ELSEVIER

Biological Psychology 52 (2000) 127–141

BIOLOGICAL PSYCHOLOGY

www.elsevier.com/locate/biopsycho

Secretory immunoglobulin A and cardiovascular activity during mental arithmetic: effects of task difficulty and task order

Gonneke Willemsen, Christopher Ring *, Sam McKeever, Douglas Carroll

School of Sport and Exercise Sciences, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK

Received 24 March 1999; received in revised form 15 July 1999; accepted 28 July 1999

Abstract

Secretory immunoglobulin A (sIgA) in saliva and cardiovascular activity were measured at rest and during mental arithmetic. Task difficulty was manipulated by presenting easy, hard, and impossible versions of the mental arithmetic task in counterbalanced order, while task novelty was operationalised as order of presentation (i.e. first, second, third). Mental arithmetic elicited significant increases in sIgA concentration and sIgA secretion rate, as well as significant cardiovascular effects. Performance decreased and rated difficulty increased with increasing task difficulty. However, sIgA and cardiovascular activity, with the exception of diastolic blood pressure, were insensitive to variations in task difficulty. In contrast, sIgA concentration and a broad range of cardiovascular variables were influenced by task novelty, with more pronounced activity characterising the task version presented first, irrespective of its level of difficulty. Task novelty would seem to be a more important determinant of sIgA and cardiovascular activity than task difficulty. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Cardiovascular activity; Mental arithmetic; Secretory immunoglobulin A; Task difficulty; Task novelty

* Corresponding author.
E-mail address: c.m.ring@bham.ac.uk (C. Ring)

PII: S0301-0511(99)00028-9

1. Introduction

Secretory immunoglobulin A (sIgA) is the predominant immunoglobulin in saliva (Hood et al., 1978), and has been shown to prevent contact of antigens and pathogens with epithelial surfaces (Kraehenbuhl and Neutra, 1992). Increases in sIgA concentration and/or secretion rate have been consistently found following exposure to acute naturalistic stressors. For instance, sIgA was elevated in air traffic controllers following a work shift (Zeier et al., 1996), football coaches during a match (Kugler et al., 1996), and students following an assessed oral presentation (Evans et al., 1994; Bristow et al., 1997) or formal examination (McClelland et al., 1985). More recently, increases in sIgA concentration and/or secretion rate have been reported in response to acute laboratory stress tests, such as computer games and mental arithmetic (Carroll et al., 1996; Willemsen et al., 1998; Ring et al., 1999).

A serendipitous finding reported by Carroll et al. (1996) was that the increase in sIgA secretion rate to a computer game occurred only in individuals with no previous experience of the game. These first time players also displayed greater pressor reactions to the computer game than experienced players, suggesting sympathetic nervous system activation. One possible explanation for these effects is that the task was more difficult for first time players than for those who had played before. Although, as yet, there are no published psychoneuroimmunological studies that have formally manipulated task difficulty, the effect of task difficulty on cardiovascular responses has been the focus of a number of studies (e.g. Light and Obrist, 1983; Carroll et al., 1986a,b; Smith et al., 1990; Wright et al., 1992). While there are exceptions, these studies generally found that hard tasks provoked greater cardiovascular activity than easy and/or impossible tasks.

Another possible explanation for the results of Carroll et al. (1996) is task novelty, since the task was novel for first time players. Studies of the effects of task novelty on cardiovascular activity indicate that the first task exposure provokes the greatest cardiovascular reaction, after which habituation occurs and the response diminishes with subsequent exposures to the same challenge (e.g. Frankenhaeuser et al., 1962; Linden, 1991; Kelsey et al., 1999). At present, there are no published psychoneuroimmunological studies explicitly examining the effects of task novelty. However, given the association between cortisol and secretory immunoglobulin A (Hucklebridge et al., 1998), it is worth noting that cortisol responded more during the first presentation of an acute stressor than during subsequent presentations, although some individuals showed no habituation (Kirschbaum et al., 1995). This suggests that task novelty might also impact on psychoneuroimmunological functioning.

The current study examined the effects of both task difficulty and task novelty on sIgA. In addition, blood pressure, heart rate, and impedance cardiographic variables were measured. Cardiovascular activity was monitored for two reasons: first, to study further cardiovascular responses to task difficulty and task novelty; second, since different patterns of cardiovascular adjustment are indicative of different sorts of underlying autonomic activation (Cacioppo, 1994), and, accord-

ingly, should shed light on the autonomic mechanisms underlying acute changes in sIgA. The latter presumes that indices of cardiovascular autonomic function can be used as proxies for sympathetic and parasympathetic influences on salivary function. However, it should be acknowledged that the neuroanatomical organisation of the heart and salivary glands is different. Nevertheless, it is reasonable to presume that changes in cardiovascular and salivary function reflect generalised sympathetic and parasympathetic activation (Cannon, 1915; Stern and Sison, 1990).

