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Heart Rate Variability Predicts Older Adults' Avoidance of Negativity

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Abstract

Objectives: The ability to produce situation-appropriate cognitive and emotional responses is dependent on autonomic nervous system (ANS) functionality. Heart rate variability (HRV) is an index of ANS functionality, and resting HRV levels have been associated with cognitive control and inhibitory capacity in young adults, particularly when faced with emotional information. As older adults' greater preference for positive and avoidance of negative stimuli (positivity effect) is thought to be dependent on cognitive control, we hypothesized that HRV could predict positivity-effect magnitude in older adults. **Method:** We measured resting-level HRV and gaze preference for happy and angry (relative to neutral) faces in 63 young and 62 older adults. **Results:** Whereas young adults showed no consistent preference for happy or angry faces, older adults showed the expected positivity effect, which predominantly manifested as negativity avoidance rather than positivity preference. Crucially, older but not young adults showed an association between HRV and gaze preference, with higher levels of HRV being specifically associated with stronger negativity avoidance. **Discussion:** This is the first study to demonstrate a link between older adults' ANS functionality and their avoidance of negative information. Increasing the efficiency of the cardiovascular system might selectively improve older adults' ability to disregard negative influences.

Keywords: aging, heart rate variability, positivity effect, negativity avoidance, eye tracking

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Cognition, emotion, and visceral states regulated by the autonomic nervous system (ANS) constantly interact with each other to ensure that individuals respond to emerging environmental and somatic demands in an appropriate manner (Levenson, 2014). Numerous studies have examined these interactions, promoting the conceptualization of physical and mental processes as outcomes of a single, functionally integrated system (Critchley, Eccles, & Garfinkel, 2013). Recently, researchers have found systematic links between indices of ANS function and cognitive (Colzato & Steenbergen, 2017; Gillie, Vasey, & Thayer, 2014) and emotional (Visted et al., 2017; Williams et al., 2015) processing in young adults. However, it is unknown whether the same is true for older adults, a group characterized by a highly varied physiological and cognitive profile (Lindenberger, 2014).

A frequently used indicator of ANS functionality is heart rate variability (HRV), a measure of the variation in the time interval between successive heartbeats (Zygmunt & Stanczyk, 2010). In general, higher HRV is assumed to reflect more efficient ANS function (Balzarotti, Biassoni, Colombo, & Ciceri, 2017), indicating the capacity of the organism to effectively mobilize processing resources as and when required (Grossman & Taylor, 2007). It has been suggested that resting HRV levels reflect the activity of the prefrontal cortex (PFC; Thayer & Lane, 2009), a brain area supporting cognitive control, goal-directed behavior, and successful emotion regulation (Benarroch, 1997). This claim has been supported by studies reporting strong associations between resting HRV levels and (a) the cortical thickness of sub-regions within the PFC (Yoo et al., 2018), (b) brain areas related to self-regulatory capabilities (Winkelmann et al., 2017), and (c) the functional connectivity between regions implicated in emotion processing (Sakaki et al., 2016).

In young adults, high levels of resting HRV have been found to primarily predict inhibitory control (Stenfors, Hanson, Theorell, & Osika, 2016), including improved memory suppression in a think/no-think paradigm (Gillie et al., 2014), inhibition of prepotent responses (Krypotos, Jahfari, van Ast, Kindt, & Forstmann, 2011) particularly in tasks requiring rapid changes in cognitive strategies (Colzato & Steenbergen, 2017), as well as greater persistence during an anagram task (Segerstrom & Nes, 2007; but see Luque-Casado, Zabala, Morales, Mateo-March, & Sanabria, 2013, for no association between HRV and executive control in young adults). Additionally, resting HRV is a reliable index of emotion regulation efficiency (Balzarotti et al., 2017; Thayer & Lane, 2009). Studies have found low-HRV individuals to exhibit exaggerated startle responses when viewing neutral and emotional pictures accompanied by acoustic startle stimuli, which is assumed to be associated with emotion regulation difficulties (Ruiz-Padial, Sollers, Vila, & Thayer, 2003). Similarly, HRV levels have been found to be negatively associated with self-reported difficulties in emotion regulation (Visted et al., 2017; Williams et al., 2015), and positively associated with traits related to improved emotional well-being such as self-compassion (Svendsen et al., 2016). Interestingly, high resting HRV levels have been found to predict improved inhibitory capacity specifically during the presentation of negative, but not positive, stimuli. That is, high-HRV participants are faster at inhibiting prepotent responses when presented with negative emotional stimuli, suggesting that these participants might be more effective at mitigating the impact of negative influences compared with their low-HRV counterparts (Krypotos et al., 2011).

