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The effect of attentional load on the breathing pattern in children

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Abstract

Experiments designed to establish the effects of video games on breathing patterns have led to contradictory results. Several authors reported that video games tended to increase breathing frequency (i.e. to reduce breath duration), whereas others reported the opposite. We postulated that video games contain different psychophysiological components which may have opposite effects on breathing pattern. On the one hand, arousal and emotion may tend to stimulate breathing. On the other, focusing attention on the game may prompt subject to inhibit any movement — including breathing — which might be a potential nuisance variable. The aim of this study was to assess the specific effects of the attentional load in an experimental environment characterized by its low emotional impact. We measured breathing variables, cardiac frequency and cortisol levels in 10 healthy children (mean age = 9.2 ± 1.5 years) who were familiar with the environment, the experimenter and the video game. Breath duration rose significantly, from 2.56 to 3.16 s, as a function of game difficulty. Cortisol levels, heart rate and the thoracic contribution to breathing displayed no significant changes. Taken together, these data suggest that focusing attention on the game tended to inhibit breathing and that previous contradictory reports in this respect were due to the confounding effects of emotion. © 1998 Elsevier Science B.V.

Keywords: Emotion; Attention; Video games; Breathing pattern

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1. Introduction

The effects of cognitive activities on breathing reflect the constant interactions between the brain stem respiratory complex and suprapontine centers for the control of breathing (Mador and Tobin, 1991; Gallego et al., 1996; Shea, 1996). Several authors studied these effects by measuring breathing variables in subjects playing video games (Turner and Carroll, 1985; Miller and Ditto, 1988; Shea et al., 1993; Chin et al., 1996). These experiments led to highly contradictory findings despite the similarity of their designs. For example, Turner et al. (1983) and Turner and Carroll (1985) reported that in normal young male adults playing a video game, breathing frequency increased by an average of 14 to over 20 breaths/min, whereas in a similar experiment by Miller and Ditto (1988), breathing frequency decreased significantly, from 19 to 15 breaths/min. The effects of video games on breathing were also analyzed by Shea et al. (1993) in children with Central Congenital Hypoventilation Syndrome (CCHS), a rare disease characterized by hypoventilation during non-rapid eye movement sleep, in order to determine whether the suprapontine centers have a specific role in the control of breathing in this disease. In CCHS patients and in normal age-matched controls, ventilation increased during the games. Recently, Chin et al. (1996) reported that playing a video game stimulated breathing under normal resting conditions, but they also observed that, when the game was played after a period of voluntary hyperventilation, it tended to inhibit breathing. Therefore in the same subjects the video game could either stimulate or inhibit breathing. Chin et al. (1996) did not attempts to explain these opposite effects. More generally, we are not aware that any attempts have been made to explain the contradictory findings in the literature regarding the ventilatory effects of video games.

In the present study, we developed the idea that the above contradictions may be due to the fact that mental tasks such as video games — and most cognitive activities emerging from natural conditions of life — comprise qualitatively different components which may have opposite effects on breathing. On the one hand, video games tend to increase arousal and may also elicit a strong emotional response in terms of joy, fear or surprise. Arousal and emotion generally tend to increase breathing frequency and ventilation (Grossman, 1983; Shea, 1996). On the other hand, the act of focusing attention on the game and more generally on unpredictable stimuli, may prompt the subjects to inhibit any movement — in particular breathing — which may act as a nuisance variable. Long ago, in 1938, Woodworth (1938) noted that there is a correlation between 'momentary attention and partial or complete inhibition of breathing'. Since this early statement, the results of many experiments have supported the idea that focusing attention tends to inhibit breathing (Stevenson and Ripley, 1952; Goldman-Eisler, 1955; Hare, 1973; Cohen et al., 1975). Obrist et al. (1970) argued that in either aversive conditioning situations or reaction time tasks with a warning stimulus, the cessation or decrease of breathing and a concomitant decrease in heart rate, could be observed. Several other motor activities, all of which constituted continuous background activity that was irrelevant to the organism's effort to cope with the experimental situation, also decreased. Boiten et al. (1994) — although not specifically with reference to breathing frequency — noted that the decrease in the depth and variability of breathing observed during demanding tasks may serve to suppress distracting and irregular breathing movement, which may otherwise interfere with task performance. Rather than leading to ubiquitous activation, the ventilatory effects of video games and probably of most cognitive tasks, may depend on the respective importance of their attentional, emotional and arousal components. Possibly, arousal and emotion stimulate breathing, whereas attentional load inhibits it. Therefore a possible explanation for the contradictions in the literature is that breathing frequency and mean ventilation increased when the experimental design elicited strong emotional or arousal responses — as was supposedly the case in the stress studies by Turner et al. (1983) and Turner and Carroll (1985). Conversely, breathing frequency and ventilation decreased whenever the experimental context did not promote any strong emotional response, so that the predominant factor was the act of focusing attention.