Task difficulty was manipulated by presenting easy, hard, and impossible versions of a mental arithmetic task in counterbalanced order, while task novelty was operationalised as the order of task presentation (i.e. first, second, third). It was hypothesised that the hard version would be more provocative than the easy and impossible versions of the task. It was also hypothesised that the first exposure would be more provocative than subsequent exposures.

2. Method

2.1. Participants

Twenty-seven students volunteered for the study. All participants were men and non-smokers. Their average age was 21.00 (SD = 2.02) years, average weight was 76.00 (SD = 9.41) kg, and average height was 1.79 (SD = 0.08) m. At the day of testing none of the participants reported symptoms of upper respiratory tract infection. Participants were asked to refrain from consuming drinks containing caffeine 1 h prior to testing, and from physical exercise and drinking alcohol from the evening prior to testing. Participants were excluded when suffering from pulmonary, cardiovascular or immune disease, or had been taking prescribed medication during the 7 days up to testing. No payment was made but participants entered a prize draw for two £25 book tokens.

2.2. Cardiovascular measurements

A Dinamap vital signs monitor 1846 (Critikon) was used to obtain systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP). The blood pressure cuff was attached to the non-dominant arm and measurements were initiated manually. Cardiac activity was measured continuously throughout the session using electrocardiography (Morgan 509 cardiac monitor) and impedance cardiography (Minnesota impedance cardiograph, Model 304B). To record the impedance signal, four circumferential mylar band electrodes (Instrumentation for Medicine) were placed around the chest and neck. The recording electrodes were placed on the surface around the base of the neck and around the thorax at the level of the xiphisternal junction. The current electrodes were placed parallel to the recording electrodes, 4 cm above and below the upper and lower bands, respectively. The distance between the recording electrodes was measured at the front and back and the average was used in the calculation of stroke volume. In addition,

three spot electrodes (3M Health Care) were placed in a modified chest configuration (Sherwood et al., 1992) to record the electrocardiogram.

Using an interactive scoring program (Kelsey and Guethlein, 1990), 1 min ensemble averages were calculated for the cardiac signals. For each of the ensemble averages, heart rate (HR) and pre-ejection period (PEP) were determined and, using the Kubicek et al. (1974) formula, stroke volume (SV) was calculated. Cardiac output (CO) was calculated as the product of HR and SV and TPR was obtained using the formula: $TPR = MAP/CO \times 80$.

2.3. Secretory immunoglobulin A (sIgA) measurements

To determine saliva volume and sIgA concentration, unstimulated saliva samples were obtained using salivettes (Sarstedt Ltd.). The participant swallowed once to dry his mouth, before placing a cotton wool swab underneath his tongue for 2 min. The sample was then placed in a salivette tube, which was sealed and frozen at -20°C for later analysis. After thawing, saliva was extracted from the cotton by centrifugation at 5×10^3 rpm for 5 min and, for each sample, saliva volume (ml/min) was obtained by weighing the amount extracted. Using a double-antibody enzyme-linked immunosorbent assay (ELISA), sIgA concentration (μg/ml) was determined. Saliva aliquots (100 μl) were assayed at a dilution of 1:1000. The coating antibody was anti-human IgA (Sigma I9506) at a dilution of 1:800. Quadruplicate assays were undertaken against a range of standards (Human IgA Sigma I-2636), 0–400 μg/ml. All samples from a subject were analysed on a single plate. The final layer consisted of a peroxidase conjugated anti-human IgA (Sigma A-4165) and the substrate ABTS (Boehringer Mannheim, tablets: 1 112 422, buffer 1 112 597). A coefficient of variation of less than 10% between quadruplicate repeats, and a standard correlation coefficient greater than 0.98 were the assay acceptance criteria. The sIgA secretion rate (μg/min) was calculated from the formula: secretion rate = (concentration × volume)/2.

2.4. Mental arithmetic task

The mental arithmetic task used was the paced auditory serial addition test (PASAT) as adapted by Willemsen et al. (1998). Participants were presented with a series of numbers and were required to add every number to the previously presented number. Numbers were presented by tape player and participants had to say the answers out loud. Task difficulty was manipulated by altering the range of the numbers presented; the easy version included only the numbers zero and one, the difficult version consisted of the numbers one to nine, and the impossible version the numbers 10–99. The presentation rate of the numbers was one number every 2.0 s, and each task lasted 8 min. Each version of the task comprised 240 numbers, resulting in 239 trials.

