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INTERRELATIONSHIPS BETWEEN AMPLITUDE AND PERIOD OF A CONTINUOUS HAND MOVEMENT[1]

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Summary.—In two experiments, subjects were trained to operate a joystick-type lever in a continuous to-and-fro movement. In the first experiment, 21 subjects had to control the "water" level of a cistern displayed on a video screen and were free to adopt any period-amplitude strategy. In the second experiment, 18 subjects had to adjust either the amplitude or the duration of successive cycles of lever pumping to target values indicated by a moving segment. Results show that (1) during steady states the amplitude and the duration of cycles remained positively correlated; (2) these variables were negatively correlated when the flow rate varied; and (3) subjects adjust the flow rate to changing target values by varying the amplitude of the cycles and only secondarily by varying duration. A superiority in perception of amplitude variations over time components could account for this. All the above features have previously been observed for breathing, suggesting that these are general properties of continuous periodic movements whatever their nervous control may be.

The analysis of kinematic ventilatory data (inspiratory and expiratory durations, tidal volume, flow rate, etc.) provides a suitable means for identifying the central mechanisms of respiratory control. Linear correlations among these kinematic variables have been observed. During steady states, i.e., when ventilatory flow is constant, the amplitude and duration of breaths present small fluctuations and remain positively correlated. When flow rate is stimulated (exercise, hypercapnia, hypoxia), these variables vary in larger proportions; negative correlations have been reported for transient states and between the mean-values for various steady states (Bechbache, Chow, Duffin, & Orsini, 1979). An imposed change in chemical drive results in an immediate compensatory change in breath volume rather than frequency (Pearson & Cunningham, 1973). Comparison of various steady states shows that for low levels of ventilation the increase in ventilation is mainly achieved by an increase in breathing amplitude, the time parameters remaining constant (Newson-Davis & Stagg, 1975). These formal properties of breathing patterns appear whatever the technique used for stimulating breathing (Hey, Lloyd, Cunningham, Jukes, & Bolton, 1975).

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The purpose of the present work is not to discuss the neurological interpretations of the above results in terms of nervous control of breathing but to investigate whether these kinematic features are specific to breathing or if they can be observed in other periodic continuous movements. We have therefore carried out a correlational analysis of a simple skill, based on analysis of a task requiring continuous and periodic movement of the hand. Correlations between amplitude and period were investigated in two different conditions, (1) when subjects had to match the mean velocity of the movement to a time-varying target but were free to combine amplitude and frequency as they wished and (2) when subjects had to adjust one of these two variables to prescribed targets.

Experiment 1

Method

Subjects.—Twenty-one university students majoring in psychology served as subjects. They reported normal or corrected-to-normal vision.

Material.—The device was composed of a 30-cm plastic joystick-type lever, directly connected to a linear potentiometer. The output signal of the potentiometer was processed by a microcomputer (Apple IIe) following transmission via an 8-bits A/D transducer (Progetec ADC 12B25M). The lever could be moved from left to right, with an angular rotation of 55° (generating a 28-cm displacement at the end of the lever). A cycle was defined as a complete-to-and-fro movement (left to right and back to left). The amplitude of each cycle was expressed as the difference (in degrees) between the far-left and the far-right positions of the lever.

Moving the lever had an action similar to hand-pumping. The left-to-right component of the movement simulated the filling of a cistern displayed on the video screen. The cistern was permanently submitted to a variable outflow, hereafter referred to as "leakage". Leakage was a discontinuous function of time, taking integer values ranging from 2 to 10, as represented in Fig. 1. Two long plateaus were included to investigate the pattern of movement during steady states. The function represented in Fig. 1 was reproduced three times in immediate succession during a session (a session therefore included six plateaus). On the video screen, a fixed arrow pointed to the target level of the cistern.

Procedure.—Subjects were seated facing the video screen. They operated the lever with the right hand. Subjects were instructed to adjust the cistern level to the target value indicated by the arrow as accurately as possible, through continuous and regular movement of the lever. No particular adjustment strategy, in terms of changing frequency or amplitude, was indicated.