The present study addressed the latter assumption, i.e. that the attentional load in itself actually tends to inhibit breathing. To do this, we measured breathing variables while subjects were performing a video game and we manipulated the attentional load by increasing the difficulty of this game. To avoid any confounding effects of emotion, the experiment was carried out with normal children who were already familiar with the game, the experimental environment and the experimenter. We took children as our study subjects primarily because video games provide a means of testing abnormalities of ventilatory control in children with CCHS. We used non-invasive measurement devices only. In addition, we used cardiac frequency and cortisol levels as potential indices of emotion (Kirschbaum and Hellhammer, 1994), in order to check that the experimental environment and procedure had no emotional impact. We postulated that under these specific conditions, the increase in the difficulty of the game would be accompanied by a concomitant decrease in breathing frequency.

2. Methods

2.1. Subjects

Ten healthy children comprising of four males and six females (mean age ± S.D.: 9.2 ± 1.5 years) each volunteered for one session. The children and their families gave their informed consent to participate in this experiment. All the children were playmates of the leading experimenter's children, whose home was used for the experiment. The children all knew the house well and also knew the experimenter. All but three subjects had extensive experience with the video game (Tetris, see below), although most had played this game on portable systems rather than on computers.

2.2. Apparatus

A respiratory inductive plethysmograph equipped with a cardiac monitor (Respitrace Plus, Non Invasive Monitoring Systems: NIMS, Miami) was used for respiratory and cardiac measurements. Its coils were placed on the chest above the nipple line and on the abdomen at the umbilical level and fixed to the skin with adhesive tape. After cleaning the skin, electrodes for ECG were placed near the right and left midclavicular lines, directly below the clavicle and between the sixth and seventh intercostal space on the left midclavicular line. The only physiological recording sensors were therefore two elastic coils and three surface electrodes, which did not elicit strong emotions in the subjects. We used the qualitative diagnostic calibration method (Sackner et al., 1989; Sartène et al., 1993) without quantitative calibration. The tidal volume was expressed as a percent variation from the baseline level recorded during an initial 5-min period. The variations in baseline volume signals were automatically filtered with a time constant of 90 s. The signals from the Respitrace were processed by the Software Respi-Events, NIMS, which allowed on-line display of the changes in rib cage volume (V_{RC}), changes in abdominal volume (V_{AB}), the sum volume ($V_{AB} + V_{RC}$), respiratory frequency (fR) and V_T (expressed as percent of baseline). Thoracoabdominal distribution was assessed by the V_{RC}/V_T percent ratio.

2.3. Video game

We used a popular game called Tetris, which requires players to translate or rotate a series of falling objects in order to construct complete horizontal lines. Each one consisted of a geometrical combination of squares forming L-shaped, I-shaped or T-shaped figures. Two keys were used to control these objects. Each completed line was cleared, thus extending the period of play. Each level ended when the height of the accumulated objects reached the top of the screen. When this occurred within less than 1 min at a given level, this level was re-run until the total duration of the game at that level was at least 1 min. Only a few seconds were necessary for the experimenter to re-run the game. Therefore at high difficulty levels, a second trial (and in some cases a third) was allowed, until a playing period of over 1 min was obtained. The corresponding data were pooled. This procedure provided ventilatory sample of at least 1 min at each difficulty level.