So far, research linking cognition and emotion to ANS functionality has focused on young adults. To the best of our knowledge, no studies have examined the association between HRV and emotion-cognition interactions in older individuals. This is of particular importance as, relative to young adults, older adults tend to show a preference for positive and an avoidance of negative information in both memory (Mantantzis, Schlaghecken, & Maylor, 2017; Mather & Knight, 2005) and attention (Isaacowitz, Wadlinger, Goren, & Wilson, 2006; Isaacowitz, Toner, Goren, & Wilson, 2008), a phenomenon known as the positivity effect (Mather & Carstensen, 2005). It has been suggested that the positivity effect reflects a cognitive control mechanism, with older adults actively prioritizing positive information and avoiding the negatives (Isaacowitz, Allard, Murphy, & Schlangel, 2009; Knight et al., 2007; Mantantzis et al., 2017; Mather & Knight, 2005). The fact that the positivity effect disappears under high cognitive load conditions, presumably because older adults cannot allocate the necessary processing resources to the prioritization of the positive/inhibition of the negative (Knight et al., 2007; Mantantzis et al., 2017; Mather & Knight, 2005), further supports this interpretation. The role of cognitive control capacity in the emergence of the positivity effect is also evidenced by neuroimaging studies showing that older adults exhibit higher PFC activation when presented with positive information compared with their younger counterparts (Ritchey, Bessette-Symons, Hayes, & Cabeza, 2011).

However, despite its name, the positivity effect does not always manifest as a preference toward positive material, but can emerge as an avoidance of negativity instead (Grühn, Scheibe, & Baltes, 2007; Isaacowitz et al., 2008; Mather & Knight, 2005). When encountering negative material, older adults tend to show higher levels of PFC activation than young adults (Murty et al., 2009), accompanied by a decrease in amygdala activity (St. Jacques, Dolcos, & Cabeza, 2010). This ‘anti-negativity’ aspect of the positivity effect is particularly interesting as it suggests that older adults use cognitive control to inhibit the influence of negative information. This leads to an intriguing question: if the age-related positivity effect is tied to cognitive control capacity and is dependent on upregulating positive and/or inhibiting negative information, could we predict the magnitude of positivity and anti-negativity preferences in older adults' cognition simply by examining individual differences in resting HRV levels? In light of recent findings showing a relationship between HRV and the strength of the PFC-amygdala connectivity throughout the adult lifespan (Sakaki et al., 2016), it is likely that older adults' higher prioritization of positive and inhibition of negative information is dependent on the successful deployment of PFC-related cognitive mechanisms, and can be indexed by HRV measures. At present, we lack an understanding of the contribution of the ANS to the strength of older adults' positivity effect, and whether ANS functionality, as measured by HRV, is associated with specific facets of the positivity effect (positivity preference vs. negativity avoidance).

In the present study, we employed an eye-tracking paradigm to assess young and older adults' preference for emotional versus neutral faces, measuring both their positivity preference and negativity avoidance. We recorded participants' fixations to pictures of faces presented in pairs of one emotional (either happy or angry) and one neutral face. Positivity preference was conceptualized as larger numbers of fixations toward, and longer fixation durations on, happy relative to neutral faces, and negativity avoidance as larger numbers of fixations toward, and longer fixation durations on, neutral relative to angry faces. We expected older adults to show the positivity effect, whereas young adults were expected to show either a slight negativity bias or no particular preference for emotional faces (Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001; Mantantzis et al., 2017).

Participants' HRV at rest was measured to investigate whether it can predict the magnitude of the positivity effect. If HRV is related to cognitive control capacity, it was expected that the association between HRV and emotional preference would be found in older but not in young adults, who do not typically show a preference toward positive and away from negative material. Based on studies suggesting that the positivity effect can manifest as negativity avoidance rather than a pure positivity preference (Grühn et al., 2007) and that high HRV predicts stronger inhibitory capacity particularly when participants are presented with negative information (Krypotos et al., 2011), we expected higher HRV levels to be related to higher negativity avoidance rather than to increased positivity in older adults. Additionally, as previous reports have suggested that the positivity effect disappears under high cognitive demands (Knight et al., 2007; Mantantzis et al., 2017; Mather & Knight, 2005), we included both a single- and a dual-task condition to examine whether the HRV-positivity effect relationship changes when a distracting secondary task is introduced. We expected the dual task to affect the magnitude of the positivity effect and potentially alter the HRV-positivity effect relationship. To assess the emotional impact of performing a demanding task, implicit affect was measured to examine age-related differences in emotionality following an easy versus a more cognitively demanding task. We expected older adults to show higher levels of positive affect than young adults (Carstensen, Pasupathi, Mayr, & Nesselroade, 2000), but this higher positivity could be dampened after performing a more demanding task.

