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Putting mood in context: Using smartphones to examine how people feel in different locations

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ABSTRACT

Does personality predict how people feel in different types of situations? The present research addressed this question using data from several thousand individuals who used a mood tracking smartphone application for several weeks. Results from our analyses indicated that people's momentary affect was linked to their location, and provided preliminary evidence that the relationship between state affect and location might be moderated by personality. The results highlight the importance of looking at person-situation relationships at both the trait- and state-levels and also demonstrate how smartphones can be used to collect person and situation information as people go about their everyday lives.

1. Introduction

We know that personality is linked to behavior. Several studies have shown, for example, that personality is linked to preferences for and success in various occupations (Judge, Higgins, Thoresen, & Barrick, 1999; Lodi-Smith and Roberts, 2007), maintaining satisfying intimate relationships (Ozer & Benet-Martinez, 2006; Roberts, Kuncel, Shiner, Caspi, & Goldberg, 2007), and how people choose to spend their free time (Mehl, Gosling, & Pennebaker, 2006; Rentfrow, Goldberg, & Zilca, 2011). Our understanding of these links is informed by interactionist theories, which argue that individuals seek out and create environments that satisfy and reinforce their psychological needs. An implication of this argument is that individuals experience higher positive affect and lower negative affect when in their preferred environments. Drawing on past research on person-environment interactions and using experience sampling and mobile sensing technology, the present research investigated whether personality traits moderate the associations between state affect and locations, which are associated with different types of situations.

Personality is linked not only to behavior, but also to affect. In one study, situational characteristics (social vs. non-social context) and personality traits (Extraversion and Neuroticism) both predicted state positive and negative affect (Pavot, Diener, & Fujita, 1990). People experienced greater positive affect both when they were high in Extraversion, and when they were in social situations, but there was no interaction: people with all levels of Extraversion experienced more positive affect in social situations. In a related study, researchers found that positive affect (but not negative affect) follows a diurnal rhythm, with people socializing, laughing and singing more and more for the first 8–10 h after waking, and then doing those activities less and less (Hasler, Mehl, Bootzin, & Vazire, 2008). Further, this study found preliminary evidence that this diurnal cycle of positive affect may be amplified for people high in Extraversion. These findings have implications for within-person variation in personality, given that affect is assumed to mediate the influence of the situation on personality states (Mischel & Shoda, 1995).

Although there is agreement that features of the environment affect how people think, feel, and behave, there is less agreement on which aspects of the environment have psychological implications (Fleeson & Noftle, 2008; Rauthmann et al., 2014). The physical environment, including location, is one objective characteristic

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often associated with a situation (Rauthmann et al., 2014; Saucier, Bel-Bahar, & Fernandez, 2007). The locations people regularly visit may be consistently associated with a constellation of factors (e.g., affect, sociability, recreation, goal pursuit), and thus represent types of situations that have psychological implications, and clear links to personality For example, the recently developed DIAMONDS taxonomy identifies several characteristics of situations that might feasibly be linked to locations (Rauthmann et al., 2014); work might be high in Duty and Intellect, and social places, such as restaurants and bars, might be high in Sociality and pOsitivity. These situational factors are connected to personality-related behaviors (Rauthmann et al., 2014), suggesting that locations should be as well.

A challenge in studying affect as it is experienced in the various types of situations that people encounter in daily life is the repeated collection of data on mood and situation type. Methodological advances such as experience sampling have made it possible to collect repeated self-reports (e.g., of affect) as people go about their daily lives. However, to date it has been difficult to simultaneously collect objective information about the type of situation in which people find themselves. One exception is a recent paper that used repeated experience sampling to examine the relationship between a person's personality traits, the types of situations they encountered, and state expressions of personality, all of which were self-reported (Sherman, Rauthmann, Brown, Serfass, & Jones, 2015). In this study, state personality (as manifested in behavior and emotions) was independently predicted by both personality traits and situation characteristics.

The advent of mobile sensing technology provides a potential solution to the challenge of collecting repeated information about both behaviors and situations: detect the type of situation using the sensors built-into today's ubiquitous smartphones. These devices come equipped with location sensors, an accelerometer that can detect a user's physical activity, a microphone that can detect ambient noise in the environment, and various other sensors. The potential is great, but little research to date has made use of sensed information to examine psychologically relevant questions.

