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Naturalistic Monitoring of the Affect-Heart Rate Relationship: A Day Reconstruction Study

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Objective: Prospective studies have linked negative affect with hypertension, cardiovascular disease, and mortality. This study aims to identify if cardiovascular activity in day-to-day settings is related to affect levels as assessed using the Day Reconstruction Method (Kahneman, Krueger, Schkade, Schwarz, & Stone, 2004). ***Design:*** 186 people underwent baseline physiological testing and were monitored naturalistically for an entire day. Multilevel models were the principal analyses used. ***Main Outcome Measures:*** We utilized an online day reconstruction survey to produce a continuous account of affect, social interactions, and activity patterns during waking hours. Ambulatory heart rate (HR) was assessed during the same period. Personality, health behavior, consumption, self-reported activity, and baseline physiological characteristics were assessed to isolate the relationships between affect and HR. ***Results:*** Negative affect predicted an elevated ambulatory HR and tiredness predicted a lower HR. Associations between negative affectivity and increased cardiovascular reactivity were maintained after taking account of baseline physiological factors, health behavior, and personality. ***Conclusion:*** Negative affect in everyday life is a reliable predictor of HR. Combining day reconstruction with psychophysiological and environmental monitoring is a minimally invasive method with promising interdisciplinary relevance.

Keywords: heart rate, negative affect, Big Five, Day Reconstruction Method

Longitudinal surveys have demonstrated that trait neuroticism and subjective distress levels increase the risk of the occurrence of stroke, cardiovascular disease, hypertension, and mortality, independent of medical risk factors (Hemingway et al., 2003; Ockenfels et al., 1995; Penninx, Leveille, Ferrucci, van Eijk, & Guralnik, 1999). The cardiovascular response to life events is one likely mechanism through which state and trait factors related to affect may modulate the effect of stressors on a range of cardiovascular health outcomes (Kulkarni, O'Farrell, Erasi, & Kochar, 1998; Rozanski, Blumenthal, Davidson, Saab, & Kubzansky, 2005). There is substantial experimental evidence that negative affect induced in laboratory settings can evoke adverse changes in physiological functioning such as decreased production of immunoglobulin A and increased cortisol secretion and cardiovasular reactivity (Buchanan, al'Absi, & Lovallo, 1999; Kibler & Ma, 2004; Tsuboi et al., 2008).

Previous research also has linked cardiovascular reactivity to fluctuations in affect in naturalistic settings (Jacob et al., 1999; Johnston, Tuomisto, & Patching, 2008; Shapiro, Jamner, Goldstein, & Delfino, 2001). However, the relationships observed typically do not separate the contribution of affect and personality or systematically specify the role of situational, consumption related, and stable biological characteristics. Carefully delineating the relative contribution of this set of factors will allow a clear specification of the role of affect and personality in reactivity outside of the laboratory. In particular, the recent literature has identified heart rate (HR) as a measure that may provide critical insight into cardiovascular reactivity in the field and potentially act as a prospective marker for both physical and mental health outcomes.

Heart Rate as a Metric of Cardiac Reactivity

There are numerous measures of cardiac reactivity (e.g., standard deviation of interbeat intervals, mean of successive differ-

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ences in interbeat intervals), of which the most commonly endorsed have been found to correlate strongly with HR ($r = -.56$ to $-.98$; Allen, Chambers, & Towers, 2007). HR is a highly responsive measure of autonomic nervous system functioning, reflecting the dual activation of the sympathetic and parasympathetic branches (Kohlish & Schaefer, 1996). Increases in HR are considered to derive from a pattern of increased sympathetic and decreased parasympathetic system activation, whereas HR decreases result from the inverse pattern (Ottaviani, Shapiro, Davydov, & Goldstein, 2008).

HR is also sensitive to both environmental and emotional changes (Carrillo et al., 2001). Large-scale prospective epidemiological studies have identified high HR as a risk factor for health outcomes such as increased cardiovascular mortality, morbidity, and myocardial infarction (Gillum, Makuc, & Feldman, 1991; Hsia et al., 2009; Kannel, Kannel, Paffenbarger, & Cupples, 1987) as well as acting as a marker for the development of hypertension in young people (Palatini et al., 2006; Selby, Friedman, & Quesenberry, 1990). Examining cardiovascular activity in naturalistic settings is of critical importance to identify the mechanisms through which cardiovascular reactivity may have cumulative effects that are protective or detrimental to cardiovascular health (Michaud, Matheson, Kelly, & Anisman, 2008).

For instance, excessive environmental demands such as chronic work stress have been shown to relate to higher HR both in and directly after work (Belkic, Landsbergis, Schnall, & Baker, 2004; Ritvanen, Louhevaara, Helin, Väisänen, & Hänninen, 2006). Momentary experiences of positive affect have been shown to attenuate ambulatory cardiovascular reactivity (Steptoe, Wardle, & Marmot, 2005). Negative affect has been associated with a rise in HR and fatigue and disengagement with a drop in HR (Kamarck et al., 2005; Shapiro et al., 2001).

