International Journal of Psychophysiology 109 (2016) 51–62

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Autonomic nervous system reactivity within the valence–arousal affective space: Modulation by sex and age☆,☆☆

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ARTICLE INFO

Article history:
Received 19 May 2016
Received in revised form 2 October 2016
Accepted 3 October 2016
Available online 6 October 2016

Keywords:
Age differences
Cardiovascular reactivity
Emotion
Pupillary response
Sex differences
Skin conductance level

ABSTRACT

In the present study, we examined how sex and age shape cardiovascular, electrodermal, and pupillary reactivity to picture series within the valence–arousal affective space in a sample of 176 healthy younger, middle-aged, and older men and women. Across participants, heart rate (HR) decelerated with increasing self-reported unpleasantness, whereas skin conductance level (SCL) and pupil size (PS) increased with increasing self-rated arousal. Systolic (SBP) and diastolic (DBP) blood pressure increased with increasing self-rated arousal when valence was pleasant but much less when valence was unpleasant. Compared to women, men exhibited a stronger correlation between valence and HR and an SBP response characterized by larger increases for pleasant high-arousal states and lower change scores for unpleasant low- and high-arousal and pleasant low-arousal states. Men's largest SCL change scores were for pleasant high-arousal states, whereas women's largest SCL change scores were for unpleasant high-arousal states. The arousal–PS relationship was stronger among women, in particular for unpleasant series. From younger to older age, there were decreases in the strength of the valence–HR, arousal–SCL, and arousal–PS relationships. Older adults had larger overall increases in SBP and DBP than younger adults, but the relationships with self-reported valence and arousal were not age dependent. We discuss how the observed sex and age effects may reflect sex and age differences in emotional processing and in basic autonomic nervous system functioning.

1. Introduction

At the level of subjective experience, valence summarizes how well one is feeling and ranges from pleasant/good to unpleasant/bad, whereas arousal refers to a sense of mobilization or energy and ranges from very calm/sleepy to very aroused/excited (Russell and Barrett, 1999). These two dimensions are supposed to define the engagement of two evolutionarily primitive motivational systems, an appetitive one associated with positive valence and approach motivation toward resources and a defensive one associated with negative valence and aversive motivation toward threats. Arousal describes the vigor of motivational activation (Lang and Bradley, 2010). With this model of emotion as the guiding theoretical framework, we aimed at investigating the reactivity of heart rate (HR), systolic and diastolic blood pressure (SBP, DBP), skin conductance level (SCL), and pupil size (PS) to series of affective pictures in healthy adults. Empirical evidence regarding response coherence among experiential and physiological response systems in emotion is mixed (Evers et al., 2014), and how this coherence is affected by individual factors is poorly understood, despite the importance of individual differences in emotion has been highlighted (Hamann and Canli, 2004). Therefore, we focused here on how these measures regulated by the autonomic nervous system (ANS) covary with self-reported valence and arousal and how sex and age modulate these relationships.

Reactions of most healthy individuals to appetitive (e.g., appetizing food, attractive nudes) and aversive (e.g., attacking humans, blood) pictures are supposed to index the early stage of approach and defense characterized primarily by orienting, attentive processing, and preparation for potential action (Lang and Bradley, 2010). ANS responses vary as a function of the valence and arousal level of affective pictures. HR deceleration, mediated primarily by increases in vagal tone (Campbell et al., 1997), is generally greater when viewing unpleasant, compared to either pleasant or neutral pictures and correlates positively with self-rated unpleasantness (Burriss et al., 2007; Gomez and Danuser, 2010; Greenwald et al., 1989; Lang et al., 1993). Blood pressure (BP) increases with increasing self-rated arousal (Gomez and Danuser, 2010) but may also depend on valence, showing larger increases in response to pleasant as opposed to unpleasant arousing material (Hempel et al., 2005; Hempel et al., 2007; Richter et al., 2011; Sarlo et al., 2005). Skin conductance, which depends on the activity of the sympathetically innervated