Method

Participants

A total of 66 healthy young adults (age range 18-25) and 63 healthy community-dwelling older adults (age range 65-79) took part in the study. Medium effect sizes have been found in studies assessing the relationship between resting HRV and cognition (Colzato & Steenbergen, 2017; Gillie et al., 2014), as well as HRV and emotion regulation self-reports (Visted et al., 2017; Williams et al., 2015). Sample size for the present study was determined based on a meta-analysis of almost 300 effect sizes suggesting that, for a medium effect size, 61 participants are required to achieve 80% power (Quintana, 2017). Young adults received course credit as part of their course requirements and older adults were compensated £10 in exchange for their participation. The study was approved by the Psychology Department's Research Ethics Committee at the University of Warwick and all participants provided written consent at the beginning of the testing session. The experimental procedures were designed and conducted in accordance with the World Medical Association Declaration of Helsinki.

Exclusion criteria included self-reported history of neurological, psychiatric or endocrine disorders, eye conditions (e.g., pupil obfuscation), and cardiovascular disease or use of medication that could affect cardiovascular functioning (e.g., β-blockers). Data from four participants (3 young, 1 older) were excluded because of use of antidepressants or other medication that could affect cognitive and cardiovascular functioning, leaving 63 young and 62 older adults in the final sample. HRV data from eight participants were unusable because of equipment malfunction ($n = 3$), high number of artifacts during recording ($n = 4$), or heart conditions not disclosed during screening ($n = 1$), leaving 62 young and 55 older adults for HRV analysis. Participants' eye movements were also visually inspected throughout the task to ensure the recording of high quality data and to exclude trials in which the pupil was not adequately tracked or artifacts were introduced (less than 0.5% of trials across all participants). Fixation data for one single- and one dual-task block belonging to two different older adults had to be excluded because the pupil could not be tracked for the majority of the trials, leaving 61 older adults for eye-tracking analysis in both single- and dual-task conditions.

Participants completed the Digit Symbol Substitution Task (DSST; Wechsler, 1981) and the Mill Hill Vocabulary Test (MHVT; Raven, Raven, & Court, 1988) to assess age differences in processing speed and crystallized intelligence, respectively. Older adults had lower DSST scores, $t(123) = -7.77$, $p < .001$, higher MHVT scores, $t(123) = 12.60$, $p < .001$, and more years of full-time education, $t(123) = 10.36$, $p < .001$, than young adults.

Characteristics of the final sample are presented in Table 1. The mean years of education and DSST scores of the older sample both fell within the usual range for older volunteers in cognitive aging studies (cf. Figure 2 of Hoyer, Stawski, Wasylyshyn, & Verhaeghen, 2004) though toward the upper ends of both distributions.

Cognitive Tasks

Emotional faces. Participants were presented with emotional and neutral faces obtained from the FACES database (Ebner, Riediger, & Lindenberger, 2010). The faces were displayed in pairs of one emotional and one neutral face presented side-by-side, one pair at a time. Based on previous findings suggesting that older adults show a stronger attentional preference toward happy and away from angry faces (Isaacowitz et al., 2006), we opted for happy and angry facial expressions as the emotional stimuli in the current study to assess older adults' positivity and anti-negativity preferences, respectively. We used an equal number of male and female, young and older, and happy and angry faces, and presented them in a pseudo-random order to ensure that no more than two pairs from the same gender, age group, and valence category were presented consecutively. The location of the emotional and neutral faces (left or right) was counterbalanced and randomized. Within each pair, the emotional and the neutral picture depicted the same person, with no single person appearing more than once throughout the experiment. Each pair remained on the screen for 5 s, followed by a 250-ms blank screen. The face pairs were preceded by a fixation cross presented for at least 750 ms on which participants had to fixate for the next trial to commence. The stimuli were presented on a 27-inch screen (gray background) with each face picture subtending a visual angle of approximately 25.8^{o} (height) × 20.9^{o} (width) at a 60-cm viewing distance.

