Chapter 21
Age-Related Changes in Physiological Reactivity to a Stress Task: A Near-Infrared Spectroscopy Study

A. Brugnera, C. Zarbo, R. Adorni, A. Gatti, A. Compare, and K. Sakatani

Abstract Aging is associated with changes in biological functions, such as reduced cardiovascular responses to stressful tasks. However, less is known about the influence of age on the reactivity of the prefrontal cortex (PFC) to acute stressors. Therefore, this study aimed to investigate the effects of a computerized-controlled stress task on the PFC and autonomic system activity in a sample of older and younger adults. We recruited a total of 55 healthy, right-handed persons (26 older adults with mean age 69.5, SD 5.8 years; and 29 younger adults with mean age 23.8, SD 3.3 years); groups were balanced for sex. Tasks included a control and an experimental condition: during both tasks individuals had to solve simple mental arithmetic problems. For the experimental condition, all participants were faced with a time limit that induced significant stress. Physiological indexes were collected continuously during the entire procedure using a 2-channel near infrared spectroscopy (NIRS) and an ECG monitoring system. Repeated measures ANOVA were used to assess changes in hemoglobin concentrations, and changes in both heart rate and performance outcomes. NIRS, ECG and performance data showed a significant interaction between the group and condition. Post-hoc analyses evidenced a significant increase in heart rate and Oxy-Hb concentration in the bilateral PFC between the control and experimental condition only in the younger group. Post-hoc analyses of behavioral data showed lower percentages of correct responses and higher response times in the older group. In summary, these results suggested that cardiovascular and cortical reactivity to stress tasks are a function of age. Older individuals seem to be characterized by blunted physiological reactivity, suggestive of

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impaired adaptive responses to acute stressors. Therefore, future studies should investigate the underlying physiological mechanisms of prefrontal and cardiovascular changes related to aging.

Keywords Older adults • Younger adults • NIRS • HR • Reactivity

1 Introduction

Aging, or the age-progressive decline in intrinsic physiological function [1], is associated with cognitive impairments as well as functional alterations of the cardiovascular system [2] and prefrontal cortex (PFC) [3]. Literature on elderly suggests that cardiac stress responses may also be impaired [2], while little is known about prefrontal reactivity to stressful tasks.

Regarding the cardiovascular system, aging leads to a reduced reactivity to stressful tasks due to a lowered maximal heart rate (HR) [2, 4]. As suggested by Uchino et al. [2], the lowered maximal HR is probably caused by a decline and compensatory processes in the aging myocardium, such as a decrease in the concentration/sensitivity of myocardial β-adrenergic receptors.

However, to date no studies have investigated prefrontal reactivity to stress in older adults. Indeed, much literature on the aging population has focused on age-related cerebral activity during cognitive tasks, finding a general cognitive decline and an impairment of executive functions [3]. These studies evidenced hypo- or hyper-activation of the PFC during cognitive tasks in older persons compared with younger adults [3, 5]. Specifically, the hyper-activity hypothesis suggests that the aging brain compensates for cognitive decline by hyper-recruiting the frontal cortex or distributing information processing among different areas [3].

Moreover, the cognitive performance of tasks which require information processing is also a function of age [3]. Due to the above-mentioned functional changes at the level of the PFC, older persons are characterized by impaired behavioral responses compared with younger adults [3]. In particular, they show delayed reaction times and a higher number of errors during cognitive tasks.

Therefore, this study aimed to investigate psychophysiological reactivity and behavioral performance during a stress task in a sample of younger and older adults using a 2-channel near infrared spectroscopy (NIRS) and an ECG monitoring system. We tested the hypotheses that during stress response: (i) prefrontal activity would be a function of age, even if we did not specify an a priori direction of the effect due to the lack of literature; (ii) cardiovascular reactivity would be reduced in older compared to younger adults, as suggested in the meta-analysis of Uchino et al. [2]; and (iii) behavioral responses (response times and percentage of correct responses) would be reduced in older compared to younger adults, as shown in earlier studies [3, 4].