☆ This research was supported by a grant of the Opo Stiftung (Zurich, Switzerland) to Patrick Gomez and Brigitta Danuser.
☆☆ We thank Miryam Cornaz, Olivier Fortini, and Bérengère Philippon for their assistance in data collection, and Dimitra Philippou for helping with data reduction.
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http://dx.doi.org/10.1016/j.ijpsycho.2016.10.002
0167-8760/

eccrine glands, has been shown to correlate positively with self-reported arousal (Burriss et al., 2007; Gomez and Danuser, 2010; Gomez et al., 2004; Greenwald et al., 1989; Hempel et al., 2007; Lang et al., 1993; Neiss et al., 2009; Sanchez-Navarro et al., 2005). PS depends on the activity of the dilator and sphincter muscles of the iris, which are innervated by the sympathetic (SNS) and parasympathetic nervous system (PNS) branches, respectively. Most studies point to a positive correlation between PS and arousal (Bradley et al., 2008; Bradley et al., 2015; Bradley and Lang, 2015; Dietz et al., 2011; Henderson et al., 2014; Jin et al., 2015; Lemaire et al., 2014; but see Franzen et al., 2009), but the relationship between PS and self-rated valence and arousal remains to be explicitly tested.

Sex differences in emotion have been investigated and discussed from different points of view (e.g., biological, socio-cultural, evolutionary, Bradley et al., 2001b; Fischer, 2000; Rupp and Wallen, 2008; Troisi, 2001; Wood and Eagly, 2002). Women may show a stronger disposition to engage the defensive motivational system when exposed to aversive cues than men, whereas men may show a stronger disposition to engage the appetitive motivational system when exposed to appetitive material (Andreano et al., 2014; Bradley et al., 2001b; Gard and Kring, 2007; Grossman and Wood, 1993; Hamann et al., 2004; Hillman et al., 2004; Rupp and Wallen, 2008; Sabatinelli et al., 2004; Stevens and Hamann, 2012). However, this evidence is based primarily on studies with young adults, and whether sex differences in emotional reactivity observed among young adults persist, attenuate, or increase in later life is unclear (Burriss et al., 2007; Denburg et al., 2003; Gavazzeni et al., 2008; Kunzmann and Grühn, 2005; Labouvie-Vief et al., 2003; Neiss et al., 2009; Seider et al., 2011).

Normal aging is associated with widespread biological changes, including changes of the ANS (Barnett et al., 1999; Matsukawa et al., 1996; Winn et al., 1994) that are likely to substantially influence neurophysiological responses of older adults to affective stimuli. However, age differences in patterns of neurophysiological activity may also reflect age-related changes in emotional processing. The amygdala activity to unpleasant vs. pleasant pictures is reduced in older adults compared to younger adults, whereas unpleasant pictures induce greater prefrontal cortex activity compared with neutral stimuli in older individuals than in younger ones (Dolcos et al., 2014; Leclerc and Kensinger, 2011; Mather et al., 2004; Nashiro et al., 2012). These patterns of neural activity are consistent with an age-related positivity effect, i.e., an age-related increase in the preference for pleasant over unpleasant information in attention and memory (Reed et al., 2014).

It is unclear whether age differences in peripheral physiological reactivity consistent with an age-related positivity effect are also observed, and, more generally, whether late adulthood is associated with more, less, or similar activation of the appetitive and defensive systems than early adulthood. Compared to younger adults, older adults have been found to exhibit both blunted (e.g., Burriss et al., 2007; Smith et al., 2005; Tsai et al., 2000), augmented (e.g., Kunzmann and Grühn, 2005; Seider et al., 2011; Smith et al., 2005), and similar (e.g., Kunzmann et al., 2005; Kunzmann and Richter, 2009; Overbeek et al., 2012) physiological reactivity to affective challenges. A number of factors – including the specific emotional contexts or measures and whether or not age-associated differences in response magnitude or pattern are considered – may explain these differences (Levenson, 2000).