Naturalistic monitoring paradigms are particularly useful considering the current lack of clarity as to whether stress reactivity in the laboratory is associated with diminished psychosocial resources or with increased resources, health, and the ability to adapt dynamically to challenge. For instance, those with higher self-rated health have been shown to have a strong cortisol response to acute stress (Kristenson, Olsson, & Kucinskiene, 2005), and depressed people have demonstrated less cardiac reactivity during stressful tasks than controls (Carroll, Phillips, Hunt, & Der, 2007; Salomon, Clift, Karlsdottir, & Rottenberg, 2009). The association observed between cardiovascular reactivity to acute laboratory stressors and reactivity in real life is often weak or inconsistent (Turner et al., 1994). It may be the case that high negative affectivity is indicative of a tendency toward subtle but chronic patterns of reactivity to everyday events and an attenuated response to more exaggerated stressors such as those encountered in laboratory studies.

However, the relationship between affect and HR in ecologically valid continuous monitoring studies remains unclear, with some studies finding no relationship (Serrano, Moya-Albiol, & Salvador, 2008), and others finding correspondence in cases controlling for demographic and biological variables but not psychological factors such as personality (Carpeggiani et al., 2005). In several studies the assessment of affect also has been restricted, for instance through the use of measures requiring participants to endorse a single point on a circular dimension (circumplex) indicative of affective space (Jacob et al., 1999). Whereas in other cases the assessment of affect has been of sufficient detail to infer intensity and allow for mixed mood states, but the high frequency of the diary assessments (e.g., 40 to 50 per day) has involved a level of burden that would be likely to interfere with the flow of daily activities (e.g., Shapiro et al., 2001).

Other characteristics of previous studies such as choosing stressful days for ambulatory monitoring, or the use of heavy cardiovascular monitors or invasive blood pressure cuffs may diminish the ecological validity of the experience assessed (Johnston et al., 2008). In the current study, an explicit attempt was made to extend previous research by integrating minimally invasive cardiovascular monitoring and by utilizing a recently developed method for assessing experience in daily life that is exogenous to the assessment period in question.

The Measurement of Experience in Naturalistic Settings

Detailed accounts of everyday life have been generated by time sampling diaries, experience sampling, and ecological momentary assessment (Hektner, Schmidt, & Csikszentmihalyi, 2007). Such ambulatory psychological assessments have demonstrated their ecological validity but can be labor intensive for participants and expensive for researchers (Fahrenberg, Myrtek, Pawlik, & Perrez, 2007). The challenge of creating multimethod accounts of behavior and experience in normal life settings involves adapting and integrating existing methods to produce measures that are noninvasive and minimally demanding (Bolger, Davis & Rafaeli, 2003).

Recently, researchers have begun to investigate the potential of retrospective alternatives to momentary assessment that are designed specifically to minimize erroneous reporting (Stone, Schwartz, Schkade, Schwarz, Krueger, & Kahneman, 2006). A key development in this literature is the Day Reconstruction Method (DRM), a survey that is structured to provide accurate and detailed retrieval of the experiences and objective circumstances of the previous day (Kahneman, Krueger, Schkade, Schwarz, & Stone, 2004). The DRM elicits quantitative information about the frequency and timing of daily activities, social interactions, and associated multidimensional affective reports that have been shown to satisfactorily approximate the results of ecological momentary assessment.

The Present Investigation

We sought to integrate methodological and technological innovations in naturalistic assessment to noninvasively examine the relationship between affect and HR. We utilized advancements in computer-aided survey design that exploit visualization and memory priming techniques to minimize recall bias in the DRM. Findings from laboratory and epidemiological studies suggest that positive affect buffers the negative health effects of psychosocial stress and that negative affect increases susceptibility to such ill-effects (Pressman & Cohen, 2005; Ryff et al., 2006; Smyth et al., 1998; Steptoe, O'Donnell, Badrick, Kumari, & Marmot, 2008).

Computer-assisted day reconstruction and both baseline and ambulatory biological measurements were used to examine how the intensity of positive and negative affect and tiredness as well as a range of physiological, behavioral, and environmental factors relate to HR. We tested (a) the hypothesis that cardiovascular reactivity is associated with affect intensity in everyday settings and that this relationship is distinct from the role of personality; and (b) that an association between affect and HR would remain having adjusted for a range of factors in addition to personality including activity engaged in, consumption, social interaction, time-of-day, and extraneous physiological and environmental factors. Specifically, we expected negative affect to increase HR, and positive affect, tiredness, and the personality factor emotional stability to be linked to a lowered HR.