2 Methods

A total of 55 healthy, right-handed persons (26 older persons with mean age 69.5, SD 5.8 years; and 29 young adults with mean age 23.8, SD 3.3 years) was recruited for this study. None of the participants was affected by neurological or psychiatric illnesses as assessed by means of a semi-structured interview.

The study was conducted in accordance with the American Psychological Association (1992) ethical standards for the treatment of human experimental volunteers; each participant provided written consent in compliance with the Declaration of Helsinki (BMJ, 1991; 302, 1194).

Participants were seated in a comfortable chair, in a silent room. During psychophysiological recording, they were instructed to avoid any movement of the body and to minimize those of the head. A 5-min rest period (baseline) was followed by completion of a randomized controlled stress task (Montreal Imaging Stress Task, MIST], designed to evoke stress responses in the subjects. After a 2-min training phase, participants were randomized to start with a 5-min control condition or with a 5-min experimental (i.e. stressful) condition. During both tasks, individuals had to solve mental arithmetic problems. In the case of the experimental condition, participants were faced with a time limit that induced significant stress. All participants completed both conditions. Details on the procedure can be found in [6]. Behavioral data of two individuals were not available due to recording problems.

We used a portable Bluetooth® CW-NIRS system (PocketNIRS Duo, DynaSense, Japan) to measure changes in concentration of Oxy-Hb, deOxy-Hb, and total-Hb in the PFC. This system uses light emitting diodes of three different wave-lengths (735, 810, and 850 nm) as light sources and one photo-diode as a detector, and has two channels (one left and one right). The sampling rate was set to 10.2 Hz. The changes in concentration of hemoglobin are expressed in arbitrary units (a.u.). Optodes were fixed to the person's forehead using adhesive patches. The NIRS setup replicated the one adopted by Tanida et al. [7]. this positioning is similar to the midpoint between electrode positions Fp1/Fp3 (left) and Fp2/F4 (right) of the international electroencephalographic 10–20 system [7], with the emitters-detectors located over the dorsolateral and frontopolar areas of the PFC. The signal was post-processed using a freely available MATLAB toolbox (N.A.P., NIRS Analysis Package).

For the autonomic measurements, we used the Pulse Sensor, a wearable Bluetooth® device produced by STMicroelectronics and manufactured by MR&D (Italy). This sensor continuously monitors heart activity. The device was positioned on the person's chest using an adhesive patch or an elastic band. Data were processed using a freely available MATLAB toolbox (Kubios HRV). For the present study, only HR was analyzed. HR data of four individuals were not available due to recording problems. The ECG of each person was visually inspected in order to correct missing beats and artifacts.

Differences in demographic variables were assessed using Fisher exact test (frequencies) or independent sample t-tests. For the latter analyses, independent variable was the group (Young and Elderly), while the dependent variables were age or years of education. For each task condition, we analyzed changes in hemoglobin concentration and HR in terms of differences from the mean baseline values. Mean Δ Oxy-, deOxy and total-Hb, mean ΔHR values and behavioral data (response times, percentage of correct responses) were subjected to repeated measures ANOVAs. For ΔOxy-Hb, the factors were the group (Young and Elderly), the condition (Control and Experimental) and the channel (Left and Right). For ΔHR and behavioral data, factors were the Group and the Condition. Post-hoc analyses were performed using Tukey's test. A p-value ≤ 0.05 was considered significant. All analyses were performed with SPSS 23.0 (IBM, USA) and STATISTICA 12.5 (StatSoft Inc., USA).

3 Results

Preliminary data analyses showed that all variables were normally distributed.

Analyses on demographic data were reported in Table 21.1. As evidenced, the two groups were balanced for sex, and were significantly different as regards age. Finally, mean years of education were significantly different between younger and older adults: all the younger participants were university students or attended at least high school, while most of the older ones attended only elementary or middle school. Educational differences between study samples were in line with the census data reported by Italian National Institute of Statistics (ISTAT), suggesting the absence of a selection bias.

