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Naturalistic monitoring of the affect-heart rate relationship: A Day Reconstruction Study

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Comments Welcome

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Abstract

Objective: Prospective studies have linked both negative affective states and trait neuroticism with hypertension, cardiovascular disease, and mortality. However, identifying how fluctuations in cardiovascular activity in day-to-day settings are related to changes in affect and stable personality characteristics has remained a methodological and logistical challenge. ***Design:*** In the present study, we tested the association between affect, affect variability, personality and heart rate (HR) in daily life. ***Measures:*** We utilized an online day reconstruction survey to produce a continuous account of affect, interaction, and activity patterns during waking hours. Ambulatory HR was assessed during the same period. Consumption, activity, and baseline physiological characteristics were assessed in order to isolate the relationships between affect, personality and heart rate. ***Results:*** Negative affect and variability in positive affect predicted an elevated ambulatory HR and tiredness a lower HR. Emotional stability was inversely related to HR, whereas agreeableness predicted a higher HR. Baseline resting HR was unrelated to either affect or personality. ***Conclusion:*** The results suggest that both state and trait factors implicated in negative affectivity may be risk factors for increased cardiovascular reactivity in everyday life. Combining day reconstruction with psychophysiological and environmental monitoring is discussed as a minimally invasive method with promising interdisciplinary relevance.

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

Introduction

The cardiovascular response to life-events is one likely mechanism through which state and trait factors related to general well-being (e.g. affect and neuroticism), may modulate the effect of stressors on a range of cardiovascular health outcomes (Rozanski, Blumenthal, Davidson, Saab, & Kubzansky, 2005; Kulkarni, O'Farrell, Erasi, & Kochar, 1998). 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 (Tsuboi, Hamer, Tanaka, Takagi, Kinae, & Steptoe, 2008; Buchanan, al'Absi, & Lovallo, 1999). 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 (Ockenfels, Porter, Smyth, Kirschbaum, Hellhammer, Stone, 1995; Penninx, Leveille, Ferrucci, van Eijk, & Guralnik, 1999; Hemingway et al., 2003). Previous research has also linked cardiovascular reactivity to fluctuations in affect in naturalistic settings (Shapiro, Jamner, Goldstein, & Delfino, 2001; Jacob et al., 1999; Johnston, Tuomisto, & Patching, 2008). 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 the clearest specification to date of the role of affect and personality in reactivity outside of the laboratory. In particular, the recent literature, which we review briefly below, has identified 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 inter-beat intervals, mean of successive differences in inter-beat 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 & Scahaerfer, 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, Moya-Albiol, Gonzalez-Bono, Salvador Ricarte, & Gomez-Amor, 2001). Prospective epidemiological studies have identified HR as a risk factor for health outcomes such as increased cardiovascular mortality, morbidity, and myocardial infarction (Gillum, Makuc, & Feldman, 1991; 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). HR has also been identified as a biological marker of resilience that is potentially indicative of amygdala activation in response to stressors (Oldehinkel, Verhulst, & Ormel, 2008). Low HR was found to be robustly associated with buffering the contributing effect of life-stressors to the development of mental illness in longitudinally tracked adolescents adjusting for pre-existing mental health problems

HR studies in laboratory settings have typically attempted to emulate the ecological context of interest in order to make inferences about what may occur in real-world settings. A robust relationship has been identified between exposure to laboratory mental stressors (e.g.

social evaluative threat, mental load) and a concomitant increase in HR (Kudielka, Schommer, Hellhammer, & Kirschbaum, 2004). Psychological states such as affect are important moderators of the cardiovascular response to laboratory stressors, but few studies have attempted to relate fluctuation in emotional experience to cardiovascular activity in everyday environments (Heponiemi, Ravaja, Elovainio, Naatanen, & Keltikangas-Jarvinen, 2006; Serrano, Moya-Albiol, and Salvador, 2008). In some cases, HR laboratory findings have been reproduced in naturalistic settings using continuous data capture (Vrijkotte, van Doornen, & Geus, 2000). For instance, excessive environmental demands such as chronic work related stress has been shown to relate to higher HR both in and directly after work (Belkic, Landsbergis, Schnall, & Baker, 2004). 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 (Shapiro et al., 2001).