The difficulty of the task was manipulated by increasing the speed and frequency of the falling objects. Each subject ran all 10 difficulty levels, from level 1 to level 10. Levels were played in order of increasing difficulty. This method was selected based on preliminary experiments suggesting that, even with warning instructions, inconsistent changes in level difficulty can cause surprise effects that disrupt the attention process and can sometimes produce negative feelings due to failure to perform the task when high difficulty levels are run first. The total duration of the game averaged 42 ± 9 min (range: 28–55 min).

Performances were assessed in terms of the number of completed (and therefore canceled) horizontal lines. Level 1 was used to train the three subjects who had never played the game before and also to familiarize the subjects with the computer, since most had played the game on other kinds of equipment. Breathing variables were recorded for 9 levels of difficulty (numbered 2–10). Level 2 corresponded to practically zero difficulty and provided the correct baseline for analysis of the specific effects of the load.

2.4. Emotion assessment

The emotional response was assessed by measuring salivary cortisol. It is generally agreed that the delay between the psychological stress and the cortisol response is approximately 20 min (Kirschbaum and Hellhammer, 1994). By chewing a small cotton swab for 30–60 s, subjects stimulated saliva flow-up to a rate that provided sufficient material. Three saliva samples were stored at − 18°C and analyzed using conventional techniques (Lac et al., 1993; Passelergue and Robert, 1995). In addition to salivary cortisol, we assessed emotional responses by the heart rate, T_I/T_{TOT} ratio and thoracoabdominal pattern of breathing, which are considered as potential indices of emotions (Boiten et al., 1994). We did not use verbal reports in this experiment, because our design required repeated assessments of emotion for each level of attentional load. In addition to the general drawbacks (Halo effects, experimenter expectancy, demand characteristics, etc.), we postulated that repetitive verbal reports would have little interpretative value in children aged approx. 9 years.

2.5. Procedure

All the tests were carried out in the afternoon at least 2 h after lunch, in order to start the experiment with stable cortisol levels. All the children knew the leading experimenter personally. She had previously explained to them that all the experiment mainly consisted of playing a video game on a computer. It took place in a room set-up in a private house which all the subjects already knew well. On arrival, they were asked to chew a small cotton swab for cortisol assessment. They were then comfortably seated facing the computer screen, with their hands on the table, their legs relaxed and their feet on the floor. The inductive plethysmograph was calibrated in this position. The subjects were asked to sit in the position described above and not to move throughout the session, except for using two fingers of their preferential hand to play the game. The total duration of the session, including the training phase (level 1), averaged 51 ± 11 min. After the last level had been completed, a second saliva sample was collected and a third one 15 min later.

2.6. Data analysis

Performance in the video game was assessed by recording the number of lines completed. Scores in the video game and cardioventilatory variables were analyzed separately, using ANOVA (Superanova Software, Abacus Concepts, Berkeley, CA) with the game difficulty (nine levels, from levels 2 to 10) as a repeated measure factor. Cortisol levels were analyzed with time as a repeated measure factor (three levels). To take account of the heterogeneous correlations among the repeated measurements with more than two degrees of freedom, we adjusted the degrees of freedom using the Huynh–Feldt epsilon factor. The within-subject main effects and interactions are given along with P-values based on these

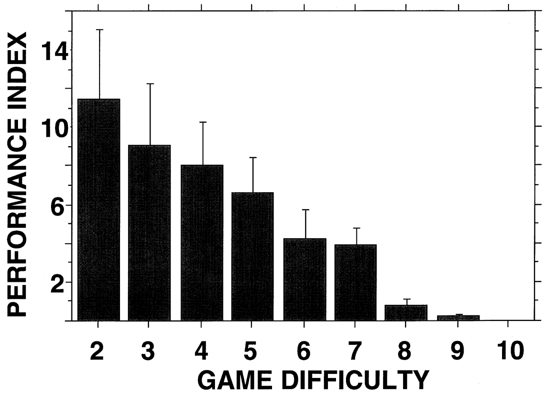

Fig. 1. Performance in the video game as a function of its level of difficulty. Values are group means ± S.E.M. ($n = 10$).

adjusted degrees of freedom (Crowder and Hand, 1991).

