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Positive affect and psychobiological processes

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Abstract

Positive affect has been associated with favourable health outcomes, and it is likely that several biological processes mediate the effects of positive mood on physical health. There is converging evidence that positive affect activates the neuroendocrine, autonomic and immune systems in distinct and functionally meaningful ways. Cortisol, both total output and the awakening response, has consistently been shown to be lower among individuals with higher levels of positive affect. The beneficial effects of positive mood on cardiovascular function, including heart rate and blood pressure, and the immune system have also been described. The influence of positive affect on these psychobiological processes are independent of negative affect, suggesting that positive affect may have characteristic biological correlates. The duration and conceptualisation of positive affect may be important considerations in understanding how different biological systems are activated in association with positive affect. The association of positive affect and psychobiological processes has been established, and these biological correlates may be partly responsible for the protective effects of positive affect on health outcomes.

Keywords

psychobiology of happiness; biology and wellbeing; positive affect

Introduction

There is accumulating evidence that feelings of positive affect confer benefit to the individual beyond the intrinsic value of being happier. Higher levels of positive affect are associated with better concurrent and future health prospects (Pressman and Cohen 2005), even after other known influences on health are accounted for (Kubzansky and Thurston 2007; Chida and Steptoe 2008). There are several plausible pathways through which positive psychological well-being may confer better health prospects; positive affect has been associated with healthy lifestyles (Grant, Wardle et al. in press); there may be a common genetic substrate that influences both affect and health or health behaviours; alternatively, positive affect may be an alias measure for other psychosocial factors known to influence health, for example social support and coping style. There is also emerging evidence that there is a direct pathway between positive affect and health, involving reduced psychobiological activation of neuroendocrine, autonomic, immune and inflammatory

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pathways. This review will discuss the nature of the association of positive affect with the activation of autonomic, neuroendocrine and immune systems.

Positive affect and wellbeing

In the positive psychology literature two types of positive wellbeing are conceptualised, eudaimonic and hedonic wellbeing. Hedonic wellbeing describes positive feelings such as happiness and contentment, and hedonic psychology examines what makes life pleasant or unpleasant (Diener, Suh et al. 1999; Kahneman, Diener et al. 1999). Measures of hedonic wellbeing determine the presence and intensity of positive affect. In contrast, eudaimonic wellbeing describes the emotions that accompany movement towards one's potential, and are typically measured by feelings such as vitality, curiosity and engagement (Diener 2000; Fredrickson 2001; Fredrickson and Losada 2005).

Hedonic and eudaimonic wellbeing are conceptually and phenomenologically distinct but the operationalisation of positive affect in the research literature is diffuse. Some studies have used feelings of engagement, mastery or progress toward goals, others have used the duration and intensity of feelings of pleasure or satisfaction as an indicator of positive affect, or used aggregates of momentary mood, where averaged or cumulative scores of momentary assessments represent positive affect. The choice of measure may be determined by the conceptual model being examined, and in considering how they relate to biological systems, the advantages and disadvantages of each should be carefully considered (Kashdan, Biswas-Diener et al. 2008; Scollon, Prieto et al. 2009). It is plausible that aggregate measures of hedonic mood are proxy measures of eudaimonic wellbeing, as the proportion of time people experience positive emotions is strongly associated with overall feelings of positive wellbeing (Diener 2009). However, hedonic and eudaimonic wellbeing may influence different biological pathways or exert different effects on the same pathways (Ryff, Singer et al. 2004) and maintaining the conceptual and operational distinction between hedonic and eudaimonic wellbeing may be important in understanding the exact nature of association of positive wellbeing and biology. This is made challenging by the ongoing discussion about the operationalisation and possible confluence of these concepts (Biswas-Diener, Kashdan et al. 2009). In this review, the associations of both enduring and more transient states of positive affect with biology are discussed, as both are associated with changes in biological activation.