Overall, participants were presented with 66 unique face pairs, 33 under single-task conditions and the remaining 33 under dual-task conditions. The first face pair in each list was included as a buffer and the remaining 32 face pairs were used in the analysis. For single-task trials, participants were asked to look at the faces naturally, as if they were at home watching television (Allard & Isaacowitz, 2008; Isaacowitz et al., 2006). Under dual-task conditions, participants had to view the faces while simultaneously performing an auditory 1-back working memory task. Single-digit numbers were played through speakers, each for 1 s and followed by an interstimulus interval of 1 s. Participants were instructed to press a key with the index finger of their dominant hand every time a number was repeated. Number onset was synchronized with the onset of the face pairs such that three numbers would be presented during each pair. Because the trial and, consequently, the first number onset would have been delayed if participants were not looking at the fixation cross within the first 750 ms, 1-back matches were programmed to occur only during the second or third number of a given trial. Numbers were presented in a pseudo-random order to ensure an equal number of matches during happy-neutral and angry-neutral pairs. Participants' response times (RTs) and error rates on the 1-back task were recorded (see Table 1 for scores).

To assess the emotional preference in participants' fixations we calculated a fixation count and a fixation duration ratio score based on previously published guidelines (Isaacowitz et al., 2006). The ratio was calculated as (emotional - neutral)/(emotional + neutral). Hence, a ratio score of zero indicates no preference for emotional or neutral faces, a positive ratio score a preference toward emotional faces, and a negative score a preference toward neutral (away from emotional) faces.

Implicit affect. To examine how cognitive task and age influence affect, participants completed the Implicit Positive and Negative Affect Test (IPANAT; (Quirin, Kazén, & Kuhl, 2009). At the end of each task (single and dual), participants were required to rate three nonwords (e.g., *TALEP*) based on how well they convey six different moods (happy, helpless, energetic, tense, cheerful, inhibited) by circling one option on a 4-point scale ranging from 1 (‘doesn’t fit at all’) to 4 (‘fits very well’). A different set of nonwords appeared at the end of each task. A composite affect score was created by subtracting the mean score for negative moods from the mean score for positive moods (see Table 1 for ratings). An implicit task was chosen as it has been shown to be more sensitive to changes in transient emotionality compared with explicit affect measures, and can accurately detect fluctuations in emotional states following mood manipulations (Quirin, Kazén, Rohrmann, & Kuhl, 2009). Furthermore, implicit tests require participants to use heuristic processes when giving their ratings that have been shown to better mirror affective states and are less subject to processing biases (e.g., social desirability) that can affect self-ratings in tests of explicit affect (Quirin et al., 2009).

Eye Tracking

Eye movements were recorded with an EyeLink 1000 desk-mounted eye tracker (SR Research, Mississauga, Ontario, Canada) at a 500-Hz sampling rate using the ‘pupil with corneal reflection’ setting. Participants were asked to place their chin on a chin rest approximately 60 cm from the screen to minimize head movements. Prior to each task, the eye tracker was calibrated using a 13-point calibration grid and subsequently validated for each participant. This procedure was repeated if the calibration/validation was below the ‘good’ threshold. A fixation recording began each time the velocity of a saccade was below 30^o/s for more than 100 ms and would stop each time this velocity threshold was surpassed.

HRV

HRV was measured at the beginning of the session. Data were recorded with a Polar H10 chest strap (Polar Electro, Kempele, Finland) placed below the participants’ pectoral muscles and relayed to a Polar V800 unit (1000-Hz sampling rate; Giles, Draper, & Neil, 2016). The present configuration has been shown to accurately record inter-beat (RR) intervals and produce HRV values that are highly consistent with an electrocardiogram when measures are taken at rest (Giles et al., 2016). Conductive electrode gel (Signa gel, Parker Laboratories Fairfield, NJ, USA) was applied to the electrodes to improve contact. Participants were asked to sit with their knees bent at a 90^o angle, feet flat on the floor, eyes closed, and hands on their thighs with palms facing up, for a period of 10 minutes (Laborde, Mosley, & Thayer, 2017).

The raw RR recordings were loaded into Kubios Version 2.2 (Tarvainen, Niskanen, Lipponen, Ranta-aho, & Karjalainen, 2014) and were artifact-corrected using the 'very low' (450 ms) option of the program to avoid distorting natural variability. For HRV values, we calculated the root mean square of successive differences (RMSSD) and the high frequency component of HRV (HF-HRV) using the final five minutes of the 10-minute recording period (Task Force, 1996). The HF-HRV component (frequency band: 0.15-0.40 Hz) was computed using a fast Fourier transformation. Across participants, less than 1% of RR intervals were identified as artifacts and corrected before further analysis. Prior to analysis, both RMSSD and HF-HRV values were natural log transformed to approximate a normal distribution (see Table 1 for means). Because Ln RMSSD and Ln HF-HRV were strongly correlated, $r(117) = .94$, $p < .001$, only Ln RMSSD was used in the analysis as it is thought to be less affected by respiratory influences (Laborde et al., 2017).