Method

Participants

Data were collected from 204 university students who volunteered to enroll in a diary study with medical testing and biological tracking. The students were compensated for taking part with either research credits toward their freshman psychology course or a cash incentive of €25. The drop-out rate was 3% (6 participants), which left a total of 198 participants in the study. An additional 12 students were eliminated from the analyses due to excessive artifactual measurement error identified during the analysis of their HR data (e.g., loss of signal, excessive number of outlier measurements). Of the 186 participants, 64 were men and 122 women aged 18 to 49 years ($M = 23.3$, $SD = 6.1$), as shown in Table 1. Every participant received information relating what the study entailed and gave informed consent.

Procedure

One hundred and 86 participants with usable data took part in the study on all 3 consecutive days. Participants underwent a medical assessment on the first day during which a series of physiological parameters were examined by trained research nurses. During this consultation detailed written and verbal instruction on the operational procedures for physiological monitoring were provided to the participants. The next day, the students were fitted with ambulatory instruments to monitor HR throughout their normal day. On the third day of the study, participants completed an online questionnaire, which included demographic information, psychometric measures, and the computer-assisted DRM.

Table 1
Descriptive Statistics for Demographic Characteristics, Personality, Health, and Health Behaviors of Participants

	M/%	*SD*	Minimum	Maximum
Age	23.3	6.1	18	49
Gender (% female)	66%			
Conscientiousness	9.5	2.8	2	14
Openness	10.9	2.2	5	14
Agreeableness	9.9	2.1	2	14
Emotional stability	9.0	2.9	2	14
Extraversion	9.5	2.7	3	14
Resting pulse[a]	74.3	11.9	43	115
Body fat (%)	28.8%	8.5	10.9	47.3
BMI (kg/m2)	23.1	3.6	13.5	43.2
Peak flow[b]	406.5	116.1	178.3	771.7
Dieting	10.1%			
Drank alcohol[c]	27.3%			
Smoke	12.8%			

[a] Given in beats per minute. [b] Given in liters per minute. [c] Drank alcohol on the day of the study.

Measures

Computer-assisted online day reconstruction. The online version of the DRM included a time diary of events followed by an assessment of objective details and affective experiences relating to the previous day. To reduce recall bias the survey follows a fixed format in which participants initially separate the day into morning, afternoon, and evening stages based primarily on meal times and subsequently break each stage down into a series of "episodes." Episodes are restricted to a time period of between 20 min and 2 hr and are demarcated at the participants discretion based on any significant change (e.g., change of place, activity, mood, presence of others). The online DRM generates a "flowchart" representation of the participant's day from diary responses to assist in the completion of items referring to specific events.

Participants then provide episode-by-episode information about the location, activities, interactions, and the subjective experiences associated with each episode as assessed by a series of 11 affect scales. The 11 items included in the affective assessment were parsed into the dimensions of positive affect (happy, calm, comfortable, affectionate, interested, confident), negative affect (impatient, depressed, stressed, irritated) and tiredness, a tripartite conceptualization of affect that has been shown to satisfactorily represent the structure of diurnal patterns of affect (Stone et al., 2006). Participants were asked to what extent they felt a given emotion using response scales ranging from 0 (*not at all*) to 6 (*very much*). The adjectives are replicated from previous DRM research with minor adjustment and are broadly similar to those used in other mood scales such as the Positive and Negative Affectivity Schedule (Watson, Clark, & Tellegen, 1988) or the Profile of Mood States (Krueger & Schkade, 2008).

Ambulatory HR monitoring. HR was assessed using the Suunto Memory Belt (Suunto Oy, Vantaa, Finland). This is a lightweight (61g) heartbeat interval recorder and is worn around the chest and has a capacity to record 200,000 consecutive beat-to-beat intervals. A comparison of recordings assessed from one of the researchers (first author) both as assessed by the Suunto device and HR information simultaneously captured from the 1,000 Hz 3-lead ECG BIOPAC MP35 data acquisition unit with BSL PRO software (Biopac Systems, Santa Barbara, CA) found no substantial difference between the heartbeat intervals recorded by both systems, $t(2206) = 0.34$, $p = .74$; $r = .995$, $p < .001$.

Briefly, accurate analysis of HR requires that every heartbeat is recorded and stored and that data are sampled with at least 1 ms accuracy. Electrocardiogram (ECG) recording provides this level of precision and information on inner heartbeat dynamics (e.g., QT interval, P-wave duration). Where high resolution inner heartbeat information is not required, light-weight wearable heartbeat interval (or R-R) recorders have facilitated simple nonintrusive high frequency and accurate collection of HR data (Buchheit et al., 2004; Serrano et al., 2008). Agreement analyses for commercially available heartbeat interval recorders and traditional ECG recorders typically find a high degree of concordance between both types of systems across a range of samples and metrics of cardiac chronotropy (Gamelin, Berthoin, & Bosquet, 2006; Heilman & Porges, 2007; Nunan et al., 2008).