Positive affect and physical health

Much of the impetus for examining the biological correlates of positive affect comes from the association of positive wellbeing with health, and the research literature showing that psychological well-being is related to better physical health is growing (Pressman and Cohen 2005; Howell, Kern et al. 2007). Establishing the causal link between positive wellbeing and health is challenged by the same feasibility and ethical constraints as studies of other emotions and health. However, studies using population based, prospective or quasi-experimental designs are suggestive of models wherein positive affect predicts health. Although it is difficult to eliminate reverse causality, where underlying biological processes or vulnerability to disease contribute to a diminution of positive affect, there are several studies that indicate the strong contribution of positive affect to morbidity and mortality.

Using a prospective epidemiological cohort study design, Kubzansky and Thurston (Kubzansky and Thurston 2007) demonstrated the potential beneficial effects of positive wellbeing. In this study, a cohort of 6025 men and women aged 25–75 years, who were free of coronary heart disease (CHD) at baseline, were tracked for an average 15 years, over which time 1141 developed CHD. Participants with higher scores on a constellation of positive wellbeing traits were at markedly reduced risk for CHD, and this effect remained

significant after accounting statistically for other known risk factors. Ostir et al (Ostir, Markides et al. 2001) have also reported that higher levels of positive affect predicted a lower incidence of stroke over a 6 year period, even after controlling for negative affect.

The most conclusive support for the positioning of health as an outcome of positive affect is provided by a recent meta-analysis of positive wellbeing and mortality (Chida and Steptoe 2008). Chida and Steptoe identified 26 articles on initially healthy populations and 30 articles on people with established illnesses. Follow-up periods ranged between 2 and 44 years in the healthy population studies and 1–20 years in studies of people with existing disease. Positive wellbeing was associated with reduced mortality, with stronger effects evident in healthy populations (adjusted hazard ratio 0.82, 95% confidence intervals 0.76 to 0.89, $p < 0.001$), than in those with existing disease (hazard ratio 0.98, C.I. 0.95 to 1.00, $p = 0.03$). Importantly, these effects persisted when analysis was limited to the better controlled studies, and were also maintained when negative affect was taken into account statistically. This is significant, since it suggests that positive affect may be protective over and above the absence of emotional distress.

Methods of investigating physiological pathways

There are two main approaches to examining positive wellbeing and physiological parameters and function; one is to examine intra-individual change and the other is to examine inter-individual differences. Testing within-person associations usually involves repeated assessment of mood and serial measures of markers of physiological function, and often uses multi-level modeling strategies in analyses. Between person or individual difference research compares biomarkers in people with higher levels of positive affect with those with lower levels of positive affect.

Cardiovascular function

Changes in cardiovascular function, especially increases in heart rate (HR) and blood pressure (BP), represent normal responses to challenge. Changes in the degree of arousal or in affective states are associated with changes in cardiovascular activity via the sympathetic nervous system (Lovallo 2004). Higher levels of cardiovascular activity are generally posited as a health risk, conversely lower levels of basal cardiovascular activity may represent lower risk. The direction of association of positive affect and cardiovascular function is determined by the type and intensity of emotional state experienced. Some positive affective states, for example, elation, represent states of arousal, with a concomitant increase in cardiovascular activity, especially heart rate and blood pressure, whereas other positive feelings, such as satisfaction with life, might be associated with a reduced cardiovascular reactivity. Thus, the arousal level and valence of emotion is a crucial contributor to association of positive affect and biological activation. The circumplex model of emotion, illustrated in Figure 1, proposes that converse emotional states share common neurobiological pathways (Posner, Russell et al. 2005) and so there may be parallels in physiological responses to different emotions, dependent on the degree of arousal the emotion elicits.

Mood inductions

There are a plethora of mood induction studies that examine associations between positive affect and cardiovascular activity. A great majority of mood induction studies have used strategies such as viewing films or recalling past personal experiences, relating concurrent changes in mood and cardiovascular activity and the dynamics of cardiovascular recovery. In a series of studies Fredrickson and colleagues (Fredrickson and Levenson 1998; Tugade and Fredrickson 2004) compared heart period, aggregated finger pulse amplitude, heart rate

