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ATTENUATION OF THE DIVING REFLEX IN MAN BY MENTAL STIMULATION

BY ALVIN ROSS AND ANDREW STEPTOE
From the Department of Psychology, St George's Hospital Medical School, London, SW17 0RE

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SUMMARY

1. A study was made of the effects of mental arithmetic, and of listening to prose, on the bradycardia produced by breath holding with and without immersion of the face in cold water.

2. Bradycardia was produced in both air and water, but the response was significantly greater on face immersion. The reaction was attenuated by mental arithmetic in both air and water. In contrast external distraction by listening to prose had no effect on cardiac response.

3. It was concluded that the diving reflex can be modified by higher nervous stimulation. The effect is apparently dependent on mental challenge, such as that provoked by arithmetic.

INTRODUCTION

Extensive investigations in animals have documented the involvement of supramedullary regions of the brain in cardiovascular regulation (Delgado, 1960; Hoff, Kell & Carroll, 1963; Hilton, 1975). Such experiments generally employ direct interventions by lesions and electrical stimulation, although some studies with natural forms of behavioural stimulation have also been performed (Zanchetti, 1976). However, examinations of higher influences on basic cardiovascular control mechanisms in man are sparse. Reductions in the sensitivity of the baroreceptor reflex during mental arithmetic have been reported, suggesting that this pathway is susceptible to cortical modulation (Brooks, Fox, Lopez & Sleight, 1978). Goodwin, McClosky & Mitchell (1972) were able to identify the contribution of central motor command to overall haemodynamic levels by provoking reflex muscular contractions during steady isometric exercise. Research into the voluntary regulation of cardiovascular indices indicates that, after training with exteroceptive feed-back, humans can exert some control over vasomotor pathways (Snyder & Noble, 1968; Steptoe, Mathews & Johnston, 1974).

Although the responses to breath holding under water are complex, the most prominent reaction is a slowing of heart rate (Folinsbee, 1974; Paulev, 1968). It has been suggested that the bradycardia is due to vagal inhibition, and that the reflex is initiated by temperature sensitive receptors in the face (Kawakami, Natelson & DuBois, 1967; Song, Lee, Chung & Hong, 1969). However, apnea and haemodynamic

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mechanisms such as alterations in venous return or raised intrathoracic pressure, may also be involved (Moore, Elsner, Lin, Lally & Hong, 1972; Daly & Angell-James, 1975).

The effects of mental stimulation and information processing on the cardiac component of the reflex are explored in the present study. A second group was tested under similar conditions, but simply listened to a spoken text as opposed to performing mental work. This was to control for the possibility that any alteration of the cardiac response was due to basic attentional mechanisms rather than the challenge of the cognitive task; there is considerable evidence that the cardiovascular adjustments in conditions of passive sensory intake differ from those occurring during problem solving (Williams, Bittker, Buchsbaum & Wynne, 1975; Obrist, 1976).

Wolf and his associates (1965, 1978) reported that bradycardia fails to develop on face immersion when subjects are harrassed or preoccupied, but have provided little substantive documentation of the response. They did not impose specific tasks or conditions, but relied on observation of natural variations in the emotional state of participants.

METHODS

Subjects

Ten males were recruited from the student population at St George's Hospital Medical School. The average age was 19 years. Each subject participated in a single experimental session. An eleventh volunteer completed two experimental sessions, having taken 160 mg propranolol 1 hr before the first session; he was a member of staff.

The subjects were divided into two groups, a mental arithmetic group ($n = 7$), and a reading group ($n = 4$).

Equipment

The electrocardiogram (e.c.g.) was recorded in lead 2 position from the limbs, and also with silver disk electrodes attached to the top and base of the sternum. The e.c.g. was displayed on two channels of a Washington 1600 MD4C oscillograph at a chart speed of 10 mm/sec, and was simultaneously stored on magnetic tape with a Racal Thermionic store 4 recorder. The taped recordings were subsequently analysed by a laboratory computer (Cambridge Electronic Design), using softwave algorithms to filter out artifacts and record each R–R interval to an accuracy of 1 msec.