In the present research, we explored the relationship between state affect and location, which can be thought to represent a type of situation. Our objective was to lay a foundation of preliminary knowledge in the under-explored domain of associations between situation types and state affect.

2. Methods

2.1. Participants

Participants were members of the general public who downloaded the free app from the Google Play store and installed it on their Android phone. The analyses reported herein include all users who provided data on the measures of interest (described below) from February 2013, when the app was released, to July 2015, when we began the analyses.

A total of 12,310 users provided relevant momentary self-reports of location (i.e., they reported being at home, at work, or in a social type of situation). Of the users who reported demographics ($N = 10{,}889$), 44% of people who reported their gender were female, 71% of people who reported their ethnicity reported being White, and the most common birth year ranges were 1980–1989 (38%), 1990–1999 (32%) and 1970–1979 (18%).

Given that these users may or may not have provided trait or state self-reports of personality, and may or may not have provided location sensor data (see Section 2.2 for why this is the case), the analyses described in the results section include different subsets of these users. Ethical clearance has not been granted for sharing the data supporting this publication.

2.2. The Emotion Sense application

Emotion Sense is a smartphone application that was designed to study subjective well-being and behavior. The app collects self-report data through surveys presented on the phone via experience sampling. By default, the app sends two notifications at random moments of the day between 8 AM and 10 PM, at least 120 min apart from one another. Clicking on a notification launches a momentary assessment, which includes measures of current affect, and measures assessing a single aspect of current behavior or context (e.g., location, physical activity, social interactions). In addition to the notification-driven surveys, the app also collects self-initiated surveys. These included longer measures of affect, and measures assessing multiple aspects of behavior and context.

As well as collecting self-report data, the app also uses open-sourced software libraries (Lathia, Rachuri, Mascolo & Roussos, 2013) to periodically collect behavioral and contextual data from sensors in the phone. The data collected through the app is stored on the device's file system and then uploaded to a server when the phone is connected to a Wi-Fi hotspot.

Emotion Sense was designed to be a tool to facilitate self-insight, providing feedback about how participants' mood relates to context and activity. In an effort to maintain user engagement over a period of weeks, participants could receive additional feedback by "unlocking" stages, in the same way that players can unlock different levels of a game after achieving certain objectives. Each stage had a particular theme (e.g., location, physical activity) that determined which behavior and context questions (e.g., "Where are you right now?", "Compared to most days, how physically active have you been today?") were asked in the self-report surveys. The second stage, related to location, is the only stage reported in these results.[1]

2.3. Measures

2.3.1. Trait personality

Users reported their personality on the Ten-Item Personality Inventory (Gosling, Rentfrow, & Swann, 2003). They rated the extent to which ten pairs of words (e.g., "Extraverted, Enthusiastic") applied to them, on a scale from 1 = *Disagree strongly* to 7 = *Agree strongly*.

2.3.2. Affect

Emotion Sense allows users to track and quantify their psychological well-being in various ways. On each self-report survey, whether notification-driven or self-initiated, users indicate their current feelings by tapping on a two-dimensional affect grid (see Fig. 1), where the x-axis denotes valence, from negative to positive, and the y-axis denotes arousal, from sleepy to alert (Russell, Weiss, & Mendelsohn, 1989).

2.3.3. Location

One way Emotion Sense assesses current location is through place self-reports. Users respond to the question "Where are you right now?", indicating whether they are at "Home," "Work," "Family/Friend's House," "Restaurant/Café/Pub," "In transit," or "Other" (see Fig. 2). We treated both "Family/Friend's House" and "Restaurant/Café/Pub" as social types of situations, and did not

[1] The eighth stage, related to personality, is reported in additional analyses in Appendix 1.