Examining cardiovascular activity in naturalistic settings is of critical importance in order to identify the mechanisms through which cardiovascular reactivity may have cumulative effects which are protective or detrimental to cardiovascular health (Michaud, Matheson, Kelly, & Anisman, 2008). Naturalistic monitoring paradigms are particularly useful considering the current lack of clarity as to whether stress reactivity in the laboratory is indicative of diminished psychosocial resources or of 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 those with low levels of depression to have more excessive cardiovascular reactions during an auditory arithmetic task (Carroll, Phillips, Hunt, & Der, 2007). The association observed between cardiovascular reactivity to acute laboratory stressors and reactivity in real life is often weak or inconsistent (Turner, Ward, Gellman, Johnston, Light & van Doornen, 1994). It may be the case that low levels of psychosocial resources and high negative affectivity are indicative of a tendency towards subtle but chronic patterns of reactivity to everyday events and an attenuated response to more exaggerated stressors as encountered in laboratory studies.

However, the relationship between affect and HR in ecologically valid continuous monitoring studies remains unclear, with studies finding no relationship (Serrano et al., 2008), and others finding correspondence in cases controlling for activity and biological variables but not important alternative psychological factors such as personality (Carpeggiani et al., 2005). In several studies the assessment of affect has also 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. 40-50 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). Similarly, 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 (EMA) (Hektner, Schmidt, & Csikszentmihalyi, 2007). Such ambulatory psychological assessments have demonstrated their ecological validity but can be labour intensive for participants and expensive for researchers (Fahrenberg, Myrtek, Pawlik, & Perrez, 2007). The challenge of creating multi-method accounts of behaviour and experience in normal life settings involves adapting and integrating existing methods to produce measures which are non-invasive and minimally demanding (Bolger, Davis & Rafaeli, 2003).

Recently, researchers have begun to investigate the potential of retrospective alternatives to momentary assessment which are designed specifically to minimize erroneous reporting (Stone, Schwarz, Schkade, Schwarz, Krueger, & Kahneman, 2006). A key development in this literature is the Day Reconstruction Method (DRM), a survey which 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 which have been shown to satisfactorily approximate the results of EMA. Advancements in computer-aided survey design have the capacity to facilitate the development of user friendly data collection systems which exploit visualisation and memory priming techniques (e.g. Gray, Gray & Wegner, 2007), which could potentially be used in order to conduct surveys such as the DRM with minimal recall bias. In addition, running psychophysiological and environmental monitoring during the period where behaviour and affect are reconstructed can help validate reported information and produce a broader account of functioning. For example, tracking important variables such as heart rate, blood pressure, galvanic skin response, global positioning, movement, and audio-visual recordings represent potential extensions to the DRM (Craik, 2000; Mehl, Pennebaker, Crow, Dabbs, & Price, 2001). Such an interdisciplinary approach allows multiple perspectives to be examined simultaneously and confounding factors in naturalistic research to be systematically controlled for (Rowe, 2008).

In the present research, we sought to integrate methodological and technological innovations in naturalistic assessment to examine the relationship between affect and heart rate (HR). Findings from both 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; Smyth, Ockenfels, Porter, Kirschbaum, Hellhammer, & Stone, 1998; Ryff et al., 2006; Steptoe, O'Donnell, Badrick, Kumari, & Marmot, 2008). Although, there is evidence that affect is associated with changes in HR, the degree to which these relationships are due to unobserved and potentially confounding factors is an open question. In addition, greater within-person variability in affect has recently been shown to be a stable individual difference trait, separable from affect, and linked with depression and neuroticism (Eid & Diener, 1999; Peeters, Berkhof, Delespaul, Rottenberg, & Nicolson, 2006). Examining the relationship between affect variability and ambulatory cardiovascular activity represents an initial step in identifying the biological correlates of this marker of affective functioning.

We utilised computer-assisted day reconstruction and both baseline and ambulatory biological measurements to examine how the intensity and variability of positive and negative affect and tiredness as well as a range of physiological, behavioural and environmental factors relate to HR. We tested (i) the hypothesis that cardiovascular reactivity is associated with affect intensity and variability in everyday settings and that this relationship is distinct from the role of personality, and (ii) that an association between both affect and affect variability and heart rate 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 and greater affect variability to increase HR, and tiredness and the personality factor emotional stability to be linked to a lowered HR. We also aimed to evaluate the feasibility and ease of use of the new computer-aided DRM and to provide preliminary objective information on the accuracy of reported activity information by analysing the concordance of reported physical activity and HR data.