A transparent Perspex tank measuring 30 × 46 × 30 cm, and filled with water to within 6–8 cm of the rim, was used for face immersion. The water was cooled to $15 \pm \frac{1}{2}$ °C with the aid of crushed ice, and water temperature was monitored with an E-Mil Perma-Line mercury thermometer.

Procedure

Subjects underwent a series of twelve trials, each consisting of an initial 30 sec base line followed by a 60 sec breath hold. All subjects carried out each of the following four procedures 3 times, in random order with a 2–4 min interval between trials.

(1) Breath holding in air.
(2) Breath holding in air with arithmetic or reading.
(3) Breath holding in water.
(4) Breath holding in water with arithmetic or reading.

In the mental arithmetic condition, individuals were presented with 1- or 2-digit numbers, every 5 sec throughout breath holding. Successive numbers were to be added or subtracted from the cumulative total, and at the end of the trial, the subject had to announce the result. In the reading condition, volunteers listened to a passage of prose read by the experimenter throughout the trial.

The participant sat in an upright chair facing the water tank, which stood on a bench 70 cm high. A practice breath hold was carried out while the subject was seated, and those in the arithmetic group were given a test run with the task while breathing normally.

The volunteer was told before each trial which condition was to follow, and then stood up to lean over the water tank (immersion trials), or over the empty bench surface next to the tank (for breath holding in air). Throughout the base line, the subject breathed normally. On a verbal cue the subject took a maximal deep breath and lowered his face until the chin and forehead were submerged, or to a similar level next to the tank. The last three members of the mental arithmetic group performed all trials wearing a nose clip. After each breath hold, the subject was allowed to sit down and recover.

For analysis, interbeat intervals were converted into heart rate, and segmented into six 10-sec epochs for each trial. Univariate analyses of variance were performed on the two groups separately, using a repeated measures design with four within-subject factors: setting (breath holding in air or water), stimulation (presence or absence of arithmetic or reading), epoch within trial, and replication of each condition (BMD, 1973). In addition, individual means were compared when appropriate using Student t tests.

RESULTS

Mental arithmetic series

Fig. 1 illustrates the heart rate changes during breath holding in the arithmetic group. Data from all subjects are averaged over the three replications of each condition.