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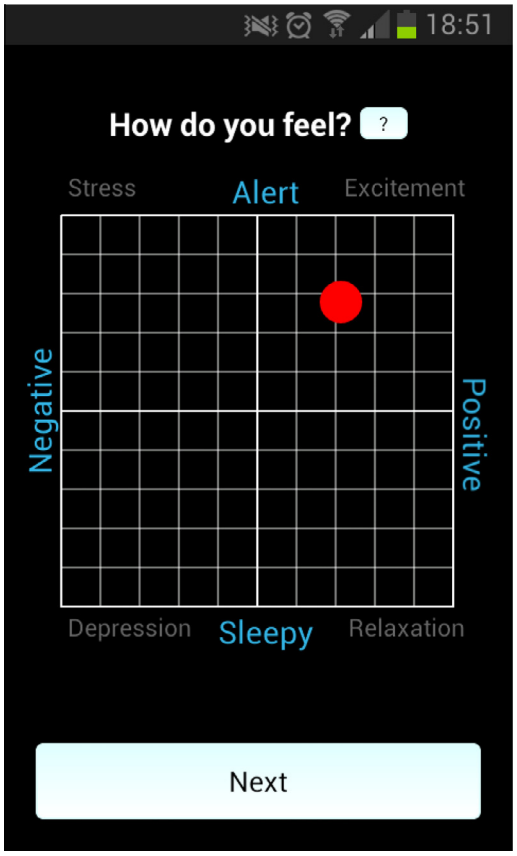

Fig. 1. Measuring mood in Emotion Sense using the affect grid: Users select a point on a grid that quantifies valence (horizontally) and arousal (vertically).

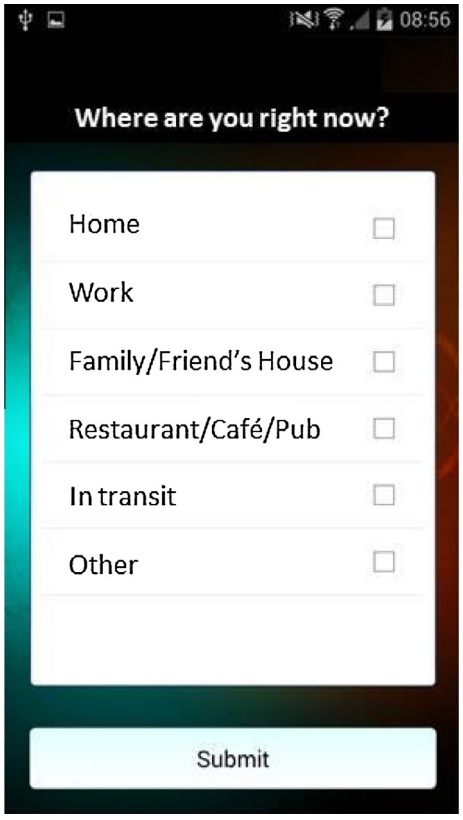

Fig. 2. An example of how users self-report their location.

examine "In Transit" or "Other" reports. These locations were expected to be ones where people spent much of their time, and visited over and over again.

Location is also sensed via the phone's location sensors. For 15 min before each survey notification and at various intervals throughout the day, Emotion Sense determines the location of the phone by collecting the latitude, longitude, accuracy, speed, and bearing of the device from its location sensors. This is a coarse measure of location, with accuracies ranging from the tens to hundreds of meters, but measuring location more accurately consumes far more battery power.

A three-step process allowed us to match self-report data (e.g., state affect and state personality) to places (i.e., home, work, social). First, we mapped each geographical location to a place by connecting the location sensor data to the location self-reports. Next, we mapped each self-report (e.g., state affect and state personality) to a geographic location by connecting the self-report to the temporally closest location sensor data. Finally, we mapped these self-report geographic locations to places using the mappings created in the first step. (See Appendix 1, Section 2.4 for more details.)

3. Results

We investigated whether a person's mood is related to the location they are in, and how that relationship is moderated by trait personality.

3.1. How is affect related to location?

We created two sets of dummy codes: one set with Home as the reference group (to compare mood at Home vs. at Work, and at Home vs. in a Social type of situation), and the other set with Work as the reference group (to compare mood at Work vs. in a Social type of situation). We ran hierarchical linear modelling, using the lme4 package in R (Bates, Maechler, Bolker, & Walker, 2014), predicting mood from the place dummy codes (level 1), grouped by user (level 2). This analysis was carried out for both the location self-reports, and the locations sensed by the phone sensors. We report results for grid valence, but see Appendix 1 for analyses examining grid arousal and alternate measures of high and low arousal positive affect and negative affect. Given that degrees of freedom are not provided by the lme4 package, we approximated them from the number of level 2 units (i.e., users) minus the number of predictors in the level 2 equation, not including the intercept, minus 1 (Raudenbush & Bryk, 2002).