2.5. Procedure

On arrival at the laboratory, participants had the procedure explained and the electrodes and blood pressure cuff were attached. Participants then undertook the three versions of the task, each version preceded by a period of 8 min baseline rest. The order of presentation of the task versions was counterbalanced across participants. During each rest period a BP reading was initiated at the start and after 2.5 and 5 min, and a saliva sample was obtained during min 7 and 8. During each task a BP reading was initiated after 1, 4, and 7 min, and a saliva sample was obtained immediately on completion of the task. Following the saliva sample, participants rated how well they performed (1 = not at all well, 7 = extremely well), how difficult they perceived the task to be (1 = not at all difficult, 7 = extremely difficult), and how aroused they were during the task (1 = not at all aroused, 7 = extremely aroused). Sessions took place between 10:00 and 17:00 h and lasted approximately 2 h, i.e. the vast majority of participants were tested at times when there is little diurnal variation in sIgA (Hucklebridge et al., 1998).

2.6. Data reduction and analysis

Using the 60-s ensemble averages for HR, PEP, and CO and their corresponding SBP, DBP and TPR values, four 2-min interval means were calculated; min 5–6 of each baseline rest, and min 1–2, 4–5, and 7–8 of each task. A series of two-way MANOVAs were performed on these data to examine the effects of task difficulty (difficulty × interval) and task novelty (order × interval) on cardiovascular activity. Wilks' lambda (λ), the associated F value, and degrees of freedom are reported. Where appropriate post hoc comparisons were undertaken using the Newman–Keuls method.

SIgA concentration and sIgA secretion rate were determined for the saliva samples taken during each baseline period and immediately after each task. Since sIgA concentration may be influenced by saliva flow rate (Brandtzaeg, 1971), sIgA secretion rate has been suggested as the appropriate measure to use (Evans et al., 1993). However, other authorities (Jemmott and McClelland, 1989) have argued that sIgA concentration is the appropriate measure, and a large number of previous studies have only reported sIgA concentration. Accordingly, analyses were performed on both sIgA concentration and secretion rate. Analogous MANOVAs to those for the cardiovascular variables were performed. Because of the large interindividual differences in sIgA secretion rates, a square root transformation was performed to increase homogeneity of variance (Myers, 1972) and the analyses presented here were performed on the transformed data. MANOVAs were also applied to the performance and self-report data. A 5% significance level was adopted in all tests.

3. Results

3.1. Task difficulty

3.1.1. Task performance and self-report measures

Task performance, indexed by the number of correct answers, and self-report data are presented in Table 1. As participants moved from easy to hard to impossible versions of the mental arithmetic task, actual and rated performance decreased and rated difficulty increased. Significant difficulty effects were found for the number of correct answers (Wilks' $\lambda = 0.01$, $F(2, 25) = 1121.58$, $P < 0.05$), rated difficulty (Wilks' $\lambda = 0.11$, $F(2, 25) = 99.04$, $P < 0.05$), and rated performance (Wilks' $\lambda = 0.19$, $F(2, 25) = 53.69$, $P < 0.05$). Post hoc analyses confirmed that for these variables each task version differed from every other version. The difficulty effect for self-rated arousal did not quite reach the conventional significance level (Wilks' $\lambda = 0.80$, $F(2, 25) = 3.15$, $P = 0.06$).

3.1.2. Cardiovascular activity

Average cardiovascular activity during the easy, hard, and impossible task versions is shown in Table 2. SBP, DBP, HR, and TPR increased from baseline rest to task, and, although there is some decline after the first minutes, activity remained elevated throughout the task. PEP shortened markedly with task onset but returned to baseline by the end of the task. Analyses revealed a significant difficulty effect for DBP (Wilks' $\lambda = 0.64$, $F(2, 20) = 5.54$, $P < 0.05$), but not for any of the other cardiovascular variables. Post hoc comparisons showed that DBP was higher during the hard task version than during the easy and impossible versions. Significant Interval effects were found for SBP (Wilks' $\lambda = 0.38$, $F(3, 19) = 10.39$, $P < 0.05$), DBP (Wilks' $\lambda = 0.17$, $F(3, 19) = 31.01$, $P < 0.05$), HR (Wilks' $\lambda = 0.48$, $F(3, 23) = 8.23$, $P < 0.05$), PEP (Wilks' $\lambda = 0.58$, $F(3, 23) = 5.51$, $P < 0.05$), and TPR (Wilks' $\lambda = 0.43$, $F(3, 23) = 10.22$, $P < 0.05$). The interval effect for CO was not statistically significant (Wilks' $\lambda = 0.74$, $F(3, 24) = 2.69$, $P = 0.07$). Post hoc comparisons revealed that for SBP, DBP, HR and TPR baseline values were consistently lower than respective task values. In general, task interval values did not vary. However, DBP was higher and PEP shorter early in the task. No significant Difficulty × Interval interactions were found. Supplementary analyses