Participants received instructions from the research nurses on how to apply electrode gel to the heartbeat recorder and the optimal method of wearing and operating the device. In accordance with previous research outliers and artifactual readings were removed from HR recordings preceding analysis (Jacob et al., 1999). Acceptable HR measurements were defined as those within the range 40 to 150 beats per minute (Shapiro et al., 2001). Outlier measurements accounted for less than 1% of the data. Ambulatory HR data was then fragmented into a series of 10-min segment averages for each individual. To accurately estimate the relationship between HR and affect, the episodes recorded in the DRM were matched to HR measurements by the start and midpoint of the episode duration. Thus, for each episode the level of HR utilized for analysis represented a combination of a 10-min average at the start of an episode and the 10-min segment surrounding the half-way point of the self-reported episode.

Personality. A short-form measure of the Big Five domains of personality, the Ten Item Personality Inventory (Gosling, Rentfrow, & Swann, 2003), was used to assess extraversion, agreeableness, conscientiousness, openness and emotional stability. The factors that emerge from this measure have been shown to converge closely with those of widely used Big Five measures (r = .65 to .87). Each factor is the sum of the scores on two of 10 items, in which each item is rated on a 7-point scale ranging from 1 (*disagree strongly*) to 7 (*agree strongly*).

Physiological parameters and consumption measures. As part of the medical assessment body mass index (BMI), was calculated from height (m) and weight (kg), as measured by the research nurses using a Leicester portable stadiometer (Invicta Plastics Ltd., Leicester, UK) and Salter scales (Salter Weigh-Tronix, West Bromwich, UK). Lung capacity was assessed using the Mini-Wright digital peak flow meter (Clement Clarke International Ltd., Harlow, UK), and percentage body fat was obtained using the validated Omron BF–306 body fat analyzer (Omron Corp., Kyoto, Japan) (Deurenberg & Deurenberg, 2002). The questionnaire component of the study also included questions related to current consumption of substances that may influence HR. Participants rated the number of alcoholic drinks they consumed on the reconstructed day, how many cigarettes they smoke per day, their exercise frequency, and whether they were currently on a diet.

Data Analyses

The real-time nature of the HR and affect data in this study, particularly the associated uneven number of repeated assessments and autocorrelation among repeated measures, make it less amenable to traditional repeated measures analysis (Stone et al., 2006). Multilevel models have the advantage of allowing simultaneous estimation of between-person and within-person effects and can analyze multiple predictors in cases in which there is an unbalanced number of cases per person (Reis & Gable, 2000). Multivariate multilevel modeling considers two random components of HR data: one due to the sampling of participants and a second related to repeated samples within persons.

Multilevel modeling was therefore used to answer most of the study questions. First, each person's HR levels were predicted by the time of day of each episode reported. As change in HR over the day may not be linear (Degaute, van de Borne, Linkowski, & Van Cauter, 1991), a series of curvilinear models were examined. The best fit was achieved by the linear time of day term with neither the second degree polynomial function (including the linear and quadratic time of day terms) nor the third degree polynomial (adding the cubic time of day term to the second degree model) producing a significantly improved fit.

Following this, the influence of the within-person affect levels on HR was estimated. To do this, linear time of day was added at Level 1 and personality was added at Level 2. A simplified representation of the Level 1 and Level 2 model is detailed below (where i represents the individual, and j represents the repeated-measures instances, or episodes):

$$\text{Level 1: } \text{HR}_{ij} = \beta_{0i} + \beta_1 \times \text{Time}_{ij} + \beta_2 \times \text{Positive Affect}_{ij} + \beta_3 \times \text{Negative Affect}_{ij} + \beta_4 \times \text{Tiredness}_{ij} + e_{ij}.$$

$$\text{Level 2: } \beta_{0i} = \gamma_{00} + \gamma_{01} \times \text{Personality}_i + r_{0i}.$$

Next, to examine the robustness of the relationship between HR and affect we added location, social interaction, and self-reported activity ratings into the model at Level 1. The effects of stable individual differences factors were added to Level 2. These included demographic, consumption, and baseline physiological factors, modeled at Level 2. The simplified model presented below was estimated using data from 1,720 episodes with usable data reported by the 186 participants.