Results

Amplitude-leakage and duration-leakage correlations.—For each subject,

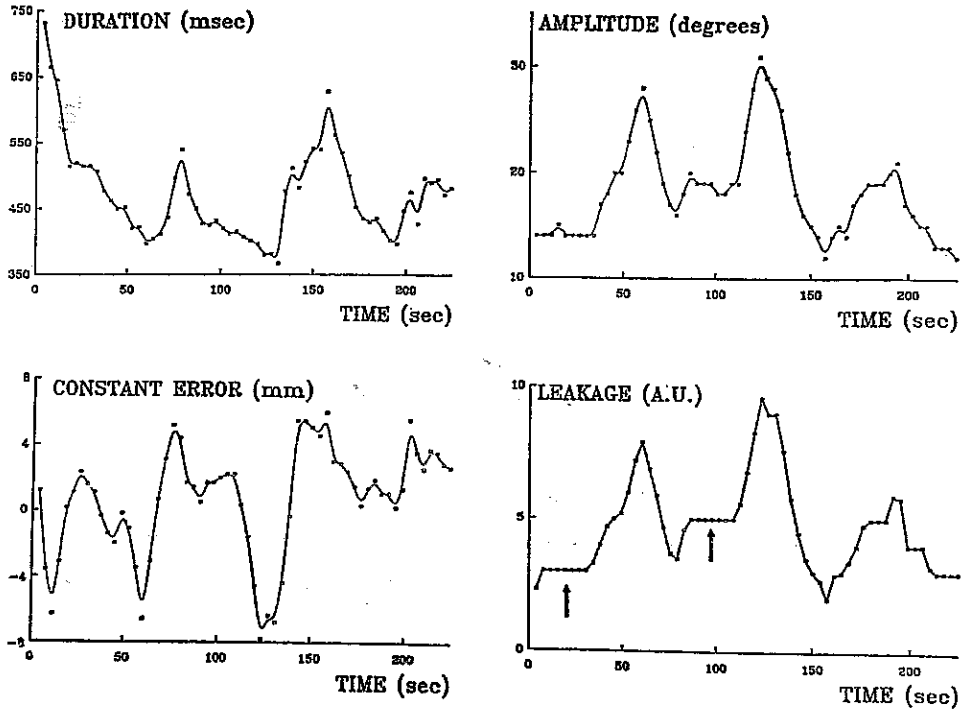

FIG. 1. Amplitude and duration as a function of time along with leakage values and deviation from the target (Constant Error). Values are over-all subjects' means and the over-all mean for each of the three identical leakage sequences (A.U.: arbitrary units). The arrows indicate the two plateaus.

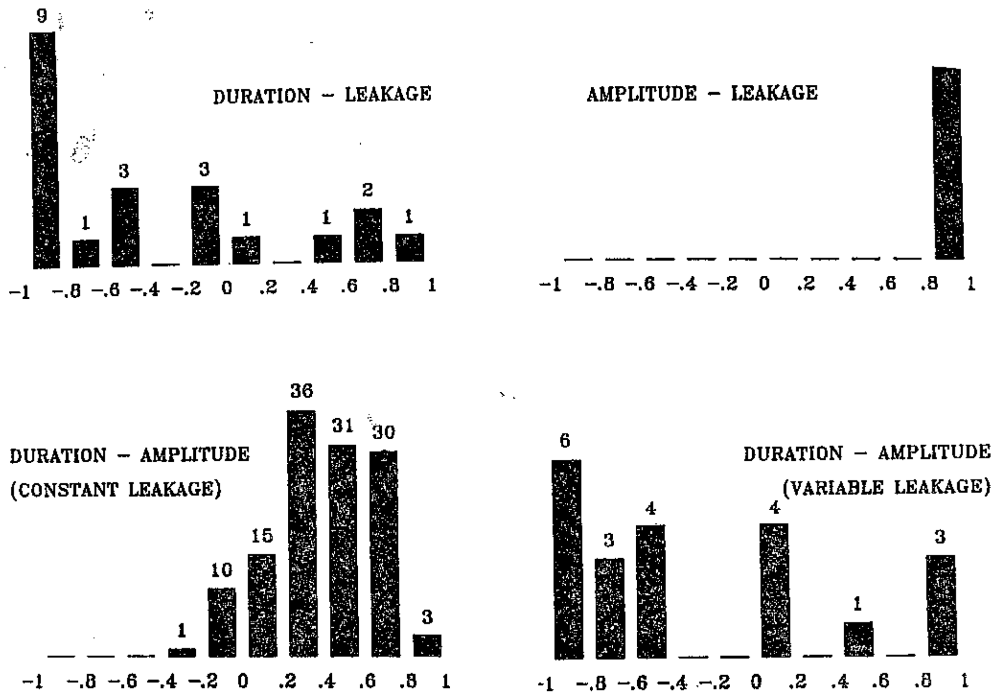

FIG. 2. Distributions of Pearson correlations between duration and leakage (upper-left histogram), amplitude and leakage (upper-right histogram), duration and amplitude for constant (lower-left histogram) and variable (lower-right histogram) leakage in Exp. 1. Values are numbers of subjects ($N = 21$, except for the duration-amplitude coefficients for constant leakage: six values per subject, $N = 126$).