Table 1
Mean and standard deviation (SD) of actual performance scores, and self-rated task performance, task difficulty, and arousal, for the easy, hard, and impossible task version of the PASAT

	Actual performance		Rated performance		Rated difficulty		Rated arousal	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Easy task	232.44	5.19	4.93	1.49	3.04	1.45	3.81	1.42
Hard task	191.44	23.89	3.56	1.50	4.63	1.36	4.30	1.59
Impossible task	56.52	20.34	1.67	0.78	6.78	0.58	4.44	1.72

Table 2
Mean and standard deviation (SD) of cardiovascular activity during baseline and task intervals of the easy, hard, and impossible task version of the PASAT

	SBP (mmHg)		DBP (mmHg)		HR (bpm)		PEP (ms)		CO (l/min)		TPR (dynes/s/cm^{-5})	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Easy task												
Baseline	121.00	8.31	66.30	8.60	65.45	9.86	108.19	12.54	8.30	1.47	868.94	172.92
Task interval 1	128.48	8.73	72.15	12.36	68.96	13.01	105.44	13.38	8.00	1.38	985.37	210.89
Task interval 2	128.07	10.55	71.67	11.97	69.56	11.81	108.48	13.75	8.05	1.34	977.94	211.70
Task interval 3	127.04	11.07	70.74	11.29	68.69	11.08	108.06	13.31	8.02	1.39	959.99	209.10
Hard task												
Baseline	121.19	8.25	66.69	10.86	65.01	9.44	107.85	12.50	8.28	1.39	882.04	156.87
Task interval 1	129.19	9.61	76.88	12.42	71.50	12.28	104.76	12.46	8.14	1.43	1003.90	235.84
Task interval 2	129.22	10.59	74.07	11.10	70.03	10.75	107.63	12.40	8.14	1.30	964.48	198.27
Task interval 3	130.26	9.86	72.81	10.05	70.47	10.98	108.37	12.90	8.08	1.34	980.24	192.42
Impossible task												
Baseline	120.11	11.08	65.19	10.75	65.31	8.72	108.72	13.40	8.27	1.62	871.63	199.69
Task interval 1	130.60	11.13	74.72	11.49	70.94	10.67	105.75	13.52	8.11	1.50	991.66	239.19
Task interval 2	128.35	10.49	72.35	10.89	68.85	10.52	106.83	13.08	8.19	1.48	926.98	202.60
Task interval 3	126.23	10.01	71.04	10.81	68.53	9.52	108.44	13.42	8.07	1.43	976.34	229.93

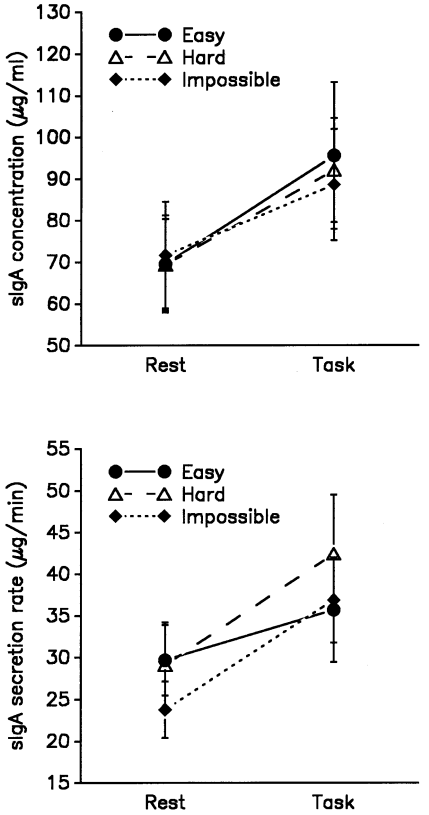

Fig. 1. Mean (SE) levels of secretory activity during rest and task periods for the easy, hard, and impossible versions of the mental arithmetic task.

revealed no variation among the three baselines for any of the cardiovascular variables.

3.1.3. Secretory immunoglobulin A

The summary data for the sIgA measures are presented in Fig. 1. Both sIgA concentration and sIgA secretion rate increased from baseline to task. MANOVA yielded no significant Difficulty effects, but significant Interval effects were found for sIgA concentration (Wilks' $\lambda = 0.69$, $F(1, 26) = 11.70$, $P < 0.05$) and sIgA secretion rate (Wilks' $\lambda = 0.66$, $F(1, 26) = 13.95$, $P < 0.05$), with task values being higher than baseline values. The three baseline levels did not vary. There were no significant Difficulty × Interval interactions.