Method

Participants

Data were collected from 204 university students who volunteered to enrol in a diary study with medical testing and biological tracking. The students were compensated for taking part with either research credits towards their freshman psychology course or a cash incentive of €25. The drop-out rate was 2% (4 participants), which left a total of 200 participants in the study. An additional 14 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 - 49 years (mean = 23.4, SD = 6.3). Every participant received information relating what the study entailed and gave informed consent. The study was approved by the Trinity College Dublin, School of Psychology Research Ethics Committee.

Procedure

One hundred and eighty six subjects with usable data took part in the study on all three 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 on-line questionnaire which included demographic information, psychometric measures and the computer-assisted DRM.

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 where 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 minutes and 2 hours and are demarcated at the participants discretion based on any significant change (e.g. change of place, activity, mood, or the presence of others). 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 adjectives included in the affective assessment were parsed into the dimensions of positive and negative affect and tiredness, a tripartite conceptualisation of affect that has been shown to satisfactorily represent the structure of diurnal patterns of affect (Stone et al., 2006). The 11 scales were divided into six items measuring positive affect (happy, calm, comfortable, affectionate, interested, confident), four items assessing negative affect (impatient, depressed, stressed, irritated) and tiredness was rated using a single item. 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 PANAS or POMS (Krueger & Schkade, 2008; Thompson, 2007)

The online DRM, has the advantage of avoiding the paper burden and practical difficulties of the hard copy version. It generates a 'flow chart' representation of the participant's day from diary responses to assist in the completion of items referring to specific events. The chart incorporates personalised reminders and start and end time-stamps for each episode displayed. The survey programme operates dynamically, reminding participants of the point in their day they are currently referring to and introducing each new episode with a memory prompt generated by the participant when completing the initial diary component.

Ambulatory Heart Rate Monitoring

Heart rate was assessed using the Suunto Memory Belt. 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 (Suunto memory belt, Suunto Oy, Vantaa, Finland). A comparison of recordings assessed from one of the researchers (MD) both as assessed by the Suunto device and HR information simultaneously captured from the 1000Hz 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 ($t(1, 2206)=.34$, $p=.74$, $r=.995$, $p<.001$). Briefly, accurate analysis of HR requires that every heartbeat is recorded and stored and that data are sampled with at least 1ms 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 non-intrusive high frequency and accurate collection of HR data (Buchheit, Simon, Viola, Doutreleau, Piquard, & Gabrielle, 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, Jakovljevic, Donovan, Hodges, Sandercock, & Brodie, 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 bpm (Shapiro et al., 2001). Outlier measurements accounted for less than 1% of the data. Ambulatory HR data was then fragmented into a series of ten minute segment averages for each individual. Episodes recorded in the DRM were matched to HR measurements by the mid-point of the episode duration. Thus, for each episode the level of HR utilized for analysis represented a ten minute average 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, was used to assess extraversion, agreeableness, conscientiousness, openness and emotional stability (Gosling, Rentfrow, & Swann, 2003). The factors that emerge from this measure have been shown to converge closely with those of widely-used Big Five measures (r = .65 - .87). Each factor is the sum of the scores on two of ten items, where each item is rated on a 7-point scale ranging from 1 (disagree strongly) to 7 (agree strongly).

Physiological confounders 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 and Salter scales. Lung capacity was assessed using the Mini-Wright digital peak flow meter, and blood glucose levels were obtained using the Accu-Chek Aviva blood glucose monitoring system. Percentage body fat was obtained using the validated Omron BF-306 body fat analyzer (Deurenberg & Deurenberg, 2002). The questionnaire component of the study also included questions related to current consumption of substances which may influence HR. Participants rated the number of alcoholic drinks they consumed on the reconstructed day, how many cigarettes they smoke per day, and whether or not 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 amongst repeated measures, make it less amenable to traditional repeated measures analysis (Stone et al., 2006). Multi-level models have the advantage of allowing simultaneous estimation of between-person and within-person effects and can analyse multiple predictors in cases where there is an unbalanced number of cases per person (Reis & Gable, 2000). Multivariate multi-level random coefficient modeling was therefore used to examine the relationship between repeated activity, HR, situation, interaction, and affect ratings at Level 1 (in this case, ratings of affect from morning through to evening episodes), nested within Level 2 which consisted of measures of personality, demographic, consumption and baseline physiological factors. The model was estimated using data from 2027 episodes reported by the 186 participants.