Procedure

Participants were asked to avoid consuming any food or drink (except for water) two hours before their scheduled visit to the lab as consumption of meals and caffeinated beverages is known to affect HRV indices (Laborde et al., 2017). All participants reported to have abided by that condition. Upon their arrival, they provided written consent and demographic information. The heart rate strap was then attached to the participants and they were given instructions on what to do during the 10-minute resting HRV recording period. After this, participants completed a short practice.[1] This began with calibration and validation of the eye tracker, followed by one single- and one dual-task block (four face pairs each) to familiarize participants with the procedure and timings. The main experiment commenced after the practice and the task order (single task, dual task) was counterbalanced across participants. The eye tracker was calibrated and validated before each task. At the end of each task, participants were asked to give their affective ratings on the IPANAT. Finally, they completed the DSST and MHVT after which they were debriefed and compensated for their participation.

Results

Because the ratios of fixation count and fixation duration were highly correlated (all *r*s > .86, all *p*s < .001) and yielded essentially the same pattern of findings, only fixation count analyses will be reported below. Fixation count ratios were entered into a three-way mixed analysis of variance with age (young, older) as the between-subjects factor, and emotion (happy, angry) and task (single, dual) as the within-subjects factors (see Figure 1 for means). This revealed a main effect of age, $F(1, 121) = 19.97$, $p < .001$, $\eta_p^2 = .142$, as young adults looked more toward the emotional, older adults more toward the neutral faces. There was also a main effect of emotion, $F(1, 121) = 48.89$, $p < .001$, $\eta_p^2 = .288$, showing that participants looked more toward happy and away from angry faces, as well as a main effect of task, $F(1, 121) = 10.85$, $p = .001$, $\eta_p^2 = .082$, with participants exhibiting a preference toward emotional faces under single-task conditions and a preference toward neutral during the dual task. These effects were qualified by an Age × Emotion interaction, $F(1, 121) = 5.62$, $p = .019$, $\eta_p^2 = .044$: whereas no age difference was found for participants' preference for happy faces, $t(121) = 1.59$, $p = .115$, older adults showed significantly greater avoidance of angry faces compared with their younger counterparts, $t(121) = -4.05$, $p < .001$. An Emotion × Task interaction, $F(1, 121) = 7.46$, $p = .007$, $\eta_p^2 = .058$, reflected the fact that whereas avoidance of angry faces was unaffected by task conditions, $t(122) = 0.40$, $p = .689$, preference for happy faces was significantly lower under dual- than single-task conditions, $t(122) = 4.67$, $p < .001$. There were no other interactions (all *F*s < 2.22, all *p*s > .139).

To examine the relationship between HRV and the positivity effect, fixation count ratios were entered into a four-way analysis of covariance with age (young, older) as the between-subjects factor, emotion (happy, angry) and task (single, dual) as the within-subjects factors, and Ln RMSSD as the covariate. (See Figure 2 for scatterplots of Ln RMSSD against the fixation count ratio for happy vs. neutral and angry vs. neutral face pairs under single- and dual-task conditions.) Results revealed an overall effect of Ln RMSSD, $F(1, 112) = 8.55$, $p = .004$, $\eta_p^2 = .071$. There was an interaction between age and emotion, as well as between emotion and Ln RMSSD, $F(1, 112) = 5.09$, $p = .026$, $\eta_p^2 = .043$, and $F(1, 112) = 6.06$, $p = .015$, $\eta_p^2 = .051$, respectively. These effects were further qualified by an Age × Emotion × Ln RMSSD interaction, $F(1, 112) = 9.77$, $p = .002$, $\eta_p^2 = .080$: whereas the slopes of the functions relating Ln RMSSD to preference for happy faces did not differ between young and older adults under either single-, B = .049, 95% CI [-.008, .107], $t(112) = 1.70$, $p = .092$, $\eta_p^2 = .025$, or dual-task conditions, B = .016, 95% CI [-.043, .076], $t(112) = 0.55$, $p = .582$, $\eta_p^2 = .003$, the slopes of the functions relating Ln RMSSD to avoidance of angry faces did differ significantly between young and older adults under both single-, B = -.108, 95% CI [-.189, -.027], $t(112) = -2.63$, $p = .010$, $\eta_p^2 = .058$, and dual-task conditions, B = -.086, 95% CI [-.157, -.016], $t(112) = -2.42$, $p = .017$, $\eta_p^2 = .050$. Furthermore, the association between Ln RMSSD and avoidance of angry faces was significant for older adults under both single- and dual-task conditions, $r(52) = -.429$, $p < .001$, and $r(53) = -.373$, $p = .005$, respectively, whereas no other correlations were significant.