ANOVA performed on ΔOxy-Hb showed an effect of the Condition ($F_{1,53} = 6.43$; $p = 0.01$. Control: $M = 0.0024$ a.u., $SE = 0.0005$; Experimental: $M = 0.003$, $SE = 0.005$). Results suggest an increased bilateral PFC activity between the control and experimental condition, regardless the group. ANOVA also showed a significant interaction between Condition*Group ($F_{1,53} = 4.82$; $p = 0.03$). Post-hoc analyses showed that only younger adults had a significant increase in ΔOxy-Hb values between the control and experimental condition ($p = 0.0060$). Means and SE are reported in Fig. 21.1 (left panel). All other effects and interactions were non-significant. Analyses performed on ΔdeOxy-Hb showed an effect of the Condition ($F_{1,53} = 8.14$; $p < 0.01$. Control: $M = -0.0094$ a.u., $SE = 0.0036$; Experimental: $M = 0.014$ a.u., $SE = 0.037$). Results suggest a decrease in deOxy-Hb concentration

Table 21.1 Frequencies, means (SD) and their respective *t*-values of demographic variables by groups

	Younger adults (N = 29)	Older adults (N = 26)	*t*-value	*p* value
Males (percentage)	13 (55.2)	15 (57.7)	/	*ns*
Age (SD)	23.8 (3.31)	69.5 (5.78)	−36.5	< 0.001
Years of education (SD)	15.4 (2.23)	8.73 (3.78)	8.05	< 0.001

ns non-significant

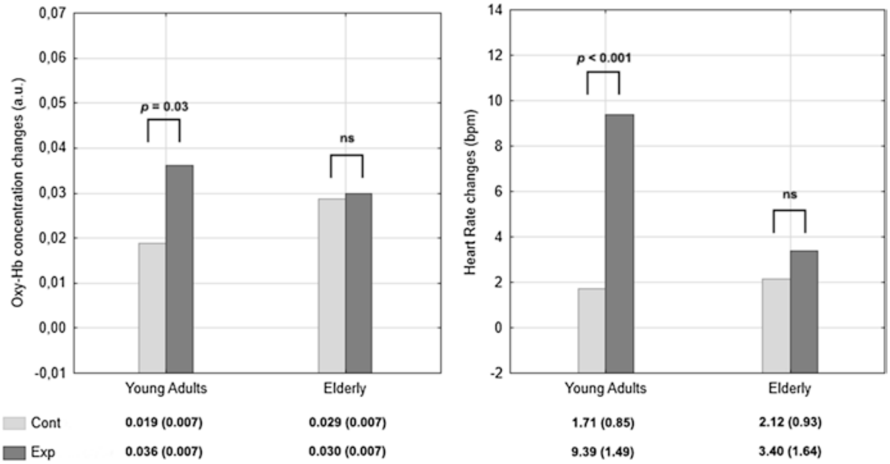

Fig. 21.1 *Left*, changes in Oxy-Hb from baseline (expressed in arbitrary units; a.u.) during the procedure in both groups. *Right*, changes in heart rate from baseline (expressed in beats per minute, BPM) during the procedure in both groups. Means and SE are reported below each group

changes from Control to Experimental condition, regardless the group. All other effects and interactions were non-significant. Finally, the ANOVA performed on total-Hb led to non-significant effects and interactions.

ANOVA performed on ΔHR showed an effect of the Condition ($F_{1,49} = 21.42$; $p < 0.001$. Control: M = 1.92 beats per minute, SE = 0.63; Experimental: M = 6.4, SE = 1.11). Results indicate that the procedure led to an increase in HR between the control and experimental condition. ANOVA also showed a significant interaction between Condition*Group ($F_{1,49} = 10.9$; $p > 0.001$). Post-hoc analyses showed that only the younger adults had a significant increase in ΔHR between the control and experimental condition ($p < 0.001$). Moreover, post-hoc analyses showed that the mean ΔHR of younger adults during the experimental condition was significantly different from the ΔHR of older adults during both conditions ($p < 0.001$). All means and SE are reported in Fig. 21.1 (right panel).

