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Heart rate and blood pressure interactions during attempts to consciously raise or lower heart rate and blood pressure in normotensive subjects

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Abstract

This study investigated the interaction between heart rate (HR) and blood pressure (BP) during conscious control under visual biofeedback and background noise conditions. Normotensive volunteers were instructed to (i) decrease and (ii) increase HR (group A, $n = 16$) or BP (group B, $n = 16$). After instructions to lower HR or BP there was no significant change in HR or BP for either group. After instructions to raise HR, HR increased significantly (13.8 ± 1.3 beats min^{-1} , $P < 0.0001$) and BP did not change. However, following instructions to raise BP, both HR and BP increased significantly: systolic BP (5.2 ± 1.5 mmHg, $P < 0.001$), diastolic BP (3.5 ± 0.9 mmHg, $P < 0.001$) and HR (8.6 ± 1.3 beats min^{-1} , $P < 0.0001$). Biofeedback and background noise did not alter the relative change in HR or BP. In conclusion, normotensive subjects were unable to reduce BP or HR under conscious control. Subjects were able to increase both HR and BP, and voluntary increases in HR did not alter BP, while voluntary increases in BP also increased HR indicating distinct HR/BP interactions during conscious control.

Keywords

heart rate control; blood pressure control; conscious control

1. Introduction

The health benefits of reducing blood pressure (BP) in hypertensive patients are well known (Banegas *et al* 1998, Chalmers 2003, Wang *et al* 2005, Franco *et al* 2005). These include reductions in the likelihood of serious medical conditions such as cardiovascular disease, myocardial infarction and stroke, as well as significant extensions in life expectancy. In addition to drug therapy, a number of alternative approaches to BP control have been investigated. These include relaxation techniques, yoga and device-guided breathing (Yen *et al* 1996, Dickinson *et al* 2008, Rosenthal *et al* 2001, Grossman *et al* 2001, Irvine *et al* 1986, Latha and Kaliappan 1991). Yen *et al* (1996) found that hypertensive individuals were able to achieve a reduction of 11 mmHg in systolic BP using taught relaxation techniques. Another technique uses conscious thought alone, and the use of biofeedback to facilitate or enhance this control has also been investigated (Hunyor *et al* 1997, Blanchard *et al* 1976). Blanchard *et al* (1976) suggested that there are no significant differences between the effectiveness of visual and auditory biofeedback, and that both are more effective than no biofeedback. Similarly, investigators have studied the ability of subjects to control heart rate (HR) in this context (Weems 1998, Lott and Gatchel 1978, James *et al* 1997). Pollard and Ashton (1982) concluded that there were no significant differences between different feedback methods, and Twentyman *et al* (1979) reported that visual feedback does not facilitate HR reduction beyond the levels achieved by general relaxation techniques. Most

studies have focused on hypertensive subjects due to the importance of reducing BP in this group. However, studies on normotensive subjects have been undertaken and are important in understanding differences in health and disease. Although it is generally agreed that normotensive subjects can significantly raise and lower HR using a variety of different techniques (Weems 1998, Lott and Gatchel 1978, James *et al* 1997, Pollard and Ashton 1982), there is mixed evidence as to whether BP can be consistently controlled in the same manner (Cejnar *et al* 1988, Lal *et al* 1998, Bowers and Murray 2004). The techniques employed in these studies included respiratory modulation (fast/deep breathing and breath holds) (Bowers and Murray 2004), as well as the use of both visual and auditory feedback (Cejnar *et al* 1988, Lal *et al* 1998).

Few studies have considered the specific interactions between HR and BP during conscious control challenges. Under normal conditions without conscious control, BP/HR interactions are mediated by the baroreflex and sympathetic and parasympathetic tone such that homeostatic BP is maintained by control of HR (Robertson 2004). However, it is unknown how attempted conscious control of BP or HR would affect these interactions. Under conscious control, the balance between subconscious regulation and conscious stimuli will determine the overall level of control and interaction between BP and HR. The study by Hunyor *et al* (1997), in addition to showing that subjects who were mildly hypertensive could voluntarily lower or raise BP by approximately 6 mmHg, also found that voluntary BP increases also increased HR while BP decreases did not affect HR. The study did not assess conscious control of HR and its affect on BP. Impaired regulation of HR and BP is associated with a range of cardiovascular diseases, and the interaction between HR and BP as measured by the baroreflex response is an ongoing area of research (Van de Borne *et al* 2000, Kitney *et al* 1985, Melcher 2008). This response is impaired in a number of patient groups, including the hypertensive (Grassi *et al* 1998). So far the interactions between HR and BP during conscious control in normotensive subjects have been neglected and are investigated in our study.