Finally, affective ratings (see Table 1) were entered into a two-way mixed analysis of variance with age (young, older) and task (single, dual) as between- and within-subjects factors, respectively. This revealed a significant main effect of age, $F(1, 123) = 5.16$, $p = .025$, $\eta_p^2 = .040$, as older adults gave more positive ratings than did young adults. There was no main effect of task and no interaction (both Fs < 1).[2]

Discussion

The present study assessed how individual differences in HRV levels can predict young and older adults' preference for emotional faces and, more specifically, the age-related positivity effect. As indicated by their gaze preferences, both young and older adults were drawn toward happy faces, particularly in the single-task condition. However, only older adults showed an avoidance of angry faces, which remained unchanged even under dual-task conditions. Higher resting HRV was associated with a stronger positivity effect in older adults, while no associations were found between HRV and emotional preference in young adults. Importantly, the HRV-positivity effect relationship uncovered in older adults appeared specifically for the anti-negativity aspect of the positivity effect, but not for their positivity preference. Higher HRV predicted greater anti-negativity when viewing angry-neutral face pairs under both single- and dual-task conditions.

Our study is the first to demonstrate that resting HRV levels are associated with the magnitude of older adults' positivity effect. Earlier studies conducted with young adults have found a relationship between HRV and cognition, such that higher levels of resting HRV can predict greater ability to deploy inhibitory control during cognitive tasks requiring the suppression of prepotent responses (Colzato & Steenbergen, 2017; Gillie et al., 2014).

Furthermore, neuroimaging studies have found resting HRV levels to be associated with the cortical thickness of brain regions related to the successful implementation of cognitive control and self-regulation (Winkelmann et al., 2017; Yoo et al., 2018). The finding that older adults' HRV was specifically associated with their capacity to inhibit negative influences, but not with the upregulation of positive material, offers novel evidence for the role of HRV as an index of older adults' inhibitory capabilities. This is in line with findings showing that high-HRV young adults show superior inhibitory capacity compared with their low-HRV counterparts, but only when presented with negative information (Krypotos et al., 2011). Our results suggest that the HRV-inhibition relationship remains intact at the upper end of the adult lifespan, with higher HRV levels allowing older adults to more effectively downregulate negative information. With studies reporting that the age-related positivity effect is a cognitive control mechanism (Knight et al., 2007; Mantantzis et al., 2017; Mather & Knight, 2005), our findings support the hypothesis that older adults use cognitive control (e.g., their attention) to inhibit negative information, and further indicate that older adults' positivity effect magnitude is determined by the fitness and overall functionality of their ANS, as measured by resting HRV levels. It is important to note that the sample of older adults participating in the present study was selective in terms of background cognitive performance, educational history and overall health. Considering the atypically healthy sample of older adults recruited, care should be taken when generalizing our findings to the broader aging population.

It has been suggested that HRV is an index of the PFC's ability to inhibit the activity of subcortical regions (e.g., the amygdala) and, consequently, individuals' capacity to regulate emotions in a situation-appropriate way (Thayer & Lane, 2009). In fact, high HRV levels at rest have been associated with stronger functional connectivity between brain networks responsible for emotion regulation across adulthood (PFC-amygdala connectivity;

Sakaki et al., 2016) as well as improved emotion regulation capacity in young adults (Visted et al., 2017; Williams et al., 2015). It should be noted that researchers have conceptualized the positivity effect as reflecting a cognitive-control-driven emotion regulation mechanism that older adults use to improve their mood (Isaacowitz, Toner, & Neupert, 2009; Isaacowitz et al., 2008; Kennedy, Mather, & Carstensen, 2004; Mather & Carstensen, 2005; Noh, Lohani, & Isaacowitz, 2011). As negativity avoidance/suppression is one of the cognitive strategies used during emotion regulation (Gross & John, 2003), the HRV-negativity avoidance relationship uncovered in the present study could be interpreted as an indication that HRV indicates older adults' emotion regulation capacity. Although there is a possibility that higher HRV is related to greater emotion regulation capacity in aging, further studies are needed to directly test that idea, and to understand how HRV indices relate to older adults' mood and their ability to effectively regulate their emotional state (Isaacowitz & Blanchard-Fields, 2012). Considering the diverse physiological and cognitive profiles observed in old age, uncovering the mechanisms that contribute to improved cognitive and emotional wellbeing would assist in the creation of individually-tailored interventions to support healthy aging.