Results

Preliminary Analyses

Participants reported approximately 11 episodes on average and the mean length of an episode 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).

Health Related Variables

Approximately 14% of the sample were current smokers, 10.1% were on a diet, and 27.3% consumed at least one alcoholic beverage during the reconstructed day. The average BMI of the participants was 23.2 (SD = 3.9), which was within the expected normal weight range, and the mean percentage body fat was 28.7 (SD = 8.7). The average peak flow indicator of lung capacity was 383 liters/minute (SD = 128), and the mean blood glucose levels were 5.2 nmol/L (SD = 0.79).

Behavioural and Situational Variables

The activities most commonly endorsed by the participants were conversing, eating, commuting and college work. In total these behaviours 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%).

Heart Rate Data

The average ambulatory HR of participants as sampled from ten minute blocks at each day reconstruction episode mid-point was 83.8 (SD = 10.8), significantly higher than the average resting HR as assessed during the baseline medical assessment (M = 74.5, SD = 11.6), t (185) = 12.4, p<.001. Heart rate sampled from the episode mid-point was moderately correlated with resting HR (r = 0.53, p<.001) and strongly correlated with ambulatory data for the entire day (r = 0.85, p<.001).

Levels of Affect, Personality, and Heart Rate

Positive affect scores were substantially higher on average across adjective components (M = 3.56, SD = 1.1, alpha = .85) than the negative affect scores (M = 1.39, SD = 1.16, alpha = .76), (t (185) = 22.3, $p<.001$). Tiredness was measured by a single item and responses were anchored around the midpoint of the 0 – 6 scale (M = 2.95, SD = 1.85). The total within-person standard deviation in each affect item across the reported episodes was calculated and affect deviation scores were summated to form measures of intraindividual variability in positive affect (mean of deviations in happiness, calmness, comfort, affection, interest, and confidence), negative affect (mean of deviations in impatience, depression, stress, and irritation) and tiredness. The mean within-person variability in positive affect was 1 (SD = 0.38) and 1.06 (SD = 0.42) for negative affect. The mean within-person change in tiredess was 1.25 (SD = 0.53).

Pearson's bivariate correlations were carried out to examine the relationships between person centred average daily affect, affect variability, average ambulatory and resting HR, and personality trait measurements at the between-person level as displayed in Table 1. Ambulatory cardiovascular activity was found to correlate positively with negative affect (r(185) = 0.17, $p<.05$.), positive affect variability (r(185) = 0.17, $p<.05$.), and agreeableness (r(185) = 0.17, $p<.05$), and a significant negative correlation was identified between HR and emotional stability (r(185) = -0.17, $p<.05$.). Contrary to our predictions, person centred tiredness levels did not predict lower HR. Resting heart rate assessed during baseline medical testing was unrelated to either affect or personality.

Approximately 13% of the variance in mean positive and negative affect scores from the DRM survey was shared. Negative affect was closely related to lower trait emotional stability (r(185) = -0.48, $p<.01$.) and positive affect to greater emotional stability (r(185) = 0.35, $p<.01$.). Greater mean tiredness levels were associated with lower emotional stability (r(185) = -0.3, $p<.01$.). Twenty five percent of the variance in aggregate positive and negative affect variability ratings was shared. Higher within-person variability in positive affect was related to lower conscientiousness (r(185) = -0.24, p<.01.). Negative affect variability was closely related to negative affect (r(185) = 0.47, p<.01.), tiredness (r(185) = 0.4, p<.01.), and emotional stability (r(185) = -0.31, p<.01.). Intraindividual variability in tiredness and

Table 1

Correlations between average ambulatory and resting cardiovascular activity, mean affect and affect variability levels, and Big Five personality traits

	HR Amb	Pulse	PA	NA	Tired	PA SD	NA SD	Tired SD	C	O	A	ES
Pulse	0.57**											
PA	0.04	0.1										
NA	0.17*	0.07	-0.38**									
Tired	0.07	0.1	-0.26**	0.53**								
PA var	0.17*	0.05	-0.17*	0.09	0.2**							
NA var	0.08	-0.09	-0.23**	0.47**	0.4 **	0.53**						
Tired var	0.06	-0.13	0.15*	-0.21**	-0.18*	0.27**	0.19**					
C	-0.05	-0.09	0.11	-0.01	-0.03	-0.24**	-0.1	-0.11				
O	0.02	0.13	0.08	-0.18*	-0.07	0.03	-0.09	0.1	-0.12			
A	0.17*	0.08	0.13	-0.04	0.06	-0.11	0.00	0.01	0.24**	0.11		
ES	-0.17*	-0.07	0.35**	-0.49**	-0.3**	-0.16*	-0.31**	0.12	0.16*	-0.03	0.23**	
E	0.014	-0.06	0.3**	-0.27**	-0.19**	-0.03	-0.05	0.14	-0.04	0.25**	0.03	0.24**