3.2. Task order[1]

3.2.1. Task performance and self-report measures

Task performance and self-report data as a function of task order are presented in Table 3. There was no task order effect on actual performance. A significant Order effect was found for rated task performance (Wilk's $\lambda = 0.72$, $F(2, 25) = 4.81$, $P < 0.05$, with performance estimated to be better with successive task presentations.

3.2.2. Cardiovascular activity

The summary cardiovascular data as a function of task order are presented in Table 4 and show that, in general, the response to the first task was larger than to the second or third task. MANOVAs yielded significant Order effects for SBP (Wilks' $\lambda = 0.52$, $F(2, 20) = 9.25$, $P < 0.05$), HR (Wilks' $\lambda = 0.67$, $F(2, 24) = 5.91$, $P < 0.05$), PEP (Wilks' $\lambda = 0.63$, $F(2, 24) = 6.96$, $P < 0.05$), and CO (Wilks' $\lambda = 0.74$, $F(2, 24) = 4.15$, $P < 0.05$). Post hoc comparisons revealed that HR was lower during the third task undertaken than during the first two tasks. SBP was higher and PEP shorter during the first task than the last two tasks, and CO differed significantly between the first and third task presentations. Baseline levels did not vary across task presentations. No significant Order effects were found for DBP and TPR. Order × Interval interactions were found for HR (Wilks' $\lambda = 0.46$, $F(6, 20) = 3.95$, $P < 0.05$), PEP (Wilks' $\lambda = 0.55$, $F(6, 20) = 2.78$, $P < 0.05$), CO (Wilks' $\lambda = 0.48$, $F(6, 20) = 3.63$, $P < 0.05$), and TPR (Wilks' $\lambda = 0.55$, $F(6, 20) = 2.73$, $P < 0.05$). Post hoc comparisons revealed that, overall, the most pronounced changes occurred from baseline to the first interval of the first task presented.

3.2.3. Secretory immunoglobulin A

Fig. 2 summarises the data for sIgA concentration and sIgA secretion rate as a function of task order. As can be seen, in general, the most marked increase over baseline occurred during the first task presented, which subsequently declined for the latter two tasks. Analyses yielded a significant Order effect for sIgA concentra-

Table 3
Means and standard deviation (SD) of actual performance scores, and self-rated task performance, task difficulty, and arousal, for the first, second, and third task presentation of the PASAT

	Actual performance		Rated performance		Rated difficulty		Rated arousal	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
First task	156.00	78.15	2.56	1.25	5.56	1.53	4.19	1.47
Second task	164.67	76.57	3.56	1.87	4.59	1.89	4.37	1.80
Third task	159.74	81.24	4.04	2.10	4.30	2.20	4.00	1.49

[1] As no changes were made to the interval structure, interval effects for task novelty are identical to those for task difficulty and are therefore not reported in the analysis of task novelty.

Table 4
Mean and standard deviation (SD) of cardiovascular activity during baseline and task interval of the first, second, and third task presentation of the PASAT

	SBP (mmHg)		DBP (mmHg)		HR (bpm)		PEP (ms)		CO (l/min)		TPR (dynes/s/cm^{-5})	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
First task												
Baseline	122.89	8.85	66.15	10.93	65.78	9.73	107.91	12.43	8.37	1.55	863.31	188.59
Task interval 1	131.63	9.79	77.41	11.43	73.33	11.69	103.33	13.81	8.08	1.44	1014.30	210.93
Task interval 2	131.37	11.27	72.96	11.90	70.53	11.39	105.61	13.03	8.28	1.40	946.29	204.84
Task interval 3	129.22	11.11	71.70	12.10	70.70	10.44	107.63	13.29	8.24	1.32	949.20	186.40
Second task												
Baseline	118.65	9.83	66.12	8.31	65.70	9.24	108.48	12.86	8.36	1.50	863.34	164.69
Task interval 1	128.15	10.85	73.35	13.06	70.66	11.67	106.06	13.01	8.10	1.48	984.18	262.26
Task interval 2	127.31	11.59	72.62	12.86	70.15	10.98	108.89	13.57	8.08	1.38	976.73	210.80
Task interval 3	128.44	10.36	71.78	9.89	69.52	10.76	108.56	13.60	8.10	1.45	963.43	198.69
Third task												
Baseline	120.67	8.80	65.89	10.88	64.30	9.01	108.37	13.17	8.12	1.43	895.95	176.25
Task interval 1	128.28	8.36	72.72	11.72	67.47	12.15	106.48	12.34	8.07	1.39	983.28	207.61
Task interval 2	126.93	7.84	72.52	9.11	67.76	10.55	108.44	12.44	8.02	1.34	946.38	198.97
Task interval 3	125.85	9.59	71.12	10.14	67.46	10.29	108.69	12.71	7.83	1.36	1003.94	240.74