(HR), diastolic blood pressure (DBP) and systolic blood pressure (SBP) in young, healthy undergraduate participants who viewed films designed to elicit positive and negative affect. In two studies, the findings suggest that after viewing amusing films there was a faster return to baseline activity levels than after viewing films designed to induce sadness or fear. However in other studies there were no meaningful differences in any measure of cardiovascular activity (Fredrickson, Mancuso et al. 2000; Christie and Friedman 2004). Gendolla and Krusken (Gendolla and Krusken 2001) used a similar design, also in healthy young adults (mean age 23), and reported no significant effect of positive affect on HR, SBP, or DBP, and in an earlier study in a similar aged sample using music to induce mood, no effects were found (Gendolla and Krusken 2001). These contrary results highlight the lack of a clear pattern of association of cardiovascular activity and positive affect in mood induction studies. Overall these studies indicate that cardiovascular activity may change concurrently with emotional state, but not in a way that is unique to positive affect.

It is possible that positive affect both moderates or mediates the cardiovascular response to negative affect or stress challenges, although there are very few studies that have attempted to tease these relationships out. In two studies, Tugade and Fredrickson (Tugade and Fredrickson 2004) examined the contribution of positive well-being to cardiovascular recovery from negative emotion arousal states, including a deliberate manipulation of the degree of positive affect. Participants completed a task designed to increase positive emotions after the induction of negative emotions. In both studies positive affect and aspects of positive wellbeing (e.g. resilience) were associated with a more rapid return to baseline measures of cardiovascular activity. In a recent study of the relationships between positive affect and cardiovascular responses to stress, we found evidence of moderation by positive affect. After induction of mental stress by a standardized laboratory challenge, diastolic pressure recovery was more rapid among participants with high positive affect, and these effects were significant after controlling for age, body mass index, and negative affect (Steptoe, Gibson et al. 2007). Levels of positive affect were also associated with lower systolic blood pressure throughout the laboratory stress session. These results suggest that positive well-being contributes to an accelerated cardiovascular recovery profile after stress or negative emotional states. Positive emotions and wellbeing may influence on cardiovascular activity via parasympathetic activation, which serves to diminish the effects of sympathetic nervous system activation on cardiovascular activity. An early study by McCraty and colleagues (McCraty, Atkinson et al. 1995) demonstrated that emotional arousal causes an increase in autonomic activation as measured by heart rate variability (HRV). In the study, HRV was monitored during the induction of positive and angry emotional states. Total autonomic activity was increased by both positive and angry states, but there was a rise in activity in the 0.08–0.15 Hz waveband (commonly termed low frequency HRV) during positive emotion induction. This may be indicative of heightened parasympathetic activity.

In sum, the associations of positive affect and cardiovascular activity examined after mood induction vary in both direction and magnitude of effect. The differences may be attributed to the type of positive affect induced and the degree of emotional arousal. The contrast in the findings of studies using passive induction (music, film) versus active engagement tasks (personal memories, event re-enactment) also indicates the importance of differentiating between states of general emotional arousal, including degree of negative affect, and positive affective states. The patterns of cardiovascular response and recovery in high arousal positive affective states are the same, albeit of lesser magnitude, as patterns observed in other states of emotional arousal, including anxiety and fear, and suggest shared autonomic system pathways that regulate cardiovascular activity.

Ambulatory studies

Ambulatory studies are much more likely to reveal associations of positive affect and basal cardiovascular activity, which may be more salient in conceptual models linking emotional affect and health outcomes. Several studies have monitored BP or HR over hours or days, and examined how these parameters change in times of positive affective state. Brosschot et al (Brosschot and Thayer 2003) found a deceleration of heart rate following a positive affective state, and in a study of people with borderline hypertension, Jeames et al 1986 reported that aggregate measures of positive affect were inversely related to SBP. These findings are in contrast to those reported by Jacobs et al (Jacobs, Myin-Germeys et al. 2007) who reported that feelings of elation and happiness were associated with increases in BP when compared to periods of feeling mellow. Notably, this pattern was also observed during periods of feeling anxious/annoyed. The differences in these findings may be attributable to several sources including the circumplex model of emotion (Posner, Russell et al. 2005). Changes associated with emotional arousal states are similar to those observed after physical activity, and as emotional arousal may co-occur with activity, and low activity levels co-occur with negative affect, attention to confounding by variation in physical activity is critical. Physical activity typically increases HR and BP irrespective of affective state, and this may be the explanation of why happy moods in everyday life have been associated with slightly greater BP in within-person studies (Schwartz, Warren et al. 1994). Positive emotional states have been associated with increased physical activity in a number of studies (Watson 1988, Ryff 2004).

