracy (Kjargaard et al., 2013). An older version of the sensors that were used in the current study had an accuracy between 2.50 and 20 metres (Vazquez-Prokopec et al., 2009). Research has shown that sensor accuracy can be greatly improved by combining multiple satellite systems such as GPS, Glonass, Galileo, and BeiDou. Galileo and BeiDou are still under construction but would allow even further improvements when they are finished (Li et al., 2015). These accuracy improvements will allow to detect movement patterns in more detail, making it easier to link them to cognitive processes.

Furthermore, future research could extend the features of “psyosphere” by adding more complex methods, such as machine-learning classification. The data from studies such as the current one might for instance be used to train an algorithm to establish links between aspects of movement or other behaviours and various psychological state and trait variables, such as having a depression (Huang et al., 2016; Saeb et al., 2016; P. S. A. Wolf et al., 2013), or being a pickpocket (Bouma et al., 2014).

Conclusion

With the findings of the current study, we hope we have made it easier for social scientists to use PTs to study movement outside of a laboratory and in a real-world setting. Moreover, we show that “psyosphere” can prepare GPS data, from psychological experiments, for the analysis with commonplace statistical methods, such as linear regression.

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Appendix

Appendix 1

State questionnaire. For all questions a 7-point Likert scale was used ranging from 1 “Not at all” to 7 “Very much”. The questionnaire for the first experiment was in Dutch and for the second in English.

State questionnaire

Construct	Question	Experiment
Alertness to Being Target of Guards 1	I had the feeling the border guard(s) targeted me	1 and 2
Alertness to Being Target of Guards 2	I thought I had attracted the border guards’ attention	1 and 2
Alertness to Being Target of Guards 3	I had a feeling that I was going to be stopped	1 and 2
Alertness to Being Target of Guards 4	I felt like I was the one being addressed by the border guard(s)	1 and 2
Alertness to Being Target of Guards 5	I had the idea that the others were paying attention to me	1 and 2
Frightened by Presence of Guards 1	I was startled when I first noticed the border guards	1 and 2
Frightened by Presence of Guards 2	I was startled by the border guards’ presence	1 and 2
Frightened by Presence of Guards 3	The border guards’ presence made me feel stressed	1 and 2
Frightened by Presence of Guards 4	The border guards’ presence made me feel tense	1 and 2
Frightened by Presence of Guards 5	The border guards’ presence made me feel watched	Only 2
Frightened by Presence of Guards 6	The border guards’ presence made me feel suspect	Only 2
Cognitive Self-Regulation 1	During this round I have tried to hide my tension	1 and 2
Cognitive Self-Regulation 2	During this round I have tried to hide my nerves	1 and 2
Cognitive Self-Regulation 3	During this round I have tried to hide my emotions	1 and 2
Cognitive Self-Regulation 4	During this round I have tried not to attract attention	1 and 2
Cognitive Self-Regulation 5	During this round I have tried to act as normal as possible	1 and 2
Awareness Movement Change in Presence of Guards 1	During this round I have changed my course as soon as I saw the border guards	1 and 2
Awareness Movement Change in Presence of Guards 2	During this round I have increased my pace as soon as I saw the border guards	1 and 2
Suppressed Impulses to Change Movement 1	I would rather have chosen a different route	1 and 2
Suppressed Impulses to Change Movement 2	I would rather have taken a detour to avoid the border guards	1 and 2
Suppressed Impulses to Change Movement 3	I would rather have run away from the border guards	1 and 2
Suppressed Impulses to Change Movement 4	I would rather have turned around	1 and 2
Suppressed Impulses to Change Movement 5	I would rather have hidden myself	1 and 2
Contemplation of Hostile Intent 1	I was wondering whether I looked suspicious to the border guards	1 and 2
Contemplation of Hostile Intent 2	I was thinking about what I had to hide from the border guards	1 and 2
Contemplation of Hostile Intent 3	I was wondering whether I was doing something that I was not allowed to do	1 and 2