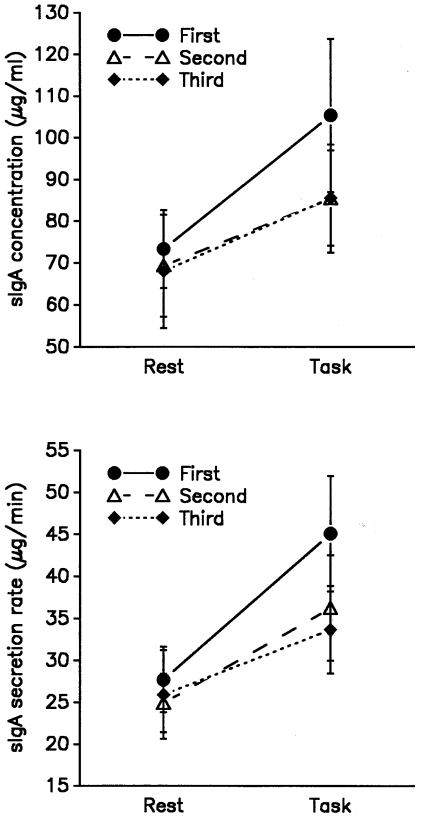

Fig. 2. Mean (SE) levels of secretory activity during rest and task periods for the first, second, and third presentation of the mental arithmetic task.

tion (Wilks' $\lambda = 0.79$, $F(2, 25) = 3.32$, $P = 0.05$), but not for sIgA secretion rate. Post hoc comparisons indicated that the response to the first task presented was associated with higher sIgA concentration. There was no variation between the three baselines.

3.2.4. Interactive effects of task difficulty and task order

In order to explore, in a preliminary fashion, the interaction between task difficulty and task order, the effect of task difficulty was analysed separately for the first, second, and third presented task. No significant effects were found. It should be appreciated, however, that these analyses have exceedingly low power to detect effects.

3.2.5. Relationship between cardiovascular and sIgA responses

Using residualised change scores, calculated using the first interval of each task, Pearson correlations were computed between cardiovascular and sIgA activity. No significant coefficients were found.

4. Discussion

In line with the results of previous studies (Carroll et al., 1996; Willemsen et al., 1998), sIgA was responsive to laboratory challenges that elicit cardiovascular activation. Contrary to predictions, however, sIgA proved unresponsive to the manipulation of task difficulty, even though task performance and self report data indicated that the task variants did differ in actual and perceived difficulty. Our present results suggest that the variations in sIgA response to a computer game associated with prior experience, observed by Carroll et al. (1996), were not a function of differences in perceived difficulty. Further, with the exception of DBP, which was highest for the hard task compared to the easy and impossible task versions, cardiovascular activity did not vary systematically with task difficulty.

While difficulty effects on a range of cardiovascular variables are reported in a number of studies (Light and Obrist, 1983; Carroll et al., 1986a,b; Smith et al., 1990), there are exceptions (Van Schijndel et al., 1984; Kelsey, 1991), and the overall picture painted by the positive studies is less coherent than first impressions suggest. For example, Carroll et al. (1986a) reported larger HR responses to hard and impossible than easy mental arithmetic challenges, whereas Carroll et al. (1986b) found diminished HR reactions to both the easy and the impossible versions. In contrast, Light and Obrist (1983) reported that HR was insensitive to the difficulty of an appetitive reaction time task, although PEP, SBP, and DBP displayed reduced responsiveness to the impossible but not the easy task variant. Smith et al. (1990), on the other hand, reported that, relative to the hard version of a speech task, both easy and impossible versions were associated with diminished HR, SBP, and DBP activity. It would appear that reduced responsiveness to the easy and impossible variants of tasks is not always found and that precise outcomes vary for different cardiovascular parameters and with different behavioural challenges.

Whereas the present study showed few effects for task difficulty, results for task novelty were more positive. A significant task order effect was found for sIgA concentration; the first task presented was associated with greater sIgA concentration levels. Task order effects were also evident for SBP, HR, PEP, and CO, and order by interval interaction effects were found for HR, PEP, CO, and TPR. These results for cardiovascular variables would suggest that task novelty affected the cardiac variables more than the vascular variables. This result is in line with studies showing that vascular reactivity remains stable or even increases during the course of a prolonged task exposure (e.g. Carroll et al. 1990; Miller and Ditto, 1991) or repeated task exposure (Kelsey et al., 1999). It would appear that novelty is associated with largely beta-adrenergic cardiovascular autonomic activation.