* Correlation is significant at the p<.05 level, ** Correlation is significant at the p<.01 level

HR Amb = Ambulatory heart rate, PA = Positive affect, NA = Negative affect, E = Extraversion, A = Agreeableness, C = Conscientiousness, O = Openness positive affect were more distinct from state and trait measures of affect (e.g. negative affect and emotional stability) than variability in negative affect.

Next we sought to examine the diurnal pattern of standardized HR and aggregated 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 characterised by a bimodal pattern spiking in between ten and eleven am and to a greater extent again at approximately three to five pm. Patterns of HR also indicate a decline from morning to evening and standardized levels appear to correspond with those previously identified in controlled environments where HR has been shown to peak in the early morning, decline to a 3pm afternoon nadir, then peak again between 6 and 8pm and decline sharply later in the evening (Degaute, Van Cauter, van de Borne, & Linkowski, 1991). HR aligns closely with negative affect from 5pm onwards as reflected in the correspondence between participants' average negative affect and heart rate levels in the

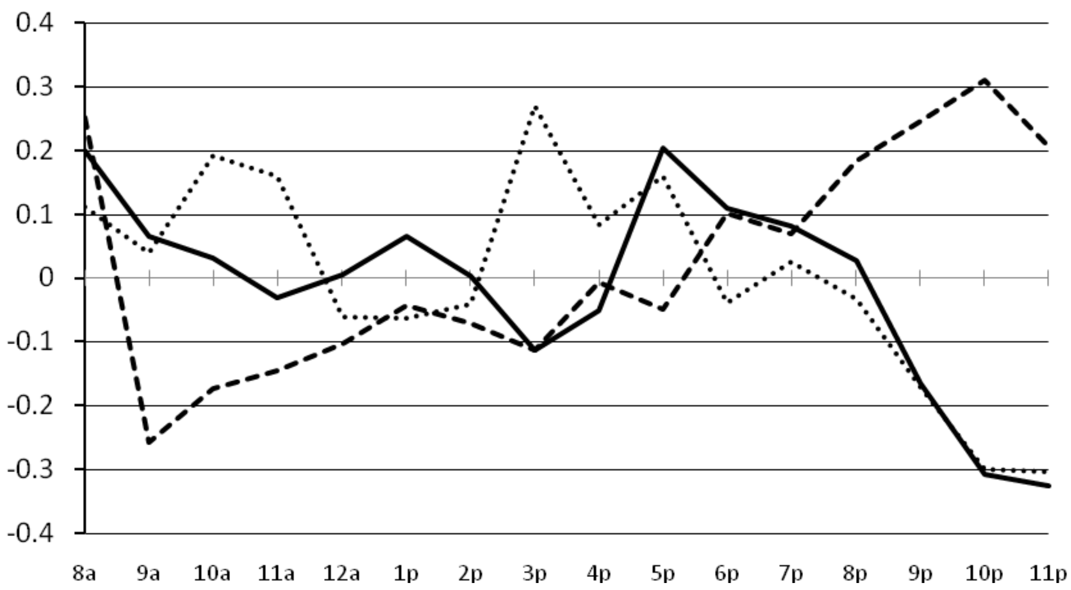

Fig. 1. The trend in standardized state positive affect (broken line), negative affect (dotted line), and HR (solid line) as a function of time of day.

evening hours, r(165) = 0.18, p<.05. A large divergence of HR and negative affect is evident at 3pm, yet further investigation identified a positive association between the variables within the episodes reported between 3 and 4 pm, r(144) = 0.2, p<.05, indicating that this divergence is due to unobserved factors (e.g. fluctuations in cortisol and/or glucose levels).