Construct	Question	Experiment
Situational Self Awareness 1	During this round I was aware of everything in my direct surroundings	1 and 2
Situational Self Awareness 2	During this round I was aware of my inner feelings	1 and 2
Situational Self Awareness 3	During this round I was aware of the way I presented myself	1 and 2
Situational Self Awareness 4	During this round I was aware of how I looked	1 and 2
Hostile Intent 1	During this round I felt I was doing something illegal	1 and 2
Hostile Intent 2	During this round I felt I had hostile intentions	1 and 2
Hostile Intent 3	My role in the experiment made me more tens than usual.	Only 1
Awareness Guard Presence 1	During this round of the experiment I felt tense because of the presence of the border guards.	Only 1
Awareness Guard Presence 2	During this round of the experiment I felt nervous because of the presence of the border guards.	Only 1
Awareness Guard Presence 3	During this round of the experiment I felt watched because of the presence of the border guards.	Only 1
Awareness Guard Presence 4	During this round of the experiment I felt suspicious because of the presence of the border guards.	Only 1
Other as Target 1	I had the feeling that the border guards targeted someone else.	Only 1
Other as Target 2	I had the feeling that the border guards meant someone else.	Only 1
Other as Target 3	I had the idea that someone else would be stopped.	Only 1

Other questions in the questionnaires. The following questions were asked to the participants but not used in the analysis. Some questions were only asked for either on of the two experiments. Since the questionnaire of the first experiment was in Dutch there are also some questions below in Dutch.

Further questions

Construct	Question	Experiment
Motivation 1	I was motivated to obtain a good score in this study	1 and 2
Motivation 2	I did the assignment as instructed.	Only 1
Motivation 3	I was motivated during the execution of the experiment.	Only 1
Strategy Start	What was your strategy in order not to be stopped in the border area?	Only 2
Strategy Finish	What would you do to (further) improve your strategy?	Only 2

Leadership question from Experiment 2

Below you see two rows of squares. In the **top row** (a.), please write down the **GPS tracker numbers** (or **card numbers)** of your fellow team members. In the **bottom row** (b.) please **indicate how much leadership each of your team members have shown**; do so using an index, with 1 indicating the strongest leader, 2 meaning second-strongest leader, etc. Use equal numbers for team members who have shown leadership equally, but please **use index 1 (strongest leader) only once.**

a. Numbers of team members **[Team1, Team2, …, Team7]**	Team1	Team2	Team3	Team4	Team5	Team6
b. Leadership index *(1=strongest, 2=second-strongest, ...)* **[Leader1, Leader2, … Leader7]**	Leader 1	Leader2	Leader3	Leader4	Leader5	Leader6

Appendix 2

How to Select a PT for Experiments

PT systems and types. GPS is one of the several systems that can be used to track movement around the world. GPS is provided by the United States of America Government and works with satellites that send out signals that can be received by GPS loggers. Based on the received signal the logger can calculate its position on the globe. Other systems that work with satellites are for instance Glonass from Russia, Galileo from the EU and BeiDou from China (Hofmann-Wellenhof et al., 2007). See Vazquez-Prokopec et al. (2009) for more details on how to select and test a GPS logger.

Alternatively, also Wi-Fi and GSM signals can be used to determine the location. Smart phones, internet-of-things (IOT) devices and specialised hardware can record the Wi-Fi and GSM signals and deduce the location (Kjargaard et al., 2013). It is also possible to track Wi-Fi and GSM enabled devices from a GSM tower (Bengtsson et al., 2011) or with Wi-Fi routers (Sevtsuk, Huang, Calabrese, & Ratti, 2009) even if the devices are not connected to the network. Cameras (Burgess et al., 2014), Bluetooth (Madan et al., 2010) and RFID (Isella, Romano, et al., 2011) are still other PTs that can be used for experiments. These technologies can all be used to determine the position of a person or object. Although this paper focuses on GPS the same methods of this paper can be also used for other PTs.

PT selection. The different systems to track movement such as GPS, GSM, Wi-Fi, cameras, RFID and Bluetooth have specific characteristics which makes them suitable for specific situations.