$$\text{Level 1: } \text{HR}_{ij} = \beta_{0i} + \beta_1 \times \text{Time}_{ij} + \beta_2 \times \text{Positive Affect}_{ij} + \beta_3 \times \text{Negative Affect}_{ij} + \beta_4 \times \text{Tiredness}_{ij} + \beta_5 \times \text{Social interaction}_{ij} + \beta_6 \times \text{Location}_{ij} + \beta_7 \times \text{Activities}_{ij} + e_{ij}.$$

$$\text{Level 2: } \beta_{0i} = \gamma_{00} + \gamma_{01} \times \text{Personality}_i + \gamma_{02} \times \text{Demographic}_i + \gamma_{03} \times \text{Health}_i + \gamma_{04} \times \text{Health Behavior}_i + r_{0i}.$$

Results

Descriptive Analyses

Preliminary analyses. The mean length of episodes on reported by participants was 73.5 minutes (SD = 55). There were no problems with the functioning of the online DRM and feedback indicated that the modal appraisal of the survey was as "interesting," assessed on a scale ranging from 1 (*very interesting*) to 5 (*very uninteresting*). The characteristics of the participants on the primary demographic, personality, health behaviors, and baseline health variables are detailed in Table 1.

Behavioral and situational variables. The activities most commonly endorsed by the participants were conversing, eating, commuting, and college work. In total these behaviors accounting for 51.4% of reported activities. In approximately 46% of episodes participants were alone and when they were with others they were most likely to be with more than one person (52.7%). The majority of episodes were reported to occur at either at home (46.6%) or in college (26.9%).

HR data. The average ambulatory HR of participants as sampled from 10-min blocks at each day reconstruction episode start and midpoint was 85.2 (SD = 15.6), significantly higher than the average resting HR as assessed during the baseline medical assessment (M = 74.3, SD = 11.9), $t(185) = 14.8$, $p < .001$. HR sampled from the episode was correlated with resting HR ($r = .57$, $p < .001$) and strongly correlated with ambulatory data for the entire day ($r = .93$, $p < .001$).

Descriptive examination of levels of affect and HR. Positive affect scores were substantially higher on average across adjective components (M = 3.56, SD = 1.1, α = .85) than the negative affect scores (M = 1.39, SD = 1.16, α = .76), $t(185) = 22.3$, $p <$ .001. Tiredness was measured by a single item and responses were anchored around the midpoint of the 0 to 6 scale (M = 2.95, SD = 1.83). The diurnal pattern of standardized aggregated HR and positive and negative affect variables as shown in Figure 1.

The positive affect composite variable rises notably over the course of the day. Negative emotions demonstrate a decline throughout the day and also are characterized by a bimodal pattern spiking in between 10 and 11 a.m. and to a greater extent again at approximately 3 to 5 p.m. Patterns of HR also indicate a decline from morning to evening and standardized levels appear to correspond with those previously identified in controlled environments in which HR has been shown to peak in the early morning, decline to a 3 p.m. afternoon nadir, then peak again between 6 and 8 p.m. and decline sharply later in the evening (Degaute et al., 1991).

Affect and HR Analysis

Multilevel modeling was used to estimate a series of models predicting HR at the episode midpoint using affect, personality traits, and potentially confounding variables as predictors. First, the best fitting unconditional model for HR was specified, and HR was found to have a significant random intercept ($p < .001$) and autoregressive covariance structure ($p < .001$). This indicated that there was substantial variation in HR levels over the course of the day and that measures co-occurring closely in time demonstrated greater concordance than more temporally distant measures.

Next, we estimated a baseline model of the association between time of day, affect, personality, and HR without adjusting for potential confounding variables. Time of day failed to significantly predict heart rate. Daily patterns of negative affect were significantly related to elevated HR, $b = 0.3$, $SE = 0.09$, $t(1673) = 3.16$, $p < .005$, controlling for closely related factors such as tiredness and emotional stability. Average negative affect levels were, however, unrelated to heart rate at rest as assessed during medical testing, $r = .04$, $p = .62$. Tiredness was associated with a substantial decrease in HR, $b = -1.17$, $SE = 0.22$, $t(1674) = -5.25$, $p < .001$. The personality trait emotional stability was related to a low HR, $b = -0.65$, $SE = 0.27$, $t(181) = -2.39$, $p < .05$, whereas agreeableness predicted a raised HR, $b = 1.1$, $SE = 0.37$, $t(181) =$ 2.99, $p < .01$.

Affect and HR adjusting for confounders. To address the robustness of the link between affect, personality, and HR identified in the initial analysis we designed a multilevel model that considered a series of behavioral, demographic, and health related variables. HR was predicted on the basis of time of day, affect (positive, negative, tired), adjusting for simultaneously estimated effects of behavioral factors (nature of activity engaged in, social interactions), location (in college, at work, in a car), and time of day at Level 1 and demographic factors (age, gender), the Big Five personality traits, physiological (BMI, lung capacity, peak flow), and consumption variables (smoking, alcohol intake, dieting) at Level 2.