Other studies suggest that parasympathetic activation is related to positive emotions in everyday life. In a study of 135 patients with coronary artery disease, Bacon et al (Bacon, Watkins et al. 2004) measured heart rate variability over 48 hours along with frequent assessments of mood, and found significant.

associations between positive mood and low frequency power, indicating the involvement of the parasympathetic nervous system (PNS). Another interesting study of older adults (mean age 74 years) involved daily measurement of BP and positive and negative affect over 60 days (Ong and Allaire 2005). The results of multilevel modeling showed that at the within-person level, daily positive well-being was associated with reduced cardiovascular reactivity to negative emotional arousal. Further, positive well-being reduced the cardiovascular activation subsequent to feelings of negative emotion.

Using ambulatory blood pressure monitors, we measured BP and HR every 20 min over a working day and evening in over 200 middle aged adults (Steptoe, Wardle et al. 2005). The analytical approach controlled for factors that may influence cardiovascular activity, including age, physical activity and BMI, and associations of positive affect and cardiovascular activity still emerged. In men but not women, there was a significant association between positive well-being and HR; the higher the aggregate levels of positive affect, the lower the HR over the day. This effect was replicated in the same sample three years after the original ambulatory monitoring phase, in addition SBP was inversely associated with positive affect. This finding is consistent with the pattern of association of affect and cardiovascular activity found in young men (Steptoe, Gibson et al. 2007). This study used two different approaches to measuring positive affect, since in addition to using a standard questionnaire measure, momentary assessments of mood over 2 days were aggregated. Interestingly, stronger physiological associations were found for aggregated momentary assessments than questionnaire measures of well-being, probably because they index participants' experience more precisely.

Cortisol

The release of pituitary and adrenal hormones is associated with emotional states through the neuroanatomical connections of the hypothalamic pituitary adrenal (HPA) system, involving subcortical brain regions responsible for affect regulation. Most studies of positive affect have studied changes in salivary cortisol levels, as these provide a convenient window through which the emotional correlates of the HPA axis function can be explored (Biondi and Picardi 1999). There are two distinct components of the diurnal cortisol profile, namely the cortisol awakening response (CAR), and the decline over the rest of the day. There are marked individual differences both in cortisol levels over the day and cortisol responses to changes in emotional state. Further, the CAR and cortisol output over the rest of the day are not strongly correlated, and may be influenced by different regulatory and developmental processes. For example, there may be a stronger genetic influence on basal cortisol and cortisol reactivity levels, and the magnitude of this influence may change across the life course (Schmidt-Reinwald, Pruessner et al. 1999; Wust, Federenko et al. 2000; Bartels, de Geus et al. 2003; Steptoe, van Jaarsveld et al. 2009).

Diurnal rhythms of cortisol

A number of studies have shown that cortisol tends to be lower when people have greater positive affect (Smyth, Ockenfels et al. 1998; Davydov, Shapiro et al. 2005; Hoppmann and Klumb 2006; Jacobs, Myin-Germeys et al. 2007). However, there are variations depending on the time of the day, age, and the method of measuring positive affect. In a study of just over 200 middle-aged working men and women, we have found an inverse association between positive affect and cortisol output over the day (Steptoe, Wardle et al. 2005). Effects were evident on working and non-working days, and persisted in a repeated assessment of the same individuals after three years (Steptoe and Wardle 2005). Effects were also independent of psychological distress, suggesting that the association was not simply due to the absence of negative affect. A similar pattern of association was reported by Simpson et al (Simpson, McConville et al. 2008); cortisol levels in the early afternoon and late evening were measured in 41 older adults (mean age 61 years) for 7 days, and the average afternoon and evening values calculated. Momentary measures of mood were also collected four times a day, on rising, in the early afternoon, in the early evening and in the late evening, and these measures were also aggregated. Lower levels of positive affect and greater variability in positive affect in the afternoon were correlated with higher evening cortisol concentrations. Interestingly, correlational analyses utilizing all data points indicate a coupling of the diurnal patterns of cortisol and positive mood, that is, the trajectories of cortisol and mood are temporally related. However, this relationship is not surprising given the well documented circadian rhythms of cortisol and the predictable diurnal rhythm of positive affect within individuals. There is significant variation in the acrophase, (the peak of the rhythm), and slope of positive mood between persons, but within person there is a stable pattern of mood rhythms across days (Clark, Watson et al. 1989; Wood and Magnello 1992; Watson 2000; Stone, Schwartz et al. 2006).