3. Results

3.1. Task performance

For all subjects, game difficulty ranged from very easy to almost impossible. Age and sex had no significant effects on performance. Relatively large inter-individual differences were observed, which possibly reflected the amount of previous practice in the game. Performance decreased significantly as a function of difficulty (Fig. 1, $F_{8,72} = 5.46$, $P < 0.0005$).

3.2. Cardioventilatory variables

The only variable which displayed a significant change as a function of game difficulty was T_{TOT}, which increased, from 2.57 ± 0.38 s to 3.61 ± 0.25 s ($F_{8,72} = 3.37$, $P < 0.019$, Fig. 2), as the level of difficulty rose. Very high T_{TOT}-values were obtained at the highest difficulty level (level 10), as confirmed by the significant contrast between this level and the pooled levels 2–9 ($F_{1,72} = 21.88$, $P < 0.0007$, Fig. 2). However, T_{TOT} increased from level 2 to level 10, displaying a significant linear trend from level 2 to level 10 ($F_{1,72} = 17.79$, $P < 0.002$; the test for quadratic trends yielded non-significant results) and also a (marginally) significant linear trend from level 2 to 9 ($F_{1,63} = 4.95$, $P < 0.062$). This confirmed that the effects of load on T_{TOT} were not confined to level 10, but affected the entire range of levels. Individual comparisons showed that T_{TOT} was higher during the difficult levels than during the easy levels in all but one subject.

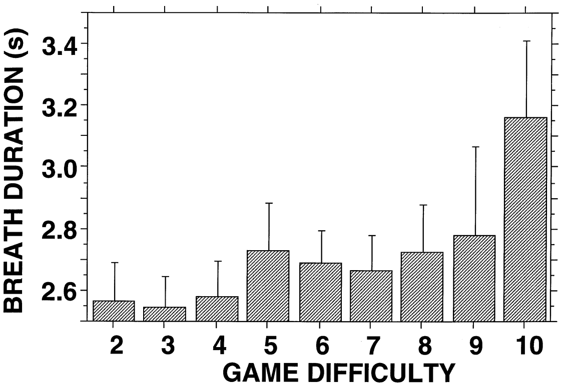

Fig. 2. Breath duration as a function of game difficulty. Values are group means ± S.E.M. ($n = 10$).

The remaining breathing variables ($T_{\mathrm{I}}/T_{\mathrm{TOT}}$, V_{T} and thoracic contribution) did not change significantly as game difficulty increased. We examined T_{TOT} variability and individual ventilatory tracings, to establish whether the increase in T_{TOT} was due to any increase in the frequency of apnea, but no such increase was observed. Mean V_{T} varied from 100 to 120% baseline, regardless of difficulty levels. Heart rate displayed no significant changes (Fig. 3).

3.3. Cortisol assessment

Because of the delayed cortisol response, only the second and third measures corresponded to processes which occurred during the game and were in fact related to the second part of it. The first measure corresponded to the period preceding the subjects' arrival at the place of experimentation. The cortisol level displayed no significant changes during the period of play. A marginally significant decrease in cortisol levels was observed ($F_{2,18} = 3.00$, $P < 0.07$, Fig. 4). Post-hoc contrasts showed that the only significant difference was that found between pre-task and task levels ($F_{1,18} = 5.70$, $P < 0.028$).

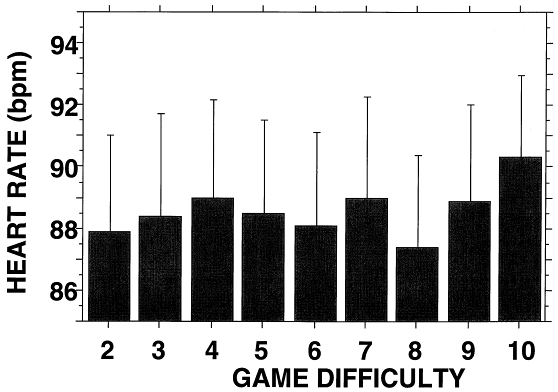

Fig. 3. Heart rate as a function of game difficulty. Values are group means ± S.E.M. ($n = 10$).