In this study we test the hypotheses that (i) untrained normotensive subjects can voluntarily decrease or increase BP or HR and (ii) conscious control of BP affects HR and vice versa. This is the first study to investigate the interactions between HR and BP during self-control of either HR or BP in normotensive subjects. It is important to establish these interactions in healthy subjects to define the ‘normal’ response which can be compared to interactions in patients and be used to identify impaired response.

2. Methods

2.1. Subjects

The study population consisted of 32 healthy subjects. None was taking medication to control either BP or HR. Each subject gave informed consent and the study was granted ethical approval by the NHS Research Ethics Committee. Subjects were divided into two equally sized subgroups: the HR challenge group (group A) and the BP challenge group (group B). Summary data for the groups are shown in table 1. Subjects in group A were asked to voluntarily (i) decrease and (ii) increase HR in separate conscious challenges. Similarly, subjects in group B were asked to voluntarily (i) decrease and (ii) increase BP in separate conscious challenges. Subjects received no coaching in self-control of HR or BP either during or before the study.

2.2. Measurements

BP and ECG lead II were recorded in all subjects. Continuous BP was recorded, using a finger-cuff BP monitoring device (Ohmeda—2300 Finapres BP Monitor) which delivers a

continuous finger arterial pressure waveform derived from photoplethysmography (Imholz *et al* 1988). Systolic and diastolic BP were determined automatically from peaks and troughs in each beat of the continuous BP waveform and confirmed visually. The continuous BP waveform from the finger-cuff BP device was recorded during each challenge. This waveform was stored on computer for later analysis with our own software as follows. The waveform was analysed to determine the average systolic and diastolic BP during each challenge. The systolic BP at each beat was obtained by automatic detection of the peak of the continuous pressure waveform during each beat. Similarly, the diastolic BP at each beat was obtained by automatic detection of the trough of the continuous pressure waveform at each beat. Automatic detection was by computer code developed in Matlab which automatically identified the peaks and troughs in the BP waveform. The waveform and detected points were plotted on the computer screen and correct detection of the peaks and troughs confirmed visually by the researcher inspecting the detected points. Then the averages of the beat by beat systolic and diastolic BPs over the challenge duration (1 min) were calculated and used for subsequent statistical analysis. Because the finger cuff is not accurate for determining absolute values of BP, resting BP was recorded three successive times at the start and end of the protocol using an electronic oscillometric arm-cuff device (Datascope—Accutorr Plus). The HR and BP profiles for the groups are displayed in table 1.

The challenges to voluntarily decrease or increase HR (group A) or BP (group B) were under different conditions of visual biofeedback and background noise. Visual biofeedback of HR (group A) or BP (group B) was provided for a subset of the challenge conditions via a screen displaying an analogue trace of instantaneous HR or BP. Visual HR biofeedback was derived from the ECG. Visual BP biofeedback was obtained from low-pass filtering the continuous BP waveform, which removed the pulsatility but retained the baseline variation and represented the mean BP. The resulting signal provided an indication of BP trend (increasing, decreasing or stable) for subjects to see in real time during the challenge. An arm-raising manoeuvre with the hand on which the BP sensor was attached was used as a functional check to demonstrate that visual feedback corresponded to the BP change. Raising and lowering the arm caused the BP feedback display to appropriately change, confirming the correct feedback prior to the commencement of the study. We wanted to assess the effect of background noise on the subjects' ability to control HR and BP as previous studies have suggested a detrimental effect (Lal *et al* 1998). The addition of background noise can be considered to more realistically simulate an actual environment in which conscious control might be undertaken by subjects either in the home, workplace or clinic where background noise is common. Background noise was generated using a laptop computer which played an audible sound at a constant and comfortable volume.

2.3. Protocol

Subjects remained supine for the duration of the study, whilst HR and BP were recorded for four 5 min periods, each under different visual biofeedback and audible sound conditions. Each 5 min period was structured as follows: minute 1, baseline recording prior to the first challenge; minute 2, the first challenge (e.g. to decrease HR (group A) or BP (group B)); minute 3, the recovery period; minute 4, baseline recording prior to the second challenge; minute 5, the second challenge (e.g. to increase HR (group A) or BP (group B)). The order in which subjects were challenged to increase or decrease HR or BP was alternated. The protocol provided a 1 min recovery period after each challenge. The recovery period was followed by a further 1 min without challenge, during which baseline recordings were obtained, providing in total 2 min between each challenge (James *et al* 1997).