GPS. GPS allows for the wide range of movement and can be used all over the globe (Hofmann-Wellenhof et al., 2007). Furthermore, GPS devises and GPS enabled smart phones are widely available and affordable. Unfortunately, GPS satellite signals can be blocked by walls, trees and mountains, and GPS loggers have a limited accuracy between 2.5 and 20 metres depending on the device (Vazquez-Prokopec et al., 2009). Therefore, GPS can be best used for data gathering outdoors over longer distances. For instance, GPS is frequently used in travel and environmental exposure studies (Chaix et al., 2013), but can also be for instance used to detect signs of depression (Palmius et al., 2017; Saeb et al., 2015). Table 1 lists which psychological variables can be studied with a specific PT.

GSM. Similar to GPS, the signals from GSM towers can be used to track locations. For instance, a smart phone app or movement logger can be used to track the GSM signals (Asakura & Iryo, 2007). GSM signal tracking is unfortunately limited to locations were GSM towers are available and needs the active participants of the individuals that are studied (active approach). Another option is to use GSM towers to track the devices that interact with the GSM network (Bengtsson et al., 2011). The benefit of using GSM towers is that the participants do not need to take any action to be tracked (passive approach). GSM towers can be for instance used to understand population movement after a disaster such as an earth quake (Bengtsson et al., 2011).

Wi-Fi. Wi-Fi can be also utilized with an active or passive approach. For the active approach, again a smartphone app or movement logger can be used to detect the signals from the Wi-Fi routers and thereby determine the location (Kjargaard et al., 2013). The passive approach is that several Wi-Fi routers track all devices that interact with the network (Sevtsuk et al., 2009). Where GSM is more suitable for large distances and mostly outdoors, Wi-Fi is often used indoors and on shorter distances. Wi-Fi can be for instanced used to study leadership patterns (Kjargaard et al., 2013).

Cameras. Videos from for instance security cameras can be used to track individuals with movement recognition software (Bouma et al., 2014). Kjargaard et al. (2013) argue that video-based approaches to follow people can be limited since they depend on areas with a high density of camera coverage.

Bluetooth. Bluetooth works within several metres and can be for instance used to approximate if face-to-face social interaction takes place. This can be for instance used to study social networks or information spreading (Do & Gatica-Perez, 2011; Eagle, Pentland, & Lazer, 2008; Madan et al., 2010). Another application of Bluetooth is to use it as a social density measurement. A device such as a smart phone can check for active Bluetooth signals in a public space to estimate how many people are close by (O'Neill et al., 2006). Finally, Bluetooth can be also used to determine relative positions. For instance, the distance to a peer. The distance can be measured with an accuracy up to 1.9 metres (Banerjee et al., 2010).

RFID. Radio-frequency identification (RFID) tags also work within several metres. Similar to Bluetooth, RFID can be used to detect face-to-face social interactions and does so more accurately than Bluetooth. Compared to Bluetooth, RFID needs specialized infrastructure and therefore scaling up RFID experiments can be more difficult (Barrat et al., 2013; Cattuto et al., 2010).

Finally, the different technologies can be also combined to get for instance a higher location accuracy (Asakura & Iryo, 2007; Kracht, 2004). The technologies can also be combined to measure different aspects of behaviour. For instance, GPS and Bluetooth can be combined to measure movement and face-to-face interactions (Adams, Phung, & Venkatesh, 2008). Smartphones are especially useful to combine PTs since they can record GPS, GSM, Wi-Fi and Bluetooth signals (Madan et al., 2010).

Appendix 3

Description of "psyosphere" on CRAN

"psyosphere" is published on the Comprehensive R Archive Network (CRAN). The description of "psyosphere" on CRAN is as following: "Analyse location data such as latitude, longitude, and elevation. Based on spherical trigonometry, variables such as speed, bearing, and distances can be calculated from moment to moment, depending on the sampling frequency of the equipment used, and independent of scale. Additionally, the package can plot tracks, coordinates, and shapes on maps, and sub-tracks can be selected with point-in-polygon or other techniques. The package is optimized to support behavioural science experiments with multiple tracks. It can detect and clean up errors in the data and resulting data can be exported to be analysed in statistical software or geographic information systems (GIS)." (Ziepert et al., 2018).