Once again time of day was unrelated to HR, as shown in Table 2. Having adjusted for the wide array of variables employed, negative affect was found to predict a raised HR, $b = 0.2$, $SE = 0.1$, $t(1690) = 1.97$, $p < .05$. The association between tiredness and lowered HR remained highly significant, $b = -0.76$, $SE = 0.23$, $t(1635) = -3.39$, $p < .01$. The relationships identified were found to be robust to the inclusion of potentially confounding behavioral, environmental, physiological, and psychological variables, as shown in Table 2.

Within-person contextual Level 1 variables and HR. Categorical effects of activity were analyzed using "relaxing" as the base category for comparison in the model. As detailed in Table 2, HR was found to be significantly higher during activities involving

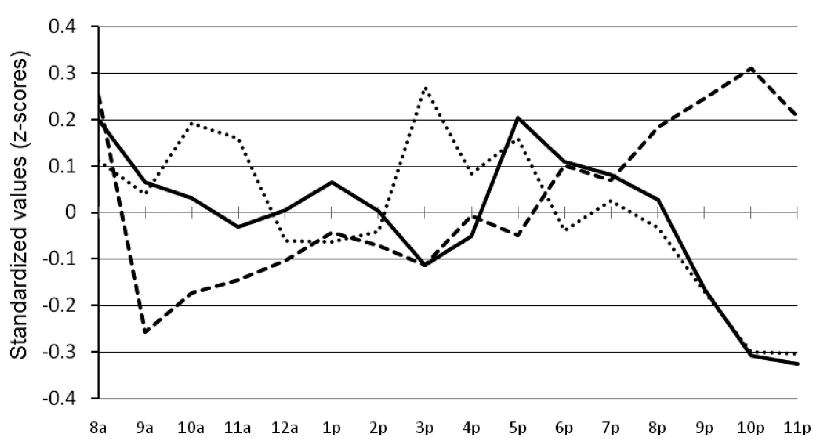

Figure 1. The trend in standardized state positive affect (broken line), negative affect (dotted line), and heart rate (solid line) as a function of time of day.

Table 2
Results of Multilevel Model Assessing the Relationship Between Heart Rate and Affect, Adjusting for Location, Activity Patterns, Demographic Factors, Personality, Baseline Health, and Health Behaviors

Variables	b	$SE\ b$
Level 1		
Intercept	80.54**	8.59
Time affect	−0.11	0.07
Positive affect	0.07	0.07
Negative affect	0.20*	0.10
Tired	−0.76**	0.23
Social interaction	1.10	0.72
Location[a]		
In college	2.03*	0.91
Work	8.53**	3.22
Car	−3.52	2.32
Other location	3.37**	0.99
Activities[b]		
Commute	4.86**	1.82
Housework	1.71	2.39
Eating	−0.21	1.56
Exercising	11.50**	2.55
Grooming	1.89	2.01
Home computer	−1.44	2.15
Music	4.99	3.03
Radio/news	−4.95	7.08
Making love	−1.53	4.46
Playing	7.63*	3.47
Praying	0.15	5.79
Preparing food	0.25	2.63
Reading	−1.45	2.09
Rest/sleep	−8.11**	2.57
Shopping	3.46	2.42
Caring for children	−0.46	4.25
Conversation	−1.19	1.57
Walking	5.44*	2.41
Television	−2.44	2.01
Paid work	−4.54	3.29
Lectures	−4.05*	2.03
College work	−2.76†	1.62
Level 2		
Conscientiousness	−0.20	0.29
Openness	0.35	0.34
Agreeableness	0.76*	0.36
Emotional stability	−0.34	0.28
Extraversion	−0.10	0.29
Age	−0.21	0.13
Male	−4.72*	2.38
BMI	0.23	0.24
Body fat	0.05	0.13
Lung capacity	−0.004	0.007
Smoke	2.62**	0.99
Alcohol	−1.11	0.74
Diet	−3.96	2.55

Note. BMI = body mass index.
[a] Home is base category for location analysis. [b] Relaxing is base category for activity analysis.
† $p < .1$. * $p < .05$. ** $p < .01$.

physical exertion such as exercising, walking, playing, and commuting, independent of time of day effects. Resting, attending lectures, and to a lesser extent college work was associated with a decline in heart rate. In a small number of cases increases in cardiovascular activity were expected but not identified (e.g., caring for children, making love). It is likely this was due to low power as each of such behaviors accounted for less than 1% of reported activities. These findings confirm that the recalled times when active behaviors were indicated to occur in the DRM survey aligned to objectively assessed changes in HR.

To evaluate location specific effects on HR, being at home was used as the situational base category for the analysis. HR was raised in college, $b = 2.03$, $SE = 0.91$, $t(1577) = 2.24$, $p < .05$, at work $b = 8.53$, $SE = 3.22$, $t(1229) = 2.64$, $p < .01$, and during times where location was labeled as other, $b = 3.37$, $SE = 0.99$, $t(1461) = 3.38$, $p < .01$.