3.1.1. Self-reported location

Of the 12,310 users who provided momentary self-reports of location, 6759 reported their mood in at least two of the three targeted locations and were used in these analyses. These users provided, on average, 23 reports of location (from 2 to 305 reports, median = 18).

The results from our analyses indicated that participants experienced a more positive mood when they reported being in a social type of situation ($M = 0.34$, $SD = 0.18$) vs. at home ($M = 0.20$, $SD = 0.31$), $\beta = 0.29$, $t(6{,}758) = 38.84$, $p < 0.001$, and when they reported being at home vs. at work ($M = 0.18$, $SD = 0.25$), $\beta = -0.08$, $t(6{,}758) = -14.18$, $p < 0.001$. (NOTE: Means and standard deviations were computed for each type of location for each person, and then averaged across people. They are unstandardized.) For more nuanced results, showing differences between high arousal and low arousal positive and negative emotions, see Appendix 1.

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3.1.2. Sensed location

Of the 12,310 users who provided momentary self-reports of location, 7582 also provided relevant momentary self-reports of mood that could be linked up to location readings from the location sensor with some degree of accuracy (see Appendix 1, Section 2.4 for details). Of these, 3646 users reported their mood in at least two of the three targeted locations and were used in these analyses. These users provided, on average, 111 reports of mood (from 2 to 1117 reports, median = 88).

Consistent with the results for self-reported locations, users reported a more positive mood when the phone sensors detected that they were in a social type of situation ($M = 0.34$, $SD = 0.17$) vs. at home ($M = 0.23$, $SD = 0.32$), $\beta = 0.20$, $t(3{,}645) = 37.22$, $p < 0.001$, and when the phone sensors detected that they were at home vs. at work ($M = 0.20$, $SD = 0.27$), $\beta = -0.11$, $t(3{,}645) = -33.97$, $p < 0.001$. For more nuanced results, showing differences between high arousal and low arousal positive and negative emotions, see Appendix 1.

3.2. Does trait personality moderate the relationship between affect and location?

Next we tested whether an individual's personality traits moderated the relationship between their location and their state affect. For example, do people high in Extraversion experience more positive affect in social types of situations compared to people low in the trait? We created two datasets: (1) a dataset that had only reports from home and work, and (2) a dataset that had only reports from home and in social types of situations. Then we ran regressions predicting state affect from the interactions between location (dummy coded as before) and each of the big five personality traits (standardized across users), entered simultaneously. When we found significant interactions involving personality, we examined the simple slopes for low and high values of the personality trait at −1 and +1 SD from the mean.

3.2.1. Self-reported location

Of the 6759 users who provided momentary self-reports of location and reported their mood in at least two of the three targeted locations, 1434 also self-reported trait personality and were included in these analyses.

The more positive mood associated with being at home vs. being at work was moderated by Openness, $\beta = -0.04$, $t(1{,}428) = -2.70$, $p = 0.01$, and Agreeableness, $\beta = 0.04$, $t(1{,}428) = 3.08$, $p = 0.002$ (see Appendix 1 for full model statistics). The mood benefits associated with being at home vs. being at work were larger for people who were high in Openness, $\beta = -0.14$, $t(1{,}428) = -7.24$, $p < 0.001$, than for people low in Openness, $\beta = -0.06$, $t(1{,}428) = -2.92$, $p = 0.004$. The mood benefits associated with being at home vs. being at work were larger for people who were low in Agreeableness, $\beta = -0.14$, $t(1{,}428) = -7.16$, $p < 0.001$, than for people who were high in Agreeableness, $\beta = -0.06$, $t(1{,}428) = -3.32$, $p < 0.001$.

The more positive mood associated with being in a social type of situation vs. being at home was moderated by Neuroticism, $\beta = 0.03$, $t(1{,}428) = 2.02$, $p = 0.04$. The mood benefits associated with being in a social type of situation vs. being at home were larger for people who were high in Neuroticism, $\beta = 0.35$, $t(1{,}428) = 15.42$, $p < 0.001$ than for people who were low in Neuroticism, $\beta = 0.28$, $t(1{,}428) = 11.37$, $p < 0.001$.