Multivariate multi-level model random coefficient modelling was used to estimate a series of models predicting HR at the episode mid-point using affect, personality traits and potentially confounding variables as predictors. Firstly, 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 model using time of day, affect, and personality as predictors (see Table 3). Daily patterns of negative affect were significantly related to elevated HR, b = 1.06, SE = 0.49, t = 2.11, p < .05, controlling for closely related affect and personality factors such as tiredness and emotional stability. Tiredness was associated with a substantial decrease in HR, b = -1.22, SE = 0.25, t = -4.87, p < .01. This finding is particularly interesting considering the absence of a raw between-person correlation between tiredness and average ambulatory HR levels. The large degree of variation in tiredness across the day appears to decrease the reliability of predictions based on average daily levels of energy, whereas momentary data is indicative of a more accurate depiction. Mirroring the between-persons correlations the personality trait emotional stability was related to a decrease in HR, b = -0.77, SE = 0.3, t = -2.56, p < .05, whereas agreeableness predicted an increase, b = 1.20, SE = 0.38, t = 3.16, p < .01. The effects identified were independent of linear time related changes in HR.

Table 3

Descriptive statistics and Results of Multilevel Random Coefficient Models Assessing Affect and Personality Related Changes in Heart Rate controlling for Time-of-Day (n =186)

Affect terms and time-of-day control	*Average (SD)*	*Beta*	*Standard Error*
Positive affect	3.56 (1.1)	0.53	0.48
Negative affect	1.39 (1.16)	0.91*	0.42
Tired	2.95 (1.85)	-1.2**	0.25
Positive affect variability	1 (0.38)	6.05*	2.45
Negative affect variability	1.06 (0.42)	-2.32	2.33
Tiredness variability	1.25 (0.53)	-0.47	1.50
Conscientiousness	9.52 (2.77)	-0.145	0.28
Openness	10.89 (2.21)	0.01	0.35
Agreeableness	9.9 (2.1)	1.2**	0.37
Emotional Stability	9.43 (2.77)	-0.77*	0.3
Extraversion	9.44 (2.77)	0.04	0.29
Time mid-point	15.7 (4.79)	-0.1	0.08

* Correlation is significant at the p<.05 level, ** Correlation is significant at the p<.01 level

Test of the Relationship between Affect, Personality, Behavioural and Health Variables, and Heart Rate

To address the robustness of the link between affect, personality and HR identified in the initial analysis we designed a multi-level model that considered a series of behavioural and health related variables. Heart rate was predicted on the basis of affect (positive, negative, tired), and the big five personality traits, adjusting for simultaneously estimated effects of demographic factors (age, gender), behavioural factors (nature of activity engaged in, social interactions), location (at home, in college, at work), and health related variables (BMI, lung capacity, blood glucose, smoking).

Categorical effects of activity were analysed using ‘relaxing’ as the base category for comparison in the model. As detailed in Table 3, heart rate was found to be significantly higher during activities involving physical exertion such as exercising, walking, grooming, and commuting, independent of time of day effects. Heart rate was reduced below levels associated with ‘relaxing’ when participants were attending lectures and to a degree when they were engaged in college work. In a small number of cases increases in cardiovascular activity were expected but not identified (e.g. caring for children, playing). It is likely this was due to low power as each of such behaviours accounted for less than 1% of reported activities. These findings confirm that the recalled times when active behaviours were indicated to occur in the DRM survey aligned to objectively assessed changes in HR.

To evaluate location specific effects on HR, being present in college was used as the situational base category for the analysis. HR was lowered in the home environment, b = -3.02, SE = 1.01, t = -2.99, p < .01. Social interactions were not predictive of HR. The demographic variables gender and age were unrelated to HR as were the health markers lung capacity, blood glucose levels, body fat, and body mass index. Smoking predicted an elevated HR, b = 5.43, SE = 2.4, t = 2.26, p < .05 and current dieting was indicative of a somewhat lowered HR, b = -5.62, SE = 2.55, t = 2.2, p < .05. We ran a baseline regression to test the association between the health variables and resting HR and found concurring results, with smoking and dieting being the only health related factors predictive of HR.