Polk et al (Polk, Cohen et al. 2005) used aggregate measures of trait positive affect obtained over 7 days in 334 adults and report somewhat different patterns of association of positive affect and cortisol. Using a multi-level model, a three-way interaction of time, sex and positive affect were revealed; men with low aggregate scores of positive affect had relatively high, flat rhythms of cortisol, and women with higher aggregate measures of positive affect had a low flat cortisol rhythm. In men, cortisol did not decline over the course of the afternoon, whereas in women the morning cortisol was low, and this level was sustained across the course of the day. The findings of flat rhythm in women with higher level of positive wellbeing parallel those reported by Ryff and colleagues (Ryff, Singer et al. 2004) who have found that women with higher levels of positive wellbeing have lower levels of

cortisol early in the day, and this level is maintained over the rest of the day. This study distinguishes between hedonic wellbeing and eudaimonic wellbeing and finds no association of hedonic wellbeing and diurnal cortisol profile. In summary, the pattern of association between positive affect and total cortisol is inconsistent, and it is possible that hedonic and eudaimonic wellbeing are related to diurnal cortisol secretion in different ways.

Cortisol awakening response

A few studies have assessed the association of the cortisol awakening response (CAR) and positive affect, and findings are mixed (Chida and Steptoe 2009). A recent study of young men illustrates this inconsistency (Steptoe, Gibson et al. 2007). The CAR was averaged over two days, and related to two different measures of positive affect. One was a standardized questionnaire, and the other was an aggregation of repeated measures of happiness over the two days. The associations between cortisol and positive affect were only evident for the aggregate measure of positive affect. This is illustrated in Figure 2, with cortisol values adjusted for age, BMI, time of waking in the morning, and negative affect. Both participants who were low and high in positive affect showed the typical CAR, but the increase in cortisol was greater in the low positive affect group. Further, in the low positive affect group, cortisol remained elevated at one hour after waking, while in the high positive affect group it had fallen to waking levels by one hour after waking.

Another study of the CAR involved the measurement cortisol on two consecutive workdays in a sample of 80 young Chinese adults (mean age 27 years) (Lai, Evans et al. 2005). Affect over the previous day, week and month was calculated and a measure of optimism, as a component of positive affect, was taken. The results show that higher levels of optimism were associated with reduced cortisol on waking and throughout the day, although this effect was only noted in males. Further, the measure of generalized positive affect was associated with the diurnal decline in cortisol in both males and females, with higher positive affect associated with lower cortisol levels in the afternoon. The mixed findings in strength and direction of association of positive affect and cortisol may be attributable to main and interactive effects of gender, the dimension and positive affect measurement strategy and age. It is likely that the associations between positive affect and cortisol change across the life course (Pruessner, Wolf et al. 1997; Kudielka, Buske-Kirschbaum et al. 2004), but the possibility that there are developmental effects on the association of affect and the CAR remains to be investigated.

Immune system

The immune system is a crucial defence against infection and other threats to health. Direct anatomical and functional links between the central nervous system and the immune system provide a biological pathway by which positive affect may influence the immune system. It is also plausible that there are indirect pathways through which positive affect influences immunity, including health behaviours. Positive affect has been associated with changes in the number of immune system cells, and also with the function of the system. Increased cellular immune competence has been linked with positive affect (Lutgendorf, Reimer et al. 2001), including greater NK cell cytotoxicity (Valdimarsdottir and Bovbjerg 1997) and increases in secretory IgA (S-IgA) responses to antigen challenge (Stone, Neale et al. 1994). Trait level indicators of positive wellbeing have also been associated with larger numbers of helper T cells (Segerstrom, Taylor et al. 1998).