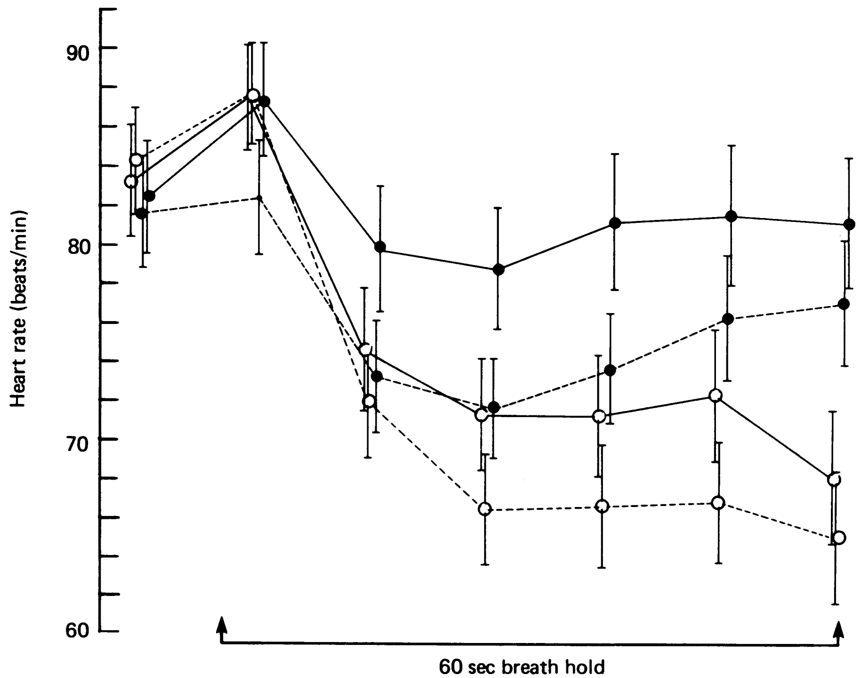

Fig. 1. Heart rate responses in the mental arithmetic (MA) series (n = 7). Mean ± S.D. for each 10 sec epoch of 60 sec breath holding trials, and for 30 sec base line. The four experimental conditions are distinguished: ●---●, breath holding in air without MA; ●—●, breath holding in air with MA; ○---○, breath holding in water without MA; ○—○, breath holding in water with MA.

Base line heart rates declined over trials, reflecting habituation and adaptation to the laboratory. The change was more pronounced before trials without arithmetic (F 2/12 = 8·63, P < 0·01), with decreases from 88·9 ± 3·38 to 78·6 ± 2·94 beats/min. Base lines before arithmetic trials fell from 85·1 ± 3·57 to 80·4 ± 3·41.

The analysis of variance indicated that the difference between breath holding in air and water was significant (F 1/6 = 29·0, P < 0·01), and that the bradycardia was lessened by the performance of arithmetic (F 1/6 = 16·3, P < 0·01). It is apparent from Fig. 1 that these effects emerged gradually over the 60 sec breath hold. Comparisons with t tests confirm that the heart rate responses in air and water in the absence of arithmetic diverged from the third 10-sec epoch onwards. Over the entire breath hold, heart rate decreased by an average of 15·5 % during face immersion, compared with 4·56 % in air. Likewise, the difference between the two immersion conditions was reliable in the third epoch (t = 4·13, two-tailed P < 0·01), and persisted until the end of trial. The average reduction from base line to the last 10 sec phase was 19·1 beats/min in the absence of arithmetic, compared with 15·0 beats/min during the task.

In the single subject tested under propranolol, the difference in response to face immersion with and without arithmetic was comparable to the pattern recorded in the drug-free state. The maximal decrease without the drug was 19·2 % on face immersion, and 15·5 % on face immersion with arithmetic; the corresponding changes recorded under propranolol were 17·2 and 13·1 % respectively.

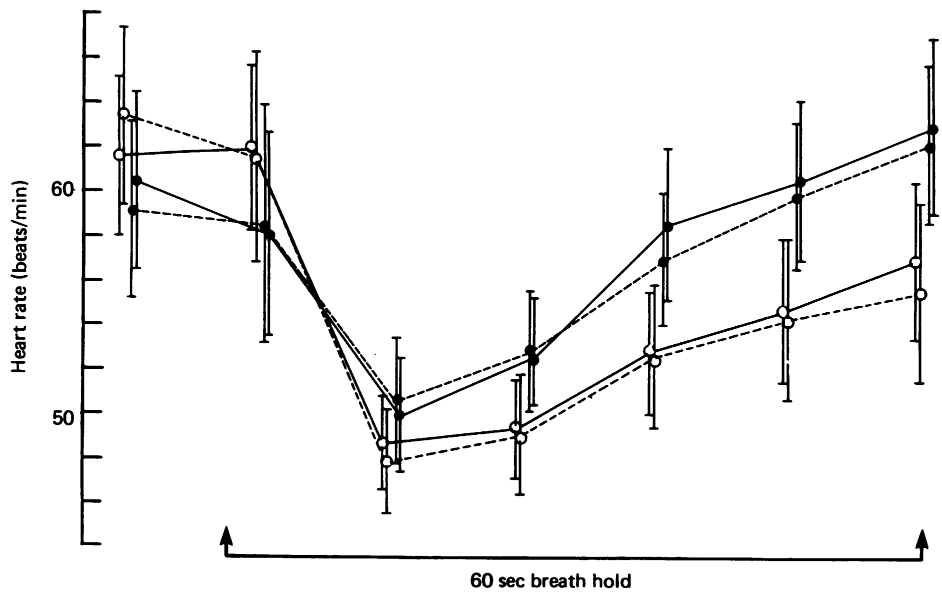

Fig. 2. Heart rate responses in the reading series (n = 4). Data averaged as in Fig. 1. ●- - -●, Breath holding in air without reading; ●—●, breath holding in air with reading; ○- - -○, face immersion without reading; ○—○, face immersion with reading.