Between-person Level 2 variables and HR. Age was unrelated to HR as were the health markers lung capacity, body fat, and BMI. Agreeableness predicted a raised HR, $b = 0.76$, $SE = 0.36$, $t(170) = 2.08$, $p < .05$, and emotional stability was no longer significantly predictive of HR. Men had a lower HR over the course of the day, $b = -4.72$, $SE = 2.38$, $t(170) = -1.99$, $p < .05$. Alcohol consumption and dieting were unrelated to HR whereas smoking predicted an elevated HR, $b = 2.62$, $SE = 0.99$, $t(172) = 2.64$, $p < .01$.

Discussion

The primary aim of this study was to examine the correspondence of affect and HR within the context of a normal week day. Substantial concordance was evident between measures of affect and patterns of HR. Increased levels of psychological distress as indexed by a composite variable of depression, irritation, stress, and impatience scores were indicative of a high HR after adjusting for personality. Negative affect remained as a significant predictor of HR after a substantial number of potentially confounding within- and between-person variables (e.g., location, activity, social situation, physiological factors, time of day, consumption) were entered into the model.

Unlike ambulatory HR, resting HR was unrelated to negative affect in daily life. This discrepancy could indicate that a heightened cardiovascular reactivity to everyday stressors is a central way that affect-mediated dysfunctional autonomic control is expressed. Specifically, experiencing high levels of negative affect may lead to increased sympathetic activity and vagal withdrawal in reaction to stressors leading to a raised ambulatory HR. Those experiencing a substantial degree of negative affect may feel unable to cope with stressors and appraise stressors as threatening rather than a challenge, thus raising their HR (Salomon et al., 2009). It is also possible that negative affect may cause sympathetic activation without the presence of an immediate stressor though this activation could be construed as reflecting prior stressors that led to affect changes such as early adversity or a history of interpersonal conflict and social isolation.

Positive affect did not appear to be predictive of HR within the multilevel models specified. This may reflect the less prolonged impact of changes in positive as opposed to negative moods on HR (Brosschot, Gerin, & Thayer, 2006). Greater tiredness was linked to a decrease in HR. This result aligns closely to previous ambulatory monitoring studies in which feelings of disengagement and sleepiness have demonstrated a robust relationship to declines in HR (e.g., Jacob et al., 1999). The relationship between tiredness and HR is likely to be indicative of diminished energetic arousal, potentially reflecting amygdala deactivation.

The association between personality and HR also warrants comment. In particular, the hypothesized relationship between emotional stability and lowered HR was identified. This finding lends some ecological validity to laboratory studies identifying greater cardiovascular reactivity to stressors among those with a higher level of neuroticism, the obverse of emotional stability (Riese et al., 2007; Schwebel & Suls, 1999). However, controlling for a substantial array of physiological, emotional, and behavioral variables eliminated the association between emotional stability and HR. This was potentially due to covariance between personality and the wide array of control variables in the final model. For instance, emotional stability is likely to be expressed in situation selection, interaction frequency, consumption, and emotional experience.

Taken together the results of the study indicate joint roles for state and trait factors closely related to negative affectivity in contributing to an elevated HR in day-to-day settings. One explanation of these results is that both personality and affect moderate the impact of everyday stressors on physiological responses in healthy young adults that may have cumulative effects on health over time. This interpretation corresponds well with the results of a recent large scale 21-year prospective cohort study that found neuroticism to be a long-term risk factor for cardiovascular disease, a relationship that was partially mediated by psychological distress, after adjusting for health, consumption, and demographic factors (Shipley, Weiss, Der, Taylor, & Deary, 2007).

The present study also contributes to the accumulating evidence indicating that Type D personality (negative affectivity and social inhibition) is predictive of adverse cardiovascular health outcomes. The D-construct has been shown to be closely proxied by high neuroticism and low extraversion (De Fruyt & Denollet, 2002; Sher, 2005; Steptoe & Molloy, 2007). Our results lend some credence to the possibility that negative affectivity, but not social inhibition may be reflected in cardiovascular reactivity in the daily life of healthy individuals, as neither extraversion nor engaging with others in social situations substantially affected HR.

In contrast to research on the D-construct, we find that the personality trait agreeableness, typically characterized by approach rather than avoidance behavior, predicts an increase in HR. Recent research has linked agreeableness to a deficit in anger regulation on receiving negative feedback that may indicate that agreeable individuals are more reactive to information that contrasts with their interpersonal orientation (Jensen-Campbell, Knack, Waldrip, & Campbell, 2007). It is also possible that agreeable people are more vigilant and receptive to information during interactions, a characteristic that has been shown to produce greater cardiovascular reactivity (Smith, Ruiz, & Uchino, 2000). Further research is required to demonstrate if the increase in cardiovascular activity identified among agreeable people can be explained by greater cardiovascular and affective reactivity in interpersonal situations, particularly those closely linked to identity and self-construction (Lyons, Spicer, Tuffin, & Chamberlain, 2000).