Each 5 min period was repeated under different challenge conditions and was structured as follows: period 1, without visual biofeedback and without audible sound (V0,A0); period 2, with visual biofeedback and without audible sound (V1,A0); period 3, with visual

biofeedback and with audible sound (V1,A1); period 4, without visual biofeedback and with audible sound (V0,A1). Between each of the four recording periods there was a 5 min (non-recorded) break during which the subjects remained supine.

2.4. Data analysis and statistics

Values used in the analysis were the average values calculated during each 1 min of baseline or challenge recording. Initially all measurements for each group and each challenge were combined to establish the overall responses to the challenges regardless of biofeedback or audible sound, and assessed for changes by the one-sample *t*-test. Differences in baseline measurements between challenges were also assessed by one-sample *t*-test. The effects of visual biofeedback and audible sound on each challenge were analysed using two-way analysis of variance. All *P* values calculated were two tailed with statistical significance $P < 0.05$.

3. Results

3.1. Assessment of the overall level of control

Subjects were unable to decrease HR (group A) or BP (group B) when instructed to do so. However, subjects asked to increase HR (group A) and subjects asked to raise BP (group B) did so very significantly. In group A, HR increased by 13.8 ± 1.3 beats min^{-1} ($P < 0.0001$). In group B, systolic BP (SBP) increased by 5.2 ± 1.5 mm Hg ($P < 0.001$) and diastolic BP (DBP) by 3.5 ± 0.9 mm Hg ($P < 0.001$) (all values mean $\pm$ standard error mean). Figure 1 shows the levels of HR and BP change achieved by each group. There were no significant differences between baseline measurements for HR, SBP or DBP between challenges, indicating that HR and BP recovered back to baseline levels after each challenge.

3.2. HR and BP interaction during challenges

Group A was unable to voluntarily lower HR and there was no change in BP during the challenge. However, the group was able to voluntarily increase HR significantly and there was no corresponding significant change in either systolic or diastolic BP during the challenge.

Group B was unable to voluntarily lower BP and there was no change in HR during the challenge. However, the group was able to voluntarily increase BP significantly and there was a corresponding significant increase in HR by 8.6 ± 1.3 beats min^{-1} ($P < 0.0001$).

3.3. Effect of challenge conditions (visual feedback and noise)

Figure 2 shows the changes in HR and BP under each challenge condition. There were no significant differences in the ability to control SBP or DBP under any of the four different challenge conditions. SBP increased slightly when subjects were asked to decrease BP in three of the challenge conditions. There were no significant differences in the ability to control HR under the different challenge conditions except during the condition when only audible sound was playing (V0,A1). Under this condition the level of HR increase achieved (8.9 ± 2.2 beats min^{-1}) was significantly lower ($P < 0.05$) than that achieved for either of the no sound conditions (V0,A0) (17.7 ± 3.3 beats min^{-1}) and (V1,A0) (15.57 ± 2.4 beats min^{-1}).

4. Discussion

Subjects were unable to voluntarily lower HR or BP below baseline levels contrary to some other studies. Previous studies in conscious control of BP have focused on hypertensives because of the clinical imperative to lower BP in these subjects, and have demonstrated the

ability of some of these patients to lower BP by more than 5 mmHg (Hunyor *et al* 1997). However, some studies have also shown reductions in BP in normotensive subjects (Blanchard *et al* 1976, Lal *et al* 1998, Bowers and Murray 2004). Our subjects received no training in conscious control methods as we were interested in the normal physiological response to the challenge, whereas other studies have focused on optimizing the level of achievable control and have trained subjects in these techniques (Weipert *et al* 1986). Although training may have enabled subjects to achieve reductions in HR and BP, it is unclear why untrained subjects found it easier to increase than to decrease levels. The study allowed 1 min to elicit a response to each challenge and this may have been insufficient time to achieve a decrease response. Anxiety is known to disturb the ability to self-control HR and, although subjects were made to feel at ease during the study, anxiety could have been increased by taking part in the study, for example due to the unfamiliar environment (Cox and McGuinness 1977). On the other hand, both groups were able to voluntarily increase HR or BP without any training. The levels of increase observed (HR: 13.8 ± 1.3 beats min^{-1} , SBP: 5.2 ± 1.5 mm Hg, DBP: 3.5 ± 0.9 mm Hg) were similar to those reported in other studies (Hunyor *et al* 1997, Blanchard *et al* 1976, Weems 1998). None of the subjects achieved increases in BP to hypertensive levels.