3.2.2. Sensed location

Of the 3646 users who reported their mood in at least two of the three targeted locations and provided momentary self-reports of mood that could be linked to location readings from the location sensor, 651 also self-reported trait personality and were included in these analyses.

As with the self-reported locations, the more positive mood associated with being at home vs. being at work was moderated by Openness, $\beta = 0.05$, $t(645) = 3.64$, $p < 0.001$. Openness showed the opposite pattern to the self-reported location data: the mood benefits associated with being at home vs. being at work were larger for people who were low in Openness, $\beta = -0.18$, $t(645) = -10.15$, $p < 0.001$, than for people high in Openness, $\beta = -0.09$, $t(645) = -4.73$, $p < 0.001$.

The more positive mood associated with being in a social type of situation vs. being at home was moderated by Extraversion, $\beta = -0.04$, $t(645) = -1.98$, $p = 0.05$, and Agreeableness, $\beta = -0.05$, $t(645) = -2.34$, $p = 0.02$. The mood benefits associated with being in a social type of situation vs. being at home were larger for people who were low in Extraversion, $\beta = 0.23$, $t(645) = 8.04$, $p < 0.001$ than for people who were high in Extraversion, $\beta = 0.15$, $t(645) = 5.60$, $p < 0.001$. The mood benefits associated with being in a social type of situation vs. being at home were larger for people who were low in Agreeableness, $\beta = 0.24$, $t(645) = 8.04$, $p < 0.001$, than for people who were high in Agreeableness, $\beta = 0.15$, $t(645) = 5.70$, $p < 0.001$.

4. General discussion

A person's momentary mood fluctuated in relation to their location (i.e., at home, at work, and in social types of situations. We used both self-reported location, and location sensed via smartphone sensors and found remarkably consistent results (on grid valence, which was reported in the main text, but also on alternate measures of high and low arousal positive and negative affect, which were reported in Appendix 1). People reported more positive affect in social types of situations than at home or work. Further, high arousal positive and negative affect were reported more at work than at home, whereas low arousal positive and negative affect were reported more at home than at work.

We found some evidence that the more positive mood associated with being in a social type of situation vs. being at home was moderated by personality. The difference in mood reported in social types of situations vs. at home was greater for people who were low in Agreeableness, low in Extraversion or high in Neuroticism. These results are consistent with the finding that Extraversion and Agreeableness are positively related to high quality social relationships, whereas Neuroticism is negatively related to high quality social relationships (Lopes, Salovey, & Straus, 2003; Lopes et al., 2004). Perhaps social types of situations are associated with greater mood gains for those who generally struggle more with their social relationships.

We also found some evidence that the more positive mood associated with being at home vs. being at work was moderated by personality. The difference in mood reported at home vs. at work was greater for people who were low in Agreeableness. This might suggest that people who are low in Agreeableness struggle more in their forced interactions with colleagues at work (thus experiencing more positive affect at home vs. at work), whereas they thrive in their chosen interactions with friends in social types of situations (thus experiencing more positive affect in social types of situations vs. at home).

These moderation results should be interpreted with caution for several reasons. First, though significant, these effects were small, $|\beta|$'s $\leqslant 0.05$. Second, the results were not always the same for the self-reported locations as they were for the sensed locations. For example, the difference in mood reported in social types of situations vs. at home was larger for people high in Openness when the location was self-reported, but larger for people low in

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Openness when the location was sensed. Finally, these results conflict with past research, which found additive effects of trait personality and situation characteristics on expressed behavior and emotion, but no interactions (Sherman et al., 2015). Further research is necessary to determine whether these results are reliable.