the mean amplitude of the lever movement was computed for each of the nine leakage values. The individual product-moment correlations between amplitude and leakage values are shown in Fig. 2, upper right panel. All the coefficients reached high positive values ($p < .01$), and they averaged .978, after transformation of r to z (cf. McNemar, 1969, p. 158). Correlations for mean durations of cycles and leakage values were similarly computed and are shown in Fig. 2, upper-left panel. These coefficients were far more heterogeneous: most were negative (10 reached $p < .05$), but three were significant and positive. This pattern of results suggests that most subjects adapted the movement to the variation of the leakage by varying the amplitude of the cycle and only secondarily by varying duration.

Duration-amplitude correlation.—Individual correlations between duration and amplitude of the cycles were computed separately for steady and transient states. For the steady states, each of the six plateaus served as a basis for computing one coefficient. For the transient states, the coefficients were computed from the nine mean values for amplitude and duration corresponding to the nine leakage values. Results are shown in Fig. 2, lower panels: during constant leakage, amplitude and durations of cycles presented variations and were positively correlated, such that the mean flow tended to be constant across cycles. For the nine leakage values, the duration and the amplitude tended to be negatively associated: when the flow increased, the duration decreased whereas amplitude increased. Of the 21 coefficients 13 were negative (nine at $p < .05$); three were significant and positive (they correspond to the three subjects who exhibited positive leakage-duration correlation).

For illustrative purposes, variations in amplitude and duration as a function of time are presented in Fig. 1 along with leakage values and the deviation from the target (Constant Error). The data were averaged over subjects and over the three identical leakage functions used for each session. The initial portion of the duration curve (which reflects in part the initial data of the session) indicates a major change which may be attributed to subjects' difficulty in performing the task at the beginning of the session. The difference between the respective weights of amplitude and duration appears clearly: amplitude variations closely parallel flow variations, which contrast with the more erratic pattern of duration curve.

EXPERIMENT 2

Method

Subjects.—Eighteen students majoring in psychology who had not participated in the previous experiment served as subjects.

Material and procedure.—The experimental setup was identical to the one used in Exp. 1. However, visual feedback was provided for either duration or

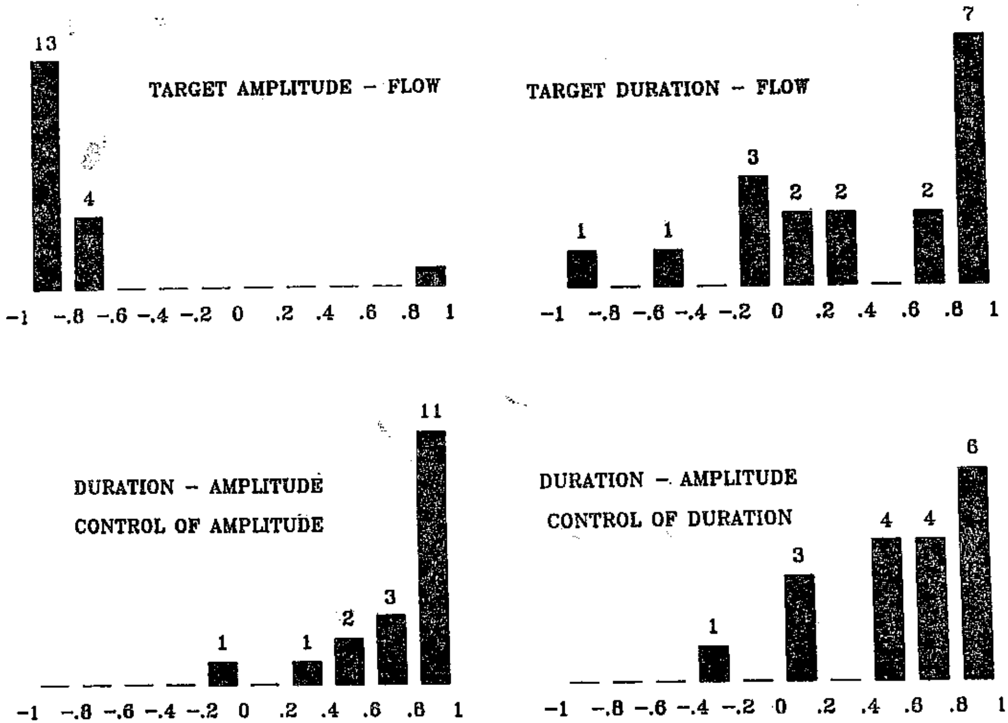

FIG. 3. Distributions of Pearson correlations between target amplitude and flow (upper-left histogram), target duration and flow (upper-right histogram), duration and amplitude during control of amplitude (lower-left histogram) and control of duration (lower-right histogram) in Exp. 2. Values are numbers of subjects ($N = 18$).