The goal of the present study was to investigate the relationships between self-rated valence and arousal and HR, SBP, DBP, SCL, and PS and how these relationships are influenced by sex and age. Across subjects, we predicted HR deceleration to increase with increasing unpleasantness, and SBP, DBP, SCL, and PS changes to increase along the arousal dimension. We were uncertain as to whether SBP and DBP could be influenced by self-reported valence because of the mixed nature of the existing literature. Regarding sex effects, the primary question was whether there are sex differences in the relationship between self-rated affect and ANS activation consistent with the hypothesis that women respond with greater defensive reactivity to unpleasant arousing contents, and men respond with increased appetitive activation to pleasant arousing contents from early to late adulthood. Concerning age effects, our main question was whether advancing age is associated with a shift in appetitive activation relative to defensive activation in line with an age-related positivity effect. Because normal aging is accompanied by functional and anatomical changes of the ANS, we predicted that there would be significant age effects for all five physiological parameters. However, given mixed findings, we wondered whether the age-group effect would concern the overall response magnitude (defined as the overall increase or decrease from baseline) and/or the response pattern within the valence–arousal affective space (defined as the relationship between self-reported affective ratings and ANS responses). Whether age effects would be different in magnitude and pattern for different ANS indices was treated as an exploratory issue.

2. Methods

2.1. Participants

Participants were 75 men and 101 women belonging to three age-groups: younger (ages 20–34 years), middle-aged (ages 40–54 years), and older (ages 60–74 years). Studies of aging and emotion often compare young adults with an older sample. With the inclusion of a middle-aged sample, nonlinear age effects can be explored. Other sample characteristics are presented in Table 1. Three additional participants completed the study protocol, but their data were unusable due to procedural flaws. The study was approved by the local ethics committee.

A screening questionnaire was used to include only respondents who (i) were proficient in French; (ii) had scores lower than 11 on the anxiety and depression scales of the Hospital Anxiety Depression Scale (Zigmond and Snaith, 1983, 14 items, example items "I get sudden feelings of panic," "I still enjoy the things I used to enjoy," Anxiety and Depression scale min = 0, max = 21; this was done to avoid the experience of excessive emotional distress among vulnerable people); (iii) reported at least "satisfactory" current general health on a 5-point scale ranging from "very good" to "very bad"; (iv) were not pregnant or breastfeeding; (v) did not use recreational/illicit drugs; (vi) had normal or corrected-to-normal vision and did not suffer from color blindness; (vii) did not have a cardiac pacemaker; and (viii) were not currently under medical treatment for any psychiatric disorder.

The participants were well-functioning individuals as shown by several indices given in Table 1. Anxiety and depression scores were very low. Mental health, physical functioning, and general health perception were better than average scores of the general local population (Richard et al., 2000). Participants' mean scores of verbal fluency were above average compared to normative data (Tombaugh et al., 1999).

2.2. Stimuli

Stimuli were 84 pictures chosen from the International Affective Picture System (IAPS; Lang et al., 2005). They were arranged into 14 series each consisting of 6 different pictures. The series represented different thematic contents. Six series were expected to be pleasant, six unpleasant, and two neutral. Moreover, the six pleasant and the six unpleasant series were expected to vary in arousal from relatively low to high. The six pleasant contents were appetizing food, erotic heterosexual couples, pleasant family scenes, pleasant nature, romantic heterosexual couples, and sport scenes. The unpleasant contents included environmental contamination, human loss, mutilated/burned bodies, physical violence, sick/injured human beings, and suffering/dead animals. The two neutral series showed household objects and neutral human activities. All pictures were landscape in orientation. Using Adobe Photoshop, mean brightness of nine pictures was modified such that mean brightness across picture series was very similar. Brightness was defined as the