Novelty has long been recognised as an important factor in the activation of physiological systems; individuals confronted with a new situation show pronounced physiological responses which diminish with repeated exposure (Frankenhaeuser et al., 1962). For example, Linden (1991) found greater HR and blood pressure responses to the first, relative to subsequent, mental arithmetic tasks. This effect was found irrespective of response requirements and the presence or absence

of distracting noise. In a recent study, Kelsey et al. (1999) compared the sensitivity of a range cardiovascular parameters to task difficulty and task novelty. Participants undertook serial subtraction by 7 s, preceded either by no task, serial subtraction by 3 s, or serial subtraction by 7 s. HR and PEP were not affected by task difficulty. However, first task exposure, irrespective of whether it was delayed (no preceding task) or was to the easy or more difficult subtraction condition, proved more provocative than subsequent task exposure. These results very much resonate with the current findings. Accordingly, it is possible that task novelty rather than task difficulty determined the differences between novice and experienced players on sIgA reactions to a computer game, observed by Carroll et al. (1996). However, any such conclusions must be tentative. The present manipulation of novelty is an imprecise analogy for the status of a novice computer game player. In addition, the present study differed from our previous one by having no explicit monetary reward. Financial incentives in this context have been found to influence physiological activity (e.g. Fowles et al., 1982).

In sum, the present data confirm that sIgA is responsive to the sorts of laboratory challenges that elicit changes in cardiovascular activity. Although unaffected by the present manipulation of task difficulty, sIgA proved sensitive to task novelty. That cardiovascular activity behaves in a largely similar manner, suggests that common mechanisms could underlie acute responses to stress in the two systems. The patterning of cardiovascular effects suggests that such mechanisms are likely to reside in the sympathetic nervous system. However, the absence of significant correlations between cardiovascular and sIgA activity in this study necessarily tempers such speculation.

Acknowledgements

The authors thank Dr Andrew Blannin for performing the assays, and William Guethlein for software support.

References

Bristow, M., Hucklebridge, F., Clow, A., Evans, P., 1997. Modulation of secretory immunoglobulin A in saliva in relation to an acute episode of stress and arousal. J. Psychophysiol. 11, 248–255.

Brandtzaeg, P., 1971. Human secretory immunoglobulin-VIII: Concentrations of parotid IgA and other secretory proteins in relation to the rate of flow and duration of secretory stimulus. Arch. Oral Biol. 16, 1295–1310.

Cacioppo, J.T., 1994. Social neuroscience: Autonomic, neuroendocrine, and immune responses to stress. Psychophysiology 31, 113–128.

Cannon, W.B., 1915. Bodily Changes in Pain, Hunger, Fear and Rage. Appleton–Century–Crofts, New York.

Carroll, D., Cross, G., Harris, M.G., 1990. Physiological activity during a prolonged mental stress task: Evidence for a shift in the control of pressure reactions. J. Psychophys. 4, 261–269.

Carroll, D., Ring, C., Shrimpton, J., Evans, P., Willemsen, G., Hucklebridge, F., 1996. Secretory immunoglobulin A and cardiovascular responses to acute psychological challenge. Int. J. Behav. Med. 3, 266–279.

Carroll, D., Turner, J.R., Hellawell, J.C., 1986a. Heart rate and oxygen consumption during active psychological challenge: The effects of level of difficulty. Psychophysiology 23, 174–181.

Carroll, D., Turner, J.R., Prasad, R., 1986b. The effects of level of difficulty of mental arithmetic challenge on heart rate and oxygen consumption. Int. J. Psychophysiol. 4, 167–173.

Evans, P., Bristow, M., Hucklebridge, F., Clow, A., Pang, F.-Y., 1994. Stress, arousal, cortisol, and secretory immunoglobulin A in students undergoing assessment. Br. J. Clin. Psychol. 33, 575–576.

Evans, P., Bristow, M., Hucklebridge, F., Clow, A., Walters, N., 1993. The relationship between secretory immunity, mood and life events. Br. J. Clin. Psychol. 32, 227–236.

Frankenhaeuser, M., Sterky, K., Jaerpe, G., 1962. Psychophysiological relations in habituation to gravitational stress. Percept. Mot. Skills 15, 63–72.

Fowles, D.C., Fisher, A.E., Tranel, D.T., 1982. The heart beats to reward: The effect of monetary incentive on heart rate. Psychophysiology 19, 506–513.

Hood, L.E., Weisman, I.L., Wood, W.B., 1978. Immunology. Benjamin/Cummings, Menlo Park, CA, pp. 40–43.