The protocol was designed so that each challenge to lower or raise HR or BP was from resting baseline levels. This was confirmed because there were no significant differences in baseline HR or BP between challenges. Similarly, baseline HR and BP between each challenge condition was not significantly different. Subjects were able to recover back to resting baseline levels even after achieving significantly elevated levels of HR and BP. This is important because each challenge and challenge condition can be considered independent of the previous one.

Visual biofeedback was found to have no effect upon conscious control of BP or HR. This is in agreement with a recent study that carried out a placebo-controlled analysis of the effectiveness of visual biofeedback in reducing BP (Hunyor *et al* 1997). In that study placebo was equally as effective as real biofeedback at eliciting a blood pressure reduction or increase. The relative change between HR and BP was also not affected by any of the four challenge conditions. Subjects were able to increase HR and BP significantly during each of the four challenge conditions.

The main focus of our study was to investigate the interactions between HR and BP in response to conscious challenges. Challenges to lower BP were unsuccessful and did not elicit an associated response in HR. Similarly, challenges to lower HR were unsuccessful and did not elicit an associated response in BP. When challenged to raise BP, HR increased significantly by on average 8.6 ± 1.3 beats min^{-1} . This is in agreement with Hunyor *et al* (1997), who observed an almost identical increase in HR in mildly hypertensive subjects. However, the most intriguing result of our study was that when challenged to raise HR, there was no corresponding change in BP. Hence, in our cohort of healthy subjects, HR was increased independently of BP, but BP was not increased independently of HR. This suggests the existence of a distinct physiological mechanism for consciously controlling HR. Our group has shown previously that yoga can alter the relationship between HR and BP changes, indicating that there is some independence (Bowman *et al* 1997). Additionally, the BP/HR interaction is likely to be affected by the technique used to achieve the control. It is known that a range of techniques are used by subjects in voluntary control of HR/BP. These include respiration, muscular tone modulation and imagery. Deep breathing, muscle relaxation and positive imagery each facilitate BP lowering, whereas fast breathing rate, increased muscle tension and negative imagery raise BP (Lal *et al* 1998). The actual physiological response to these control stimuli is a complex interplay between sympathetic and parasympathetic nervous systems and baroreflex control which mediate HR/BP

response and interaction. It is interesting to speculate on the differing HR/BP interactions we observed in our study. Increasing HR increases cardiac output and, assuming peripheral resistance was maintained, would increase BP. This coupled response is the one we observed when asking subjects to control BP. However, when subjects were asked to increase HR, they did so without increasing BP, suggesting that peripheral resistance was lowered simultaneously to compensate for the increased cardiac output, perhaps mediated by relaxed muscle tone. Our objective was to establish the HR/BP interactions in normotensive subjects. Further studies would be required to establish the effects of gender and age on these interactions or to study these interactions in patients, such as those with hypertension.

5. Conclusion

Normotensive subjects were unable to consciously decrease HR or BP from resting levels. BP/HR interactions are different for subjects controlling HR compared to subjects controlling BP. This study provides reference normative data for the interaction between HR and BP during conscious self-control of either HR or BP in healthy individuals. So far this response has been unknown and will be useful for future studies to compare the response in patient groups such as those with hypertension. An abnormal response might be indicative of impaired haemodynamic regulation.

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Figure 1.

Change in HR and BP for both groups during attempts to raise and lower HR (group A) and BP (group B). Mean $\pm$ SEM (standard error mean) are indicated.

Figure 2.

Change in HR and BP under each of the challenge conditions for both group A (a)–(f) and group B (g)–(l). (a) The change in HR and (b) and (c) the change in BP for HR increase challenges. (d) The change in HR and (e) and (f) the change in BP for HR decrease challenges. (g) The change in HR and (h) and (i) the change in BP for BP increase challenges. (j) The change in HR and (k) and (l) the change in BP for BP decrease challenges. The horizontal-axis labels are the different conditions under which the challenges were performed as described in the text. Mean $\pm$ SEM are indicated. The symbols indicate that there were statistical differences ($P < 0.05$) between conditions V0,A0 and V0,A1 (†) and also between conditions V1,A0 and V0,A1 (‡).

Table 1

Subject characteristics by the study group (mean $\pm$ SD (standard deviation)). Heart rate and blood pressure values are those taken at rest at the start of the study.

	Study group	
	Group A (n = 16)	Group B (n = 16)
Age (years)	37 $\pm$ 15	32 $\pm$ 14
Gender (M/F)	8/8	11/5
Heart rate (beats min ⁻¹)	69 $\pm$ 10	69 $\pm$ 12
Systolic blood pressure (mm Hg)	117 $\pm$ 13	119 $\pm$ 11
Diastolic blood pressure (mm Hg)	70 $\pm$ 8	72 $\pm$ 14