The present study overcomes limitations of previous studies that lacked important methodological criteria, in particular concerning the measurement of affect, the representativeness of the assessment context, the consideration of personality factors, and the rigorous control of potentially confounding covariates. The utilization of continuous scales incorporating multidimensional components of both positive and negative affect allows fine-grained inferences about the relative contribution of various affect dimensions to be made (Mauss & Robinson, 2009). Incorporating personality factors is advantageous as pervasive traits condition the situations individuals select themselves into, thus the assessment of personality allows a clearer specification of the contribution of the situation to experience. Also, a substantial degree of overlap has been identified between personality traits and affect variables (e.g., extraversion and happiness, agreeableness and affection) both in previous analyses and in the present study, and it is therefore preferable to delineate which component is contributing to HR at a given time point.

It is also important to adjust for confounding factors such as consumption, biological factors, and environmental conditions that have been shown to correlate with both affect and HR (e.g., body fat, peak flow, activity levels). In support of this rationale, in the present study smoking was indicative of a substantially raised HR, most likely due to the effect of nicotine on activating the sympathetic nervous system. In addition, the potentially busier college and work environments were related to a higher HR than the home setting. We also observed substantially raised levels of HR during times of self-reported active behaviors such as exercising, walking, commuting, and playing indicating that the DRM was effective in identifying periods of increased physical activity.

One major caveat of the study involved the method of control for physical activity. Previous studies have shown only modest relationships between objectively recorded activity levels and subjective reports (r = .24 to .61; Welk, Wickel, Peterson, Heitzler, & Fulton, 2007). The recent development of multichannel ambulatory accelerometry devices has made possible the collection of high frequency objective behavioral data. These devices utilize enhanced computer processing and storage capacities, sophisticated algorithms, and sensitive piezoresistive and piezocapacitive sensors to perform complex analyses to separate movement and posture and to gauge the intensity of action (Bussmann, Ebner-Premier, & Fahrenberg, 2009). In particular, activity monitoring can operate as a method of separating the movement and posture related information out of HR analyses to produce an account of the psychophysiological response to emotion (Myrtek, 2004).

Incorporating ambulatory activity monitoring into the current study would have allowed for a stringent control of behavior thus testing the possibility that movement during episodes associated with negative affect may explain the negative affect-HR relationship. However, several commentators have argued that care is warranted when controlling for factors such as posture or movement that may be causal antecedents of affect (Jacob et al., 1999; Shapiro et al., 2001). As specific movements are strongly linked to affective states and their initiation may induce those states (Koch, Holland, Hengstler, & van Knippenberg, 2009; MacLachlan, 2004), controlling for affect-relevant behavioral information may diminish genuine mood effects on psychophysiology.

A caveat of the DRM protocol was that it requires that episodes be at least 20 min long and the average length of episodes reported was approximately 70 min meaning that briefer episodes are often missed. Encouraging episodes to be reported using a shorter time frame would enhance the sampling frequency of the DRM and potentially improve the estimates identified. Running a more high-frequency moment-by-moment measurement of affect alongside the DRM, would allow the relative accuracy of the DRM in HR prediction to be gauged. Although the DRM is retrospective, it is structured to carefully evoke contextual information and has been shown to replicate affect patterns identified by experience sampling (Kahneman et al., 2004). As demonstrated in the current study, it is possible to administer the DRM to relatively large samples in an online setting to assess subtle intraday variation in affect patterns. Combining real-time tracking of human functioning with online DRM is also achievable with relatively little additional participant burden. This integrative approach to the study of real-world behavior was found to generate what we believe is an optimal level of sufficiently low respondent burden and high data reliability. Matching day reconstruction data to information derived from technological innovations such as psychophysiological and behavioral monitoring (e.g., Hasler, Mehl, Bootzin, & Vazire, 2008), ambulatory assessments of pollutants and crowding (e.g., Gold et al., 2000), and momentary changes in health markers (e.g., markers of inflammation and neuroendocrine functioning) is likely to facilitate collaboration between health psychology researchers and numerous other disciplines (Mehl, 2007).

In conclusion, this study demonstrates substantial correspondence between HR and state and to lesser extent trait affectivity in the context of daily life. This is evident from the raw concordance of HR and psychological distress, and multilevel analysis of the relationship between HR, personality, and affect. Most convincing, controlling for a wide range of episodic and personality variables, negative affect in an episode predicts higher HR. This finding and the lack of concordance between resting HR and affect emphasizes the value of ambulatory HR monitoring as a paradigm for the analysis of episodic human emotion.

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