Hucklebridge, F., Clow, A., Evans, P., 1998. The relationship between salivary secretory immunoglobulin A and cortisol: Neuroendocrine response to awakening and the diurnal cycle. Int. J. Psychophysiol. 31, 69–76.

Jemmott, J.B. III, McClelland, D.C., 1989. Secretory IgA as a measure of resistance to infectious disease: comments on Stone, Cox, Valdismarsdottir, and Neale. Behav. Med. 12, 63–71.

Kelsey, R.M., 1991. Electrodermal lability and myocardial reactivity to stress. Psychophysiology 28, 619–631.

Kelsey, R.M., Blascovich, J., Tomka, J., Leitten, C.L., Schneider, T.R., Wiens, S., 1999. Cardiovascular reactivity and adaptation to recurrent psychological stress: effects of prior task exposure. Psychophysiology 36, 818–831.

Kelsey, R.M., Guethlein, W., 1990. An evaluation of the ensemble averaged impedance cardiogram. Psychophysiology 27, 24–33.

Kirschbaum, C., J. Prüssner, J.C., Stone, A.A., Federenko, I., Gaab, J., Lintz, D., Schommer, N., Hellhammer, D. H., 1995. Persistent high cortisol responses to repeated psychological stress in a subpopulation in healthy men, Psychosom. Med., 57, 468–474.

Kraehenbuhl, J.R., Neutra, M.R., 1992. Molecular and cellular basis of immune protection of mucosal surfaces. Physiol. Rev. 72, 853–879.

Kubicek, W.G., Kottke, F.J., Ramos, M.V., Patterson, R.P., Witsoe, D.A., Labree, J.W., Remole, W., Layman, T.E., Schoening, H., Garamela, J.T., 1974. The Minnesota impedance cardiograph B Theory and applications. Biomed. Eng. 9, 410–417.

Kugler, J., Reintjes, F., Tewes, V., Schedlowski, M., 1996. Competition stress in soccoer coaches increases salivary immunoglobulin A and salivary cortisol concentrations. J. Sports Med. Phys. Fit. 36, 117–120.

Light, K.C., Obrist, P.A., 1983. Task difficulty, heart rate reactivity, and cardiovascular responses to an appetitive reaction time task. Psychophysiology 20, 301–312.

Linden, W., 1991. What do arithmetic stress tests measure? Protocol variations and cardiovascular responses. Psychophysiology 28, 91–102.

McClelland, D.C., Ross, G., Patel, V., 1985. The effect of an academic examination on salivary norepinephrine and immunoglobulin levels. J. Human Stress 11, 52–59.

Miller, S.B., Ditto, B., 1991. Exaggerated sympathetic nervous system response to extended psychological stress in offspring of hypertensives. Psychophysiology 28, 103–113.

Myers, J.L., 1972. Fundamentals of Experimental Design. Allyn and Bacon, Boston.

Ring, C., Carroll, D., Willemsen, G., Cooke, J., Ferraro, A., Drayson, M., 1999. Secretory immunoglobulin A and cardiovascular activity during mental arithmetic and paced breathing. Psychophysiology 36, 602–609.

Sherwood, A., Royal, S.A., Hutcheson, J.S., Turner, J.R., 1992. Comparison of impedance cardiographic measurements using band and spot electrodes. Psychophysiology 29, 734–741.

Smith, T.W., Baldwin, M., Christensen, A.J., 1990. Interpersonal task influence as active coping: effects of task difficulty on cardiovascular reactivity. Psychophysiology 27, 429–437.

Stern, R.M., Sison, C.E.E., 1990. Response patterning. In: Cacioppo, J.T., Tassinary, L.G. (Eds.), Principles of Psychophysiology: Physical, Social, and Interferential Elements. Cambridge University Press, Cambridge, pp. 216–252.

Van Schijndel, M., De Mey, H., Naring, G., 1984. Effects of behavioral control and Type A behavior on cardiovascular responses. Psychophysiology 21, 501–509.

Willemsen, G., Ring, C., Carroll, D., Evans, P., Clow, A., Hucklebridge, F., 1998. Secretory immunoglobulin A and cardiovascular reactions to mental arithmetic and cold pressor. Psychophysiology 35, 252–259.

Wright, R.A., Williams, B.J., Dill, J.D., 1992. Interactive effects of difficulty and instrumentality of avoidant behavior on cardiovascular reactivity. Psychophysiology 29, 677–686.

Zeier, H., Brauchli, P., Joller-Jemelka, H.I., 1996. The effects of work demands on immunoglobulin A and cortisol in air traffic controllers. Biol. Psychol. 42, 413–423.