amplitude of the left-to-right component of each cycle. This was provided during the right-to-left component of cycles and consisted of a moving horizontal segment displayed on the video screen. The target was represented by a horizontal line; subjects were instructed to maintain the moving segment as close to this line as they could. There were six different randomly ordered target values (i.e., six different positions of the line). Target durations ranged from 0.4 to 1.5 sec., and target amplitude ranged from 18 to 47°.

At the beginning of the session, the notions of period and amplitude of the periodic movement were briefly explained to all subjects. Subjects were randomly divided into two groups of nine. Each session was divided into two phases: Group 1 subjects practiced duration control (with corresponding feedback) during the first phase and amplitude control during the second phase. This order was reversed for Group 2. Subjects were informed at the beginning of each phase which variable (amplitude or duration) was relevant.

Results

Dependent variables were the duration and amplitude of the left-to-right component of each cycle. Data were averaged separately for each of the two successive tasks and for each of the six targets. Data from the two groups (amplitude, duration, and absolute deviation from the target) were not significantly different, excluding any effect of task order. These data were pooled for correlational analysis. Product-moment correlations were computed separately for each task for the six pairs of mean-values (one for each target value); these data are shown in Fig. 3 (the mean flow was computed as the ratio amplitude/duration).

Correlation target amplitude-flow and target duration-flow.—The upper-right diagram shows heterogeneous values which nevertheless tend to be positive. In contrast, the upper-left diagram shows a high homogeneity of data. When controlling amplitude with large targets, subjects tend to decrease the velocity of their movement, which results in a decrease of the mean flow.

Correlation duration-amplitude for the two tasks.—A strong positive correlation was observed when subjects controlled the amplitude, similar to what was observed during the steady states in the previous experiment. On the other hand, when controlling duration, many subjects dissociated this variable from the amplitude, which could change in either direction or remain steady. This accounts for the number of nonsignificant correlations between amplitude and duration in the duration task, as well as the dispersion shown in the target duration-mean flow diagram.

Discussion

In the present study, some of the methods used to investigate breathing patterns have been applied to a nonventilatory movement. The manual movement under consideration was in no way a model of breathing, either from a dynamic or from a kinematic point of view. Right-left and left-right components were both active (although only the latter contributed to filling the cistern in the first experiment or setting the moving segment in the second experiment); this contrasts with the important differences between (active) inspiration and (passive) expiration. Moreover, this skill was mainly voluntary whereas breathing pattern studies are mainly concerned with automatic breathing. These and many other differences make direct comparison difficult. However, they do not negate the aim of this study which was to clarify the general properties of distinct continuous and periodic movements.

As long as the task did not require flow modifications, amplitude and duration were positively associated. This trend was observed when subjects were instructed to maintain constant leakage (Exp. 1) and when subjects attended to either amplitude or duration (Exp. 2). Ventilatory data present similar characteristics. During spontaneous breathing, the total duration of cycles is related to the tidal volume (Priban, 1963). This correlation was also observed in a previous experiment when subjects had to control inspiratory duration in conditions similar to those of the second experiment: subjects tended to increase the amplitude of breathing at the same time despite the discomfort it produced (Gallego, Ankaoua, Lethielleux, Chambille, Vardon, & Jacquemin, 1986).

When the task required flow modifications, the amplitude and the duration of cycles were negatively related, which parallels Bechbache, *et al.*'s (1979) report on ventilatory data. The increase of flow relied on both increase of amplitude and decrease of period, but leakage variations were more accurately related to amplitude than to period, as indicated by the results of Exp. 1. To compensate for leakage, subjects are more likely to adopt a strategy based on amplitude than on frequency changes. Breathing behavior is also characterized by a pronounced increase in amplitude for augmenting mean flow rate, at least at low levels of ventilation: during incremental load exercises, inspiratory and expiratory durations remain essentially constant with changes in tidal volume up to a threshold of 1.41, then inspiratory and expiratory durations decrease as volume increases (Lind & Hesser, 1982). A similar strategy has been observed during rebreathing (Clark & Von Euler, 1972). As regards voluntary control of breathing, studies have shown that it is easier to keep ventilation at a constant level by adjusting tidal volume to imposed modifications of frequency than the reverse (Katz-Salamon, 1984). This strong asymmetry between amplitude and frequency in the control of a completely different movement has also been reported by Den Brinker, Stabler, Whiting, and Van Wieringen (1986): in their study, subjects had to perform a slalom-type ski movement on a simulator comprising a platform moving over bowed rails. They were instructed to match the frequency or the amplitude to fixed values or to perform in as fluent a way as possible. Subjects received informative feedback either on amplitude, frequency, or fluency. Subjects who attended to amplitude were not only successful with respect to this parameter but also with respect to frequency and fluency. In contrast, subjects who attended to frequency did less well on the amplitude measure than the other two groups. This result, along with the present study, suggests that the control of a continuous periodic movement does not rely on amplitude and frequency in similar ways: amplitude appears as the leading variable.