There is also consistent support for the beneficial effects of positive affect on antibody levels and antibody responses to antigens, although it is possible that effects are driven by levels of emotional arousal rather than mood valence. Increases in positive affect after mood induction have repeatedly demonstrated rises in S-IgA (Stone, Cox et al. 1987; Njus, W. et

al. 1996; Stone, Marco et al. 1996; Hucklebridge, Lambert et al. 2000), although almost all of these studies have small numbers of participants and many do not test for a significant effect of the mood induction manipulation. Two of these studies included a contrast condition and report increases in S-IgA associated with negative affect as well (Njus, W. et al. 1996; Hucklebridge, Lambert et al. 2000). Further, in an ambulatory study of affect over two weeks Evans et al (Evans, Bristow et al. 1994) found no association of S-IgA with positive affect, although on days with more negative affect, S-IgA was higher. Studies using aggregate measures of affect obtained over several weeks have demonstrated a higher S-IgA response on days with high positive mood (Stone, Cox et al. 1987; Stone, Neale et al. 1994). Taken together these studies are suggestive of an association of positive affect and antibodies, but future research will need to assess the contribution of arousal and other potential influences such as cortisol and, negative affect on the relationship between positive affect and antibody responses.

Functional changes in the immune system are likely tied to the intensity and duration of positive affect, which is directly linked to the strategy used to induce mood. Induction techniques using stimuli that are personally relevant to the participant, such as recalled experience, may be more salient and thus activate biological pathways in a more intense or prolonged manner. Futterman et al (Futterman, Kemeny et al. 1992; Futterman, Kemeny et al. 1994) have shown that the performance of monologues and scenarios constructed from participant actors' personal experiences increase the number and activity of immune cells, as indicated by NK cell cytotoxicity and lymphocyte proliferation in response to an antigen. The duration of high positive affect states is also a contributor to the association of affect and NK cell activity although effects of positive affect on the immune system are not always shown (Berk, Tan et al. 1989; Valdimarsdottir and Bovbjerg 1997), regardless of the intensity or duration of mood (Knapp, Levy et al. 1992). The increases in cell numbers found in studies of positive affect parallel those found in stress challenge studies (Segerstrom and Miller 2004) and it is likely that positive emotional states are arousing in the same manner as stressed states as per the circumplex model of emotion, with subsequent activation of the sympathetic nervous system (Posner, Russell et al. 2005).

The functional significance of the association of positive affect and the immune system was demonstrated in a series of studies by Cohen and colleagues (Cohen, Kearney et al. 1999; Cohen, Doyle et al. 2003; Cohen, Alper et al. 2006). In one study 334 healthy, adult volunteers were quarantined and monitored for the development of biologically verified upper respiratory infections after inoculation with a rhinovirus (Cohen, Alper et al. 2006). Participants provided daily measures of positive affect over the previous 3 week period in order to assess 'positive emotional style'. Those with high positive emotional style were up to three times less likely to develop symptoms of infection, and a dose-response relationship was demonstrated between higher positive emotional styles and the lower risk of developing a cold. A large number of control factors (including age, sex, education, negative affect, and virus-specific antibody status before challenge) were not able to explain decreased risk for colds among persons with higher dispositional positive affect and there was no relationship between negative emotional styles and colds. These findings are similar to those of Marsland et al (Marsland, Cohen et al. 2006) who measured antibody responses following vaccination for hepatitis B. More effective immune function is indicated by greater antibody responses, and in the Marsland et al study positive affect was associated with heightened immune responses independently of age, gender, health behavior and negative affect.