Similar to previous work (Grühn et al., 2007), older adults' positivity effect emerged more consistently as anti-negativity rather than a positivity preference. The anti-negativity remained intact under dual-task conditions, possibly due to the relatively undemanding nature of the distractor task used in the present study (Allard & Isaacowitz, 2008). The fact that participants' performance in the dual task was very high (approximately 1.9% error rate across the two age groups) supports this reasoning. On the other hand, the dual task was effective in eliminating the preference for happy faces. Therefore, it would be interesting for future research to investigate the relationship between HRV, the positivity effect, and task demands in more detail. It should also be noted that no systematic differences were found for participants' affective ratings after single- versus dual-task conditions. Although we found higher levels of positive affect in older relative to young adults, an indication that the affective test was sensitive enough to uncover the expected age-related differences in emotionality, the dual task was potentially too easy to significantly influence participants' implicit affect. Future studies should consider using more demanding paradigms to examine the effects of task difficulty on affect and the positivity effect.

Overall, the finding that individual differences in HRV can predict the magnitude of the age-related positivity effect could have important implications for older adults' health and wellbeing. Over the years, studies have found lifestyle factors, including exercise and dietary changes, to prominently affect HRV indices (Kemp & Quintana, 2013). Recently, researchers have suggested a bidirectional relationship between HRV and cognition and emotion, such that HRV is not simply a marker of processing capabilities, but also a factor that influences the efficiency of cognitive control and emotion processing mechanisms by inducing corresponding neural oscillations (Mather & Thayer, 2018). This could mean that any lifestyle changes aiming to increase cardiovascular fitness could not only improve overall health, but also increase older adults' capacity to inhibit negative emotionality and, potentially, improve their mental and psychological wellbeing. Building upon previous work proposing that individual differences in older adults' cognitive control capabilities might be the determining factor behind older adults' positivity preference (Mather & Knight, 2005), our results extend such findings and suggest that cardiovascular fitness and overall functionality of the ANS could be a crucial factor of older adults' cognitive control capacity and their ability to downregulate negativity when faced with emotional information. Researchers interested in further exploring emotion-cognition interaction in aging should adopt a more integrated approach that includes the evaluation of the synergistic effects of cognitive, emotional and physiological factors.

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Footnotes

[1]During practice, participants also consumed an orange drink that contained either glucose or an artificial sweetener. Drink type had no appreciable influence on the results and will not be considered here.

[2]The HRV-gaze preference relationship did not change substantially after controlling for implicit affect.

Table and Figure Legends

Table 1. Characteristics of the Sample, Cardiovascular Indices at Baseline, and Performance on the IPANAT and the Secondary Task, With Results of Comparisons (T-Tests) Between Age Groups

Figure 1. Fixation count ratio score (mean ± 1 standard error of the mean) during emotional-neutral face pair presentation as a function of age (young, older) emotion (happy, angry) and task (single, dual). Zero signifies no preference, and a positive/negative ratio score shows preference toward/away from the emotional face. Asterisks indicate ratio scores significantly different from zero on *t*-tests; all *p*s < .001.

Figure 2. Association between resting HRV (Ln RMSSD) and young and older adults' fixation count ratio during presentation of happy-neutral (left panels) and angry-neutral (right panels) face pairs under single-task (top panels) and dual-task (bottom panels) conditions.