The above observations suggest that information related to amplitude and time components of a periodic movement are processed by the subject in different ways. The control of amplitude (Exp. 2) is basically a positioning task, which is correctly achieved by slow adjustments, in particular for large target displacements which are more difficult to perform. Such an ubiquitous strategy might account for the low between-subjects variability observed on the amplitude-control task. Conversely, the large between-subjects variability in correlations for time control suggests that the time-production task generates a variety of strategies. In some subjects, this control could be mainly based on kinesthetic cues, the duration being linked to the amplitude of displacement (high positive correlation). Other subjects might adopt a counting strategy: in this case, the amplitude and time components of the movement are largely dissociated (low correlation). Lesser acuity in estimating the time components of the movement, as compared with perception of amplitude which is directly based on movement-related proprioceptive information, might explain the leading role of amplitude, as Katz-Salamon (1984) has suggested for voluntary breathing.

These similarities between breathing and the present skill may indicate that both movements present common kinematic features despite the different ways they are centrally controlled. Breathing frequency and amplitude are generally assumed to be controlled by the bulbopontine rhythm generator to fulfill metabolic and behavioral requirements while minimizing the force or work of the respiratory muscles (Hämäläinen, 1983). In particular, this may be related to the principle of "maximum comfort" of breathing suggested by Otis, *et al.* (1950), which is probably related to minimization of accelerations. The positive correlation between amplitude and period observed in the present study, which has precisely this same effect, might be similarly interpreted.

The present work shows that analysis of breathing pattern cannot be reduced to its metabolic aspects and must also be analysed in the context of general motor skills. Periodic and continuous skills, based on time and amplitude components may indeed share some common features. The joint investigation of the cognitive strategies, perceptual information, and mechanical laws underlying the control of these features may provide insights into their origin.

REFERENCES

BECHBACHE, R. R., CHOW, H. H. K., DUFFIN, J., & ORSINI, E. C. (1979) Effects of hypercapnia, hypoxia, exercise and anxiety on the pattern of breathing in man. *Journal of Physiology*, 293, 285-300.

CLARK, F. J., & VON EULER, C. (1972) On the regulation of depth and rate of breathing. *Journal of Physiology*, 222, 267-295.

DEN BRINKER, B. P. L. M., STABLER, J. R. L. W., WHITING, H. T. A., & VAN WIERINGEN, P. C. W. (1986) The effects of manipulating knowledge of results on the learning of slalom-type ski movements. *Ergonomics*, 29, 31-40.

GALLEGO, J., ANKAOUA, J., LETHIELLEUX, M., CHAMBILLE, B., VARDON, G., & JACQUEMIN, C. (1986) Retention of ventilatory pattern learning in normal subjects. *Journal of Applied Physiology*, 61, 1-6.

HÄMÄLÄINEN, R. P. (1983) Optimization of respiratory airflow. In B. J. Whipp & D. M. Wiberg (Eds.), *Modelling and control of breathing*. New York: Elsevier Biomedical. Pp. 181-188.

HEY, E. N., LLOYD, B. B., CUNNINGHAM, D. J. C., JUKES, M. G. M., & BOLTON, D. P. J. (1966) Effects of various respiratory stimuli on depth and frequency of breathing in man. *Respiration Physiology*, 1, 193-205.

KATZ-SALAMON, M. (1984) Assessment of ventilation and respiratory rate by healthy subjects. *Acta Physiologica Scandinavica*, 120, 53-60.

LIND, F., & HESSER, C. M. (1984) Breathing pattern and lung volume during exercise. *Acta Physiologica Scandinavica*, 120, 123-129.

MCNEMAR, Q. (1969) *Psychological statistics*. New York: Wiley.

NEWSON-DAVIS, J., & STAGG, D. (1975) Interrelationships of the volume and time components of individual breaths in resting man. *Journal of Physiology*, 245, 481-498.

OTIS, A. B., FENN, W. O., & RAHN, H. (1950) Mechanics of