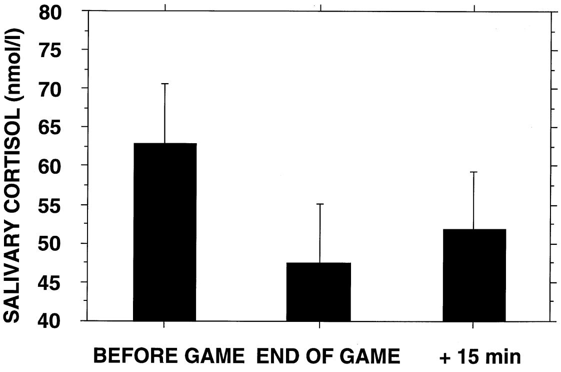

Fig. 4. Salivary cortisol levels before the game, immediately after it ended and 15 min after it ended. Values are group means ± S.E.M. ($n = 10$).

4. Discussion

We observed that the increase in game difficulty was accompanied by a significant increase in breath duration, whereas no concomitant changes were observed for heart rate or the level of salivary cortisol. This level was slightly higher before the experiment than just immediately after it. The first cortisol level corresponded to common situations of natural life before the subjects arrived in the experimental room (transportation, meeting people, etc.). The fact that this first level was higher than post-task levels supported our belief that the emotional impact of the experiment was low. Moreover, none of the variables known to be affected by emotions, such as the T_I/T_{TOT} ratio or thoracic contribution to breathing (Boiten et al., 1994), displayed any significant changes. Taken together, these data suggest, as expected, that the video game had no particular emotional impact. This may be easily explained by the fact that the participants in this experiment were familiar with the experimental environment and with the leading experimenter. In addition, most of them were also familiar with the game before the experiment. Accordingly, we discarded the emotional factor as a possible cause of the changes observed in T_{TOT}. Instead, we considered that these changes were caused by the attentional load imposed by the video game.

One possible limitation of this interpretation is that the present study was not designed to check the non-specific effects of the experimental context. It might be objected that the increase in T_{TOT} was not specifically caused by the increase in the attentional load, but rather to a progressive decrease in pre-task arousal. This possibility is consistent with the fact that the tasks were presented at increasing difficulty levels, thus potentially creating confounding between the effects of difficulty and the effects of time spent playing the game. It is unlikely that the increase in T_{TOT} associated with the increase in task difficulty was merely an effect of time, for several reasons: firstly, any non-specific effect of the experimental context on the breathing pattern would probably also have affected other physiological data, in particular the heart rate. This, however, was not observed. Secondly, because the delay between a psychological stress and the cortisol response is approx. 20 min, we considered that the two post-task cortisol levels reflected processes which occurred during the second part of the game. The cortisol level tended to rise (although not significantly) during this period, which indicated that it was unlikely that stress decreased. Thirdly, direct observation of the subjects while they were playing the game in no way supported the idea that they became increasingly relaxed, even if such observation was necessarily less objective than heart rate or cortisol level assessment. On the contrary, it seemed that the increased mental effort as the difficulty of the game increased was clearly reflected by subjects' facial expressions.

Taken together, these arguments support the above interpretation that the increase in T_{TOT} was in fact caused by the increase in the attentional load and that emotional factors played a minor role in this experiment.

We mentioned that previous experiments designed to show the effects of video games on breathing patterns yielded contradictory results. The present observation that T_{TOT} increased as a function of mental load is in line with the findings of Miller and Ditto (1988). Nevertheless, the magnitude of the effect reported by these authors (an increase in T_{TOT} from 3.1 to 4.0 s, after conversion of frequency data into T_{TOT} data for better comparison) was smaller than in the present study, in which T_{TOT} rose from 2.6 to 3.6 s. As suggested above, the discrepancy between the results of different studies may be due to the presumed difference in the respective roles of emotional and attentional factors. It is possible that the experimental procedure designed by Miller and Ditto (1988) — in particular the fact that subjects were given electric shocks — triggered an emotional response which was superimposed on attentional effects. If so, the emotional response may have counteracted the effects of the attentional load. This may explain why the changes reported by these authors were smaller than those which occurred in the present experiment. It is noteworthy that the control subjects in the experiment performed by Turner et al. (1983) — who were instructed to mimic the actions involved in playing the video game, i.e. to mimic playing without any attentional load but presumably with the emotional effects of the experimental situation — displayed a significant decrease in T_{TOT} from 4.2 to 3.3 s. Shea et al. (1993) reported that children with CCHS and normal children ($n = 5$ in each group) decreased in T_{TOT} during a video game, with no significant between-group difference. Our finding of an increase in T_{TOT} contrasts with these previous observations. This discrepancy may be due to the fact that Shea et al. (1993) presented the game to the subjects only once to avoid the possibility of learned responses. Possibly, the emotional response caused by the novelty of the task may have stimulated breathing, thus counteracting the inhibitory effects on breathing of focusing attention on the game.

As noted above, the decrease in ventilatory activity which may accompany a demanding task was interpreted by previous authors as a natural restriction designed to curb the disturbing effects of breathing on the ongoing task. In the present case, this interpretation raises several difficulties. Unlike what occurs in sound detection tasks, respiratory sounds can hardly have been a disturbance in the present experiment (Rousey et al., 1964). Disturbances of mechanical origin were also unlikely because subjects rested their arm on a fixed support and therefore the arms were not affected by ventilatory movements. We cannot rule out the possibility that respiratory sensations may interfere with any concurrent task in a non-specific way, but it is difficult to specify the exact nature of this interference. Therefore it is difficult to find either empirical or conceptual support for the hypothesis that the participants in the present experiment inhibited breathing in order to facilitate performance of the task. However, it should be noted that the possible disturbing effects of breathing is not necessarily restricted to its sensory consequences. Specifically, it may be postulated that spontaneous breathing in awake subjects does indeed require a minimal amount of attention, as do most motor skills, even those considered as highly automatized (Gallego et al., 1991). According to this hypothesis, we may postulate that this level of attentional resources was no longer available during the game and that spontaneous breathing was consequently disrupted. Schematically, this alternative hypothesis suggests that, during highly demanding tasks, subjects tend to ‘forget’ to breathe, rather than to ‘stop’ breathing.

Our hypothesis that spontaneous breathing during wakefulness requires a certain amount of attentional resources may account for the apparently contradictory results reported by Chin et al. (1996). These authors observed that the video game (Tetris, the same as in the present study) increased mean ventilation, contrarily to the present results. However, in the study by Chin et al. (1996), none of the adult subjects had previous experience of video games and only 15 min of initial practice was allowed, in order to avoid learning effects. This contrasted with the present experiment in which the subjects were already familiar with the game. In the study by Chin et al. (1996), the amount of previous exposure to the game was confounded with the condition regarding the hyperventilation challenge (before and after hyperventilation). Possibly, the first game test elicited a stronger emotional response than the second, so that the inhibitory effects of the attentional load only predominated in the second test.

The fact that our data were obtained in children raises the issue of whether they can be extrapolated to adults. This may be a particularly important issue since in recent years several authors have suggested that learning processes are major contributors to respiratory homeostasis [e.g. Somjen (1992)]. Under this hypothesis, the role of the reflex chemoreceptor feedback is to provide the early experiences without which the central nervous system is unable to learn to adapt the appropriate feed-forward controls when the environment or the organism undergo changes and to fine-tune the breathing pattern determined by feed-forward mechanisms (Somjen, 1992). Thus, interference effects of attentional processes on the breathing pattern may depend on these learning processes and therefore may not be the same in childhood and adulthood.

In conclusion, this study supports the idea that in certain circumstances, the act of focusing attention on a task may have an inhibitory effect on breathing and that previous contradictory reports in this respect were due to the confounding effects of emotion. However, the present study only provides a partial answer to this general concept. Our belief that the present experimental situation did not produce any strong emotional impact is based on the absence of significant changes in several psychophysiological variables (cortisol levels, heart rate, etc.). Future experiments should make it possible to separate the manipulation of the difficulty of the task from its emotional impact, possibly by using films both as emotional triggers and experimental material for demanding tasks.

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