Cytokines

An efficient immune system response to challenge requires the appropriate regulation of cytokines, and changes in the levels of cytokines are critical to the activation of the cellular immune system response. To date there are few studies to examine positive affect and

cytokines, although in mood induction studies, changes in IL-2, IL-3, IL-6 and TnF α are noted (Mittwoch-Jaffe, Shalit et al. 1995). Researchers have assessed both the plasma concentration of cytokines and the *in vitro* release of cytokines from cells stimulated by immunogens. The two methods may show different effects (Steptoe, Hamer et al. 2007). In a recent study of healthy adults we have found an inverse association of positive affect and IL-6, although this association was only evident in women (Steptoe, O'Donnell et al. 2008). These effects were independent of covariates such as age, ethnicity, socioeconomic status, BMI, smoking and depressed mood. This supports an earlier finding of an inverse association of trait positive affect and IL-6 (Friedman, Hayney et al. 2007). The sex difference we observed may be due to differences in emotional processing between men and women or to differences in bioactivation associated with emotions, as differences in both pathways have been found (Taylor, Klein et al. 2000) (Stroud, Salovey et al. 2002). However it is not yet known if sex differences exist in physiological correlates of positive affect, or if the differences are rooted in differences in patterns of affective responses (Kelly, Tyrka et al. 2008). We have also found that women have larger IL-6 responses to stress challenge (Steptoe, Owen et al. 2002) and so models of positive affect and the immune system need to consider the sex specificity of the psychobiological responses and the circumplex model of emotion (Posner, Russell et al. 2005).

Fibrinogen and C reactive protein

Fibrinogen and c-reactive protein are both indices of systemic inflammation. C-reactive protein increases after an acute stressor, although changes may take several hours to emerge, in contrast to fibrinogen which has a more rapid response to stress (Colley, Fleck et al. 1983; Pepys and Hirschfield 2003). We have observed inverse associations between positive affect and C-reactive protein concentration in women although not in men (Steptoe, O'Donnell et al. 2008). These effects were independent of covariates such as age, ethnicity, socioeconomic status, BMI, smoking. We do not know why effects were only present in women, although IL-6 promotes the production of C-reactive protein and we have found that women showed larger IL-6 responses to acute stress than men (Steptoe, Owen et al. 2002). We have also found an inverse association between positive affect and fibrinogen stress responsivity, where responsivity is less in individuals who have higher levels of positive affect. At baseline, there were no differences between happier and less happy people, but the less happy people had much larger fibrinogen responses (Steptoe and Wardle 2005). This is illustrated in figure 2, which also shows that in the least happy people fibrinogen remained elevated at 45 minutes post stress, but had fallen to levels below baseline in the happiest people.

Conclusion

The biological correlates of positive affect are only beginning to be described but there is converging evidence that positive affect has an effect on biology, and that it is correlated with health-protective biological responses. Many of the studies of the patterns of biological activation associated with positive affect have used mood induction paradigms, and it is possible that that observed associations are at least partly explained by the level of arousal engendered by positive emotions. However, studies that have incorporated trait or aggregate measures of positive affect have also demonstrated effects of positive affect on the activation of several biological systems, and it is plausible that sustained positive affect leads to an overall reduction in the baseline levels of activation of the neuroendocrine, autonomic and immune systems. The conceptual differences between hedonic and eudaimonic wellbeing should guide future research to elucidate the biological correlates of both transient and sustained positive affect. An expansion of the research literature on the psychobiological correlates of positive affect is needed before more definitive patterns of

association emerge, however findings to date suggest that positive affect activates the neuroendocrine, autonomic and immune systems in distinct and functionally meaningful ways.

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Figure 1.
The circumplex model of emotion. The horizontal axis represents the valence dimension and the vertical axis represents the arousal dimension.

Figure 2. Mean cortisol sampled on waking, 30 minutes and 60 minutes later in young men divided on the basis of EMA assessments into low (solid line) and high (dotted line) positive affect groups. Values are adjusted for age, BMI, time of waking, and negative affect. Error bars are standard error of the mean. Adapted from Steptoe et al, 2007.

Figure 3. Mean plasma fibrinogen sampled at baseline (base), immediately following challenging behavioral tasks (tasks), and 45 min post-tasks (recovery), in participants in the highest (solid line) and lowest (dashed line) of a cohort of 209 individuals. Adapted from Steptoe et al (2005).