Having adjusted for the aforementioned wide array of variables employed, negative affect was found to marginally predicted a raised HR, b = 0.79, SE = 0.44, t = 1.8, p <.1. Emotional stability marginally predicted a lower HR, b = -0.52, SE = 0.31, t = -1.68, p <.1 and agreeableness a significantly raised HR, b = 0.81, SE = 0.38, t = 2.13, p <.05. Similarly, the

Table 4

Results of Multilevel Random Coefficient Models assessing the relationship between Affect, Personality, Location, Health related, Demographic, and Behavioral factors and Changes in Heart Rate (n = 183)

	Beta	SE		Beta	SE
Positive affect	0.25	0.48	Age	-0.08	0.13
Negative affect	0.79†	0.44	Gender	-3.18	2.45
Tired	-0.82**	0.26	Commute	4.88*	2.05
PA variability	6.23*	2.42	Housework	3.29	2.65
NA variability	-2.42	2.29	Eating	1.12	1.77
Tired variability	-1.31	1.48	Exercising	12.16**	3.22
Conscientiousness	0.06	0.30	Grooming	4.89*	2.21
Openness	0.11	0.35	Home Computer	-1.49	2.43
Agreeableness	0.81*	0.38	Music	0.67	3.85
Emotional Stability	-0.52†	0.31	Radio/News	-2.19	7.82
Extraversion	0.07	0.29	Making Love	0.73	4.97
Time mid-point	-0.08	0.08	Playing	0.95	4.00
Home	-3.02**	1.01	Praying	4.52	6.35
Work	5.08	3.71	Preparing food	0.45	2.88
Car	-4.39	2.70	Reading	-0.55	2.39
Other location	0.99	1.12	Rest/Sleep	-7.44**	2.77
In college[a]			Shopping	3.70	2.67
Smoke	5.43*	2.40	Caring for children	-0.05	4.68
Alcohol	0.01	0.79	Conversation	-1.27	1.77
Diet	-5.62*	2.55	Walking	9.49**	2.64
BMI	0.15	0.24	Television	-2.89	2.30
Body fat	0.15	0.13	Paid work	-1.72	3.99
Lung capacity	0.00	0.01	Lectures	-6.58**	2.26
Blood glucose	1.08	1.15	College work	-3.41†	1.84
Presence of others	0.54	0.8	Other	1.44	2.08
			Relaxing[a]		

** p<0.01, * p<0.05, † p<0.1

[a] Base category for activity analysis, PA = Positive affect, NA = Negative affect

association between positive affect variability and increased HR remained significant, b = 6.23, SE = 2.42, t = 2.57, $p < .01$, as did the association between tiredness and lowered HR b = -0.82, SE = 0.26, t = 3.15, $p < .01$. The relationships identified appeared robust to the inclusion of potentially confounding behavioural, environmental, physiological and psychological variables.

Discussion

The primary aim of this study was to examine the correspondence of affect and heart rate within the context of a normal day 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 higher HR. After adjusting for personality, negative affect remained a significant predictor of HR. However, entering a substantial number of other potentially confounding variables (e.g. location, activity, social situation, physiological factors, time of day, consumption) into the model reduced the relationship to a marginal effect. In contrast, positive affect did not appear to be predictive of HR either at the between persons level using daily averages or within the multi-level models specified. This may reflect the less prolonged impact of changes in positive as opposed to negative moods on HR (Brosschot, Gerin, & Thayer, 2006). More variable patterns of positive affect were robustly related to a higher heart across all analyses. Experiencing diverse changes in positive affect has previously been linked to poorer psychosocial resources and implicated in the development of nonclinical depression and the progression of major depression (Peeters et al., 2006; McConville & Cooper, 1996). Our results point to the stability of patterns of positive affect as a potential pathway through which psychological functioning may moderate the relationship between stressors and health. Greater tiredness was linked to a marked decrease in HR with an estimated 3 bpm difference between episodes where tiredness was 1 SD below or above the mean having adjusted for all control variables. This result aligns closely to previous ambulatory monitoring studies where feelings of disengagement and sleepiness have demonstrated a robust relationship to declines in HR (e.g. Jacob et al., 1999).

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 ecological validity to laboratory studies identifying greater cardiovascular reactivity to stressors amongst those with a higher level of neuroticism, the obverse of emotional stability (Schwebel & Suls, 1999; Riese, Rosmalen, Ormel, Van Roon, Oldehinkel, & Rijsdijk, 2007). Taken together the results of the study indicate joint roles for trait and state 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 which may have cumulative effects on health over time. This interpretation corresponds well with the results of a recent large scale twenty one 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). 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 affected HR. However, as the operation of the inhibition component of the

D-construct in social contexts is the essential factor distinguishing the personality type from depression our findings do not support the proposition that social inhibition impacts on cardiovascular functioning in normal life. It is potentially more likely that social inhibition may lead to underreporting of physical symptoms or may be a response to illness in patients with heart failure (Steptoe & Molloy, 2007).