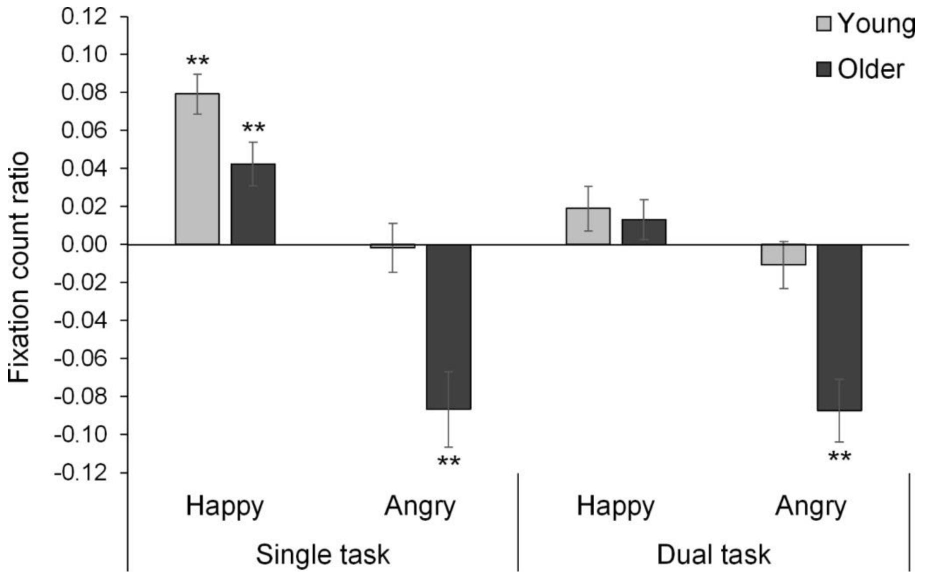
Table 1

Characteristics of the Sample, Cardiovascular Indices at Baseline, and Performance on the IPANAT and the Secondary Task, With Results of Comparisons (T-Tests) Between Age Groups

	Young	Older	*p* value
Characteristics			
N (M/F)[1]	63 (15/48)	62 (22/40)	-
Age	18.83 (1.04)	71.61 (3.66)	-
Years of education	12.89 (0.41)	16.18 (2.49)	< .001
DSST[2]	68.86 (9.79)	54.95 (10.20)	< .001
MHVT[3]	15.75 (3.67)	24.03 (3.68)	< .001
Baseline cardiovascular indices[4]			
Heart rate (bpm)	80.77 (12.46)	68.22 (9.73)	< .001
Ln RMSSD	3.54 (0.55)	2.74 (0.58)	< .001
Ln HF-HRV	6.43 (1.13)	4.28 (1.10)	< .001
IPANAT scores[5]			
Single task	0.65 (2.20)	1.20 (2.17)	.156
Dual task	0.37 (2.00)	1.18 (2.42)	.044
Secondary task			
Response time (ms)	1061.12 (128.19)	1249.18 (127.36)	< .001
Error rates (%)	1.51 (3.26)	2.27 (3.82)	.238

Note. All values except for N (M/F) are given as means (with standard deviations).

[1]Number of participants in each age group (males/females). [2]Digit Symbol Substitution Test (Wechsler, 1981). [3]Mill Hill Vocabulary Task (Raven, Raven, & Court, 1988). [4]Heart rate and HRV values were available for 62 young and 55 older adults. [5]Composite scores in the IPANAT ranging from -9 for very negative to +9 for very positive.



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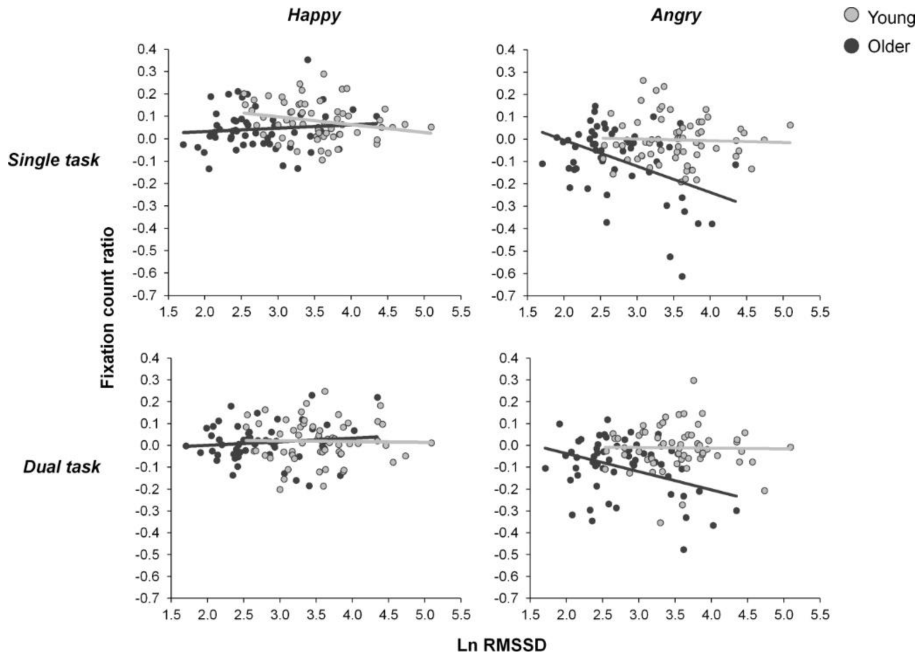

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