Reading series

Average heart rate changes in the reading group are summarized in Fig. 2.

Basal levels again decreased over successive trials, but did not differ before task and no task conditions. It can be seen in Fig. 2 that the pattern of responses was different from that in the arithmetic condition, with maximal bradycardia appearing 10–20 sec into breath holding.

The low resting rate of individuals in this group may have contributed to the difference; nevertheless, the average decrease on face immersion (without stimulation) was 14·7 %, so subjects responded to a similar degree in the two series.

The analysis of variance confirmed that heart rates were again lower with than without the face immersion (F 11/33 = 13·8, P < 0·001). However, reactions were unaffected by the presence of reading; thus the differences seen with arithmetic were not repeated in this group.

DISCUSSION

The heart rate response to face immersion in man has little in common with the oxygen conserving reflex of diving mammals. Most diving animals exhale before immersion, and the bradycardia is frequently delayed for several seconds; the receptors initiating the reflex also differ between species (Andersen, 1966).

The response in man is temperature dependent, since the heart rate reduction is greater in cold water (Moore *et al.* 1972). Neither Folinsbee (1974) nor Smith & Hong (1977) recorded reliable differences between responses to breath holding in air and 31 °C water, but effects emerge with temperatures below 25 °C. Consequently, a water temperature of 15 °C was maintained during this study. The reaction also varies with lung volume, with the largest adjustments after inspiration to vital capacity, and smaller responses at lower volumes (Song *et al.* 1969). However, the pattern of anticipatory breathing may be important, as hyperventilation can lead to an artificially elevated heart rate; this will magnify the apparent size of the bradycardia (Raper, Richardson, Kontos & Pattersen, 1967). It is probable that many variations in the size of cardiac responses reported in the literature are due to differences in base line measurements and in breath holding duration. For example, Openshaw & Woodroof (1978) found no differences between breath holding at full inspiration in air and water. However basal heart rate was monitored for only 5 sec while breath holding continued for just 20 sec. In the present study, breath holding was preceded by a single maximal inspiration, calculated by Paulev (1968) to be within 10 % of vital capacity.

Posture also affects the reflex, so supine, sitting and standing positions have all been investigated (Song *et al.* 1969). The bradycardia produced while standing leaning forward is greater than that recorded during erect standing; therefore all trials were carried out in the same stooping posture during this study (Smith & Hong, 1977). Although results cannot be precisely compared across different investigations, the average changes of 15·0 % and peak mean reductions of 27·4 % in water are similar to those reported elsewhere at this temperature (Song *et al.* 1969).

Since the breath holding and face immersion were identical whether or not arithmetic calculations were being performed, it is unlikely that haemodynamic or mechanical factors account for the differences in response. The comparison between groups suggests that the attenuation of bradycardia with arithmetic was not simply a function of distraction, or attention to external stimulation. The mental work appears to have modified the neural reflex at a central level, either through inhibiting vagal outflow, or by provoking antagonistic β adrenergic activation. Mental arithmetic is known to provoke sympathetic reactions, and may have done so here (Brod, Fencl, Hejl & Jirka, 1959). However, the differential cardiac responses were not abolished in a single subject tested after oral administration of 160 mg propranolol; consequently, modulation of vagal tone may have been involved. Electrical stimulation of limbic and cortical structure in animals can provoke cardioinhibitory vagal responses, while apnea may modify reactions (Gebber & Klevans, 1972; Daly, Korner, Angell-James & Oliver, 1978). There is also a considerable experimental literature on humans indicating that psychological influences on the heart rate are mediated by parasympathetic fibres, as well as through sympathetic responses (Obrist, 1976). This study shows that cortical activity can produce substantial attenuation of the cardiac reflex elicited by breath holding and face immersion.

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