In contrast to research on the D-construct we find that the personality trait agreeableness, typically characterised by approach rather than avoidance behaviour, predicts an increase in heart rate. Recent research has linked agreeableness to a deficit in anger regulation upon receiving negative feedback which 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 more 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 amongst 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, Tuffer, & Chamberlain, 2000).

A secondary aim of the current study was to evaluate the efficacy of the computer-assisted DRM. Administering the DRM in an online setting was a feasible and non-labour intensive method of data collection. Combining real-time tracking of human functioning with online DRM was also achievable with relatively little additional participant burden. The diurnal pattern of HR identified in this sample aligned closely with the intra-day variation found in standardized physical and social environments (Degaute et al., 1991; Degaute, Van Cauter, van de Borne, & Linkowski, 1994; Richards, Nicholls, Espiner, Ikram, Cullens, & Hinton, 1986), supporting the validity of integrating cost-effective heart rate monitoring into naturalistic research. Our findings also lend further support to the validity of self-reported activities and their timing as assessed by the DRM instrument. For instance, we observed raised levels of HR during times of self-reported active behaviours such as exercising, walking and grooming and lower HR during inactive behaviours such as when resting or at lectures. As previously demonstrated the operational characteristics of the DRM were also found to make it amenable to the identification of subtle intra-day variation in affect patterns (Stone et al., 2006).

The present study overcomes limitations of previous studies which 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. One limitation of previous naturalistic monitoring work centres on the measurement of mood using restricted versions of the affective circumplex model of affect or categorical assessments which require the participant to endorse a single mood at a particular time-point (Jacob et al., 1999). This approach does not permit the analysis of distinctions between different affect items which may be similar in valence and also does not facilitate the measurement of mixed affect states. The utilisation of continuous scales incorporating multi-dimensional components of both positive and negative affect allows for more fine-grained inferences to be made in this regard (Mauss & Robinson, In press). 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 which have been shown to correlate with both affect and HR (e.g. body fat, blood glucose levels, lung capacity). In support of this rationale, in the present study dieting predicting lowered heart HR and 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 home environment was related to a lower HR than the potentially busier college setting. However, demographic characteristics such as gender and age did not appear to impact on HR, nor did baseline health biomarkers such as BMI and lung function. Although the current study controls for numerous biological, behavioural, and environmental confounds several methodological challenges remain. Whilst the DRM represents a progression in retrospective assessment a synchronized integration of experience sampling, DRM and heart monitoring would be required to gauge the relative accuracy of the DRM in HR prediction. The analysis of movement and posture through accelerometry is a useful tool which could assist future studies. In particular, accelerometry can operate as a method of separating the movement related artefact out of HR analyses in order to produce a highly precise account of the psychophysiological response to situational and psychological factors (Myrtek, 2004). For instance, systematic specification of the role of physical activity would rule out the possibility that HR decreases inferred to be in response to disengagement and tiredness may be a result of lowered levels of activity.

In conclusion, this is one of only a few studies that have examined the correspondence between HR and affect in the context of daily life. There is clearly a substantial association between HR and state negative affect and trait emotional stability. This is evident from the raw concordance of HR and psychological distress, and both between-person and multi-level analysis of the relationship between HR, personality and affect. Most convincingly, controlling for a wide range of episodic and personality variables, negative affect in an episode predicts higher heart rate. This finding and the lack of concordance between resting HR and affect indicates that ambulatory heart rate monitoring may be a valuable paradigm in the analysis of episodic human emotion and in understanding the flow of everyday embodied experience (MacLachlan, 2004). The integrative approach to the study of real-world behaviour and experience employed in the current study 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 behavioural monitoring (e.g. Hasler, Matthias, Mehla, Bootzina, & Vazire, 2008), ambulatory assessments of pollutants and crowding (e.g. Gold et al., 2000), and momentary changes in health markers is likely to facilitate collaboration between emotion researchers and numerous other disciplines. Constructing an integrated DRM-ambulatory monitoring research platform may also be a valuable tool for researchers who want to explore the interplay between biological, environmental, economic, and psychological factors and in so doing illuminate the nature of embodied experience and its consequences for health and well-being.

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