ANOVA performed on Response Times showed an effect of Group ($F_{1,51} = 31.7$; $p < 0.001$. Younger adults: M = 2.97, SE = 0.26 s; Older adults: M = 5.15, SE = 0.28 s) and an effect of Condition ($F_{1,51} = 59.9$; $p < 0.001$. Control: M = 4.8, SE = 0.28; Experimental: M = 3.33, SE = 0.11). The interaction between Group*Condition was also significant ($F_{1,51} = 8.5$; $p = 0.005$). Post-hoc analyses showed that all comparisons were significantly different (all $p < 0.001$), except for the Response Time of younger adults during the control condition compared with the Response Time of older adults during the experimental condition. Finally, ANOVA performed on the percentage of correct responses showed an effect of Condition ($F_{1,51} = 1720$; $p < 0.001$. Control: M = 93.8%, SE = 0.08%; Experimental: M = 52.1%, SE = 0.5%). The interaction between Group*Condition was also significant ($F_{1,51} = 7.46$; $p = 0.008$). Post-hoc analyses showed that all comparisons were significantly different (all p-values <0.05), except for the percentage of correct responses between younger and older adults during the experimental condition.

4 Discussion

In summary, our results suggest that cardiovascular and cortical reactivity to stress tasks are a function of age. Indeed, when compared to younger adults, older individuals seem to be characterized by a blunted cortical and cardiovascular reactivity to a stressful psychosocial task and by behavioral impairments.

Regarding the cortical responses, results showed a bilateral increase in ΔOxy-Hb and a decrease in ΔdeOxy-Hb between the control and experimental condition, irrespective of the group. Therefore, during the experimental condition, participants recruited more cognitive resources in order to solve the mathematical tasks when faced with a time limit. Figure 21.1 shows that, during the control condition, PFC activity in older adults was greater than that of younger adults, even though the difference was not significant. These results are suggestive of PFC hyper-recruitment [3] in older adults when faced with a simple mathematical task. Interestingly, only younger adults experienced a significant bilateral increase in PFC activity between the control and experimental condition. Compared with younger adults, levels of oxygenated hemoglobin in the older adults remained almost identical during the entire procedure. Therefore, our results show reduced cortical reactivity to stress tasks in older adults compared with younger adults. It is worth noticing that the between-group differences in NIRS data were observed only with Oxy-Hb concentration changes.

Regarding cardiological responses, our results confirm previous reports [8]. Indeed, the experimental (i.e. stressful) condition was characterized by increased HR irrespective of the group. However, Fig. 21.1 shows that only younger adults experienced a strong cardiovascular reactivity between the control and experimental (i.e. stressful) condition. Uchino et al. [2] hypothesized that aging leads to a specific decline and compensatory process in the myocardium that, in turn, reduces maximal heart rates.

Finally, during the control condition, compared to younger adults, the response times and percentage of correct responses of older adults were higher and lower, respectively. These results are similar to those reported by others [3]. Older adults seem to suffer from a generalized delay in reaction time and have less attentional resources, due to functional changes in prefrontal activity [3]. Nevertheless, it should be noted that these findings could be (in part) due to the less familiarity of older persons with the use of a PC compared with younger adults. Moreover, the lower educational level among elderly could have potentially influenced our results.

In conclusion, although it is well known that behavioral and cardiac responses are blunted in older adults [2, 3], this is the first NIRS study to investigate cortical reactivity to stressful tasks in older versus younger adults. In these study samples, we found evidence of reduced cortical and cardiovascular reactivity, as well as decreased behavioral performances. However, additional studies are required to confirm these explorative findings and to expand knowledge in this field.

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