The current results are consistent with an average layperson's intuition: when people are asked to reflect on the factors that affect their expression of traits, they often mention the location (Saucier et al., 2007). Although the physical characteristics of a location may be directly related to the expression of traits (e.g., people may express more Neuroticism in unfamiliar environments, or less Extraversion in green spaces), it is likely that the psychological characteristics that become associated with a particular location are actually driving the relationship. For instance, being at home may be associated with spending time with family, and taking on a more communal role, whereas being at work may be associated with competition, and taking on a more agentic role. Rauthmann et al. (2014) proposed eight situational factors with psychological consequences: Duty, Intellect, Adversity, Mating, pOsitivity, Negativity, Deception, Sociality. We expect that the three locations we examined varied in many of these factors (e.g., Intellect may be more of a factor at work than at home or in social types of situations, whereas Sociality may be more of a factor in social types of situations than at work or at home); these assumptions could, of course, be tested in a future study. Future work is needed to determine which characteristics of a situation are active in the locations that we examined, but also in locations more broadly. This knowledge about what types of locations are likely to present situations high in each type of characteristic would allow future mobile sensing studies to sample a more complete set of locations. The usefulness of mobile sensing for testing questions about person-environment interactions will depend on its ability to sample from locations with a wide range of situational characteristics, and its ability to accurately label locations according to their characteristics with as little user intervention and training as possible.

Smartphone sensors provided a powerful means of passively detecting the type of situation a user is encountering, and reducing the burden of self-reports in the current study. Their usefulness in future studies may depend on how capable they are of detecting other psychologically relevant situational factors. In this study, we focused on using location sensors to learn the semantics of places, so that we could examine relationships between place, affect, and personality. Collecting data from other sensors could augment this analysis, as well as provide other signals that may characterize the type of situation that a user is encountering. For example, collecting Wi-Fi scans can be used for finer-grained, indoor localisation (Gao et al., 2011), and bluetooth sensors can be used to detect co-located bluetooth devices of other study participants (Eagle & Pentland, 2006). Smartphones' microphones can be used to measure ambient noise (Lathia, Rachuri, Mascolo, & Rentfrow, 2013); with sufficient training data, these can even be used to analyze participants' speech (Rachuri et al., 2010). Recent work has shown that the ambiance of a place can also be derived from photographs taken there (Redi, Quercia, Graham, & Gosling, 2015). Work is needed to establish the validity of data from various sensors to assess psychologically meaningful situational characteristics.

One way to establish the validity of sensor data is to compare it to self-reports, as we did in this study. However, various decisions need to be made in order to sample sufficient data from the sensors at the right times and at the right level of detail. In this study, the place label (home, work, or social) given to a particular geographic location (latitude, longitude pair) was inferred by matching self-reported location to location sensor data (see Appendix, Section 2.4). This process has a number of limitations. First, if a participant has never self-reported their location in a particular geographic area, we cannot make any inferences about that place. While there are methods that attempt to infer place semantics based on other signals (e.g., time of day/day of week), we limited our analysis to those places that were explicitly labelled. We matched location samples with place self-reports based on a fixed temporal threshold of 15 min; reducing this constant may improve the accuracy of location inferences, at the expense of reducing the number of labelled self-reports. Finally, we assumed that a user was in the same place if the two location samples were less than 1600 m from one another. In highly dense urban environments, this may not necessarily be the case.

Even if phone sensors are shown to measure situational characteristics with some level of validity, work is needed to understand the capabilities and limitations of the sensors. We used location data that was passively captured from participant's devices in order to infer where they were at the time of reporting their state personality or their mood. While location sensors are broadly reliable (indeed, they are used for mapping applications), they do not work when a user has disabled their device's location services, and they do not work in all types of situations, such as underground or, in some cases, indoors. Obtaining a highly accurate and recent location sample is possible, but it is a time- and battery-consuming task, since it requires turning on the GPS sensor, waiting for it to obtain a satellite fix, and then collecting the data. Instead, we resorted to collecting coarse-grained data, which is easier and quicker to sample and more energy-efficient, but may be less accurate.

The current results bolster the call for further research of within-person variation in affect and personality. We found evidence that people experience fluctuations in state affect when they are in different locations. As research continues to identify the factors of a situation that are psychologically meaningful, future work will be able to investigate the interactive effects of various situational factors on people's feelings and behavior. The combination of experience sampling and mobile sensing allowed us to collect large amounts of within-person data in the current work, and could prove invaluable to further study, to the extent that phone sensors can objectively measure psychologically active situational variables. The current study describes how people feel and behave in different locations, but as a field we are just beginning to learn about the full extent to which feelings and behavior vary by type of situation.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jrp.2016.06.004.

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