Contribution of Chemical and Non-Chemical Drives to Breath-Holding Determined by Visual Analog Scale (VAS)

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Summary Chemical and non-chemical contributions to breath-holding time (BHT) were directly determined by using a visual analog scale (VAS). These values were compared with those indirectly calculated from the method proposed by Godfrey and Campbell (1968). The magnitude of non-chemical factor at low $P_{CO_2}$ in our study was substantially less than the one obtained by the above investigators. We conclude that Godfrey and Campbell's model postulating linear augmentation of non-chemical sensation is inappropriate to explain dyspnea profile during breath-holding.

Key words: breath-holding, chemical factor, non-chemical factor.

Breathlessness is an important determinant to limit performance in both physiological and pathophysiological respiratory activities. In the case of dyspnea during breath-holding (BH), Fowler (1954) first demonstrated that repeated BH was possible by using the exhaled airway gas at the breaking point (BP). Therefore, it is now known that breath-holding time (BHT) is not only determined by the chemical composition of blood gas (chemical drive) but also by the factors related to the cessation of respiratory movement (non-chemical drive).

Godfrey and Campbell (1968) attempted to resolve the relative contribution of these two drives by repeating BH with approximately 7% CO$_2$ in O$_2$. They observed the linear elevation of end-tidal $P_{CO_2}$($P_{etiCO_2}$) with time ($t$) and the inverse linear relationship between progressively shortened BHT with successively increased $P_{etiCO_2}$ from repeated BH trials. The product of the former slope ($P_{etiCO_2}$-$t$ slope) and the latter ($S_{BH}$) was assumed to represent the relative contribution of the
chemical drive in BH, and the remaining portion was considered as non-chemical drive. Their estimation was based on the assumption that both chemical and non-chemical drives increased linearly with time and also that the breathless sensation increased linearly until BP.

Using a visual analog scale (VAS) which quantitatively evaluates the sensory score for breathlessness based on Stevens' psychophysical law (Stevens, 1957), we directly measured the degree of dyspnea for both drives and examined the validity of the assumption mentioned above.

Eight healthy subjects (6 males and 2 females) participated in this study with informed consent. Seven percent CO$_2$ in O$_2$ in an amount of 80% VC of each subject was taken into an anesthesia bag, which was connected to a mouthpiece via a three-way stopcock. The subject first breathed room air in a resting condition with the mouthpiece in place, then expired maximally. Thereafter the subject repeated twice to respire all the amount of the test gas in the bag and held his breath after full inspiration. The subject measured the VAS score by himself and adjusted the location of an indicator by turning a hand-controlled potentiometer. When he culminated in BP, he expired maximally and immediately inspired all the expired gas, then held his breath again. VAS scaling was resumed. Such BH procedure was repeated at least 4–5 times during one run. Each subject made 5 runs with a 15-min rest in between.

VAS scaling was also conducted during spontaneous breathing of 7% CO$_2$ in O$_2$. This run was made 2 times in each subject, with interruption for at least a 15-min period.

$PET_{CO_2}$ was measured continuously during free breathing and at full expiration following BP by an infrared analyzer (Sanei, 1H21). VAS score was graded from 0 to 100: i.e., not at all breathless, 0; maximal breathlessness, 100 (Adams et al., 1985). Intermediate scores were designated as follows: very very weak (just noticeable), very weak, weak, moderate, somewhat strong, strong, and very strong at 5, 10, 20, 30, 50, 70, and 90, respectively. Both $PET_{CO_2}$ and VAS scores were continuously recorded on a pen-recorder.

Figure 1 illustrates the actual recording of one BH run. $PET_{CO_2}$ was seen to increase linearly with time. This is because $PET_{CO_2}$ was equilibrated with alveolar-arterial $P_{CO_2}$, thus yielding the open loop condition in CO$_2$ transport system (Read and Leigh, 1967). Alleviation of breathlessness can be seen just after strong respiratory movement at BP. This magnitude of VAS drop was considered to represent non-chemical and the remaining portion of VAS chemical contributions to BH, respectively. The amount of VAS drop at BP was found to diminish with repeating BH maneuver during the run. It was noted that the scaling of the VAS score was reproducible in all the subjects examined in this study.

Figure 2 illustrates the averaged magnitude of % chemical contribution to BH obtained from VAS scaling at different $PET_{CO_2}$ levels. The horizontal column with hatched area indicates the mean ± S.D. value calculated by the method of Godfrey and Campbell (1968). Apparent discrepancy is seen at low $PET_{CO_2}$, i.e., the first
Fig. 1. Simultaneous recording of airway $P_{ET}CO_2$ and VAS during repeated BH trials with 7% CO$_2$ in O$_2$. End-tidal $P_{CO_2}$ ($P_{ET}CO_2$) increased progressively at successive BP's. VAS score dropped immediately after strong respiratory movement at BP. The magnitude of VAS drop progressively decreased with increasing BH trials. BP, breaking point; VAS, visual analog scale; BH, breath-holding.

BH in the run.

Figure 3 shows the VAS score against $P_{ET}CO_2$ during free CO$_2$ rebreathing. A good linearity is observed.

Since VAS increased linearly with linear augmentation in $P_{ET}CO_2$ in the free breathing, the first assumption by Godfrey and Campbell (1968) proposing direct proportionate relationship between respiratory sensation and $P_{CO_2}$ appeared to be validated by the present study. On the other hand, the magnitude of chemical contribution at low $P_{ET}CO_2$ determined by the present VAS scaling exceeded substantially that of Godfrey and Campbell (1968). It follows therefore that non-chemical contribution must be significantly ($p<0.01$) lower than that predicted by their model in this $P_{ET}CO_2$ region. Four possibilities to explain this discrepancy were considered. First, profile of augmenting dyspnea intensity by the non-chemical factors is exponential, so that its contribution to the first BH is relatively weak. Secondly, stimulus interaction between $P_{ET}CO_2$ and non-chemical factors increases with augmentation of $P_{ET}CO_2$. Third, the number of respiratory movement at BP
Fig. 2. Relative contribution of chemical drive to BH. The horizontal column with hatched area represents the mean ± S.D. value calculated by the method of Godfrey and Campbell (1968). The chemical contribution at low $P_{ETCO_2}$ is substantially higher than the horizontal column. Each closed circle with bars indicates mean ± S.E.

Fig. 3. VAS score against $P_{ETCO_2}$ during spontaneous breathing of 7% CO$_2$ in O$_2$. Each closed circle with bars indicates mean ± S.E.

is not sufficient to eliminate the non-chemical factors accumulated during BH, so that its contribution to BH may have been evaluated unduly low with repetition of BH. This possibility was disproved by Godfrey and Campbell (1969), but we found that subjective feeling of discomfort increased with repeating BH. Therefore, this may need to be re-investigated. Fourth, the magnitude of chemical and non-chemical contributions by the method of Godfrey and Campbell (1968) was determined on the basis of only one value from a single run, whereas our data were determined at several successive BP's. Therefore, the former value cannot represent the possible time-dependent change during the run. Further investigation is necessary to clarify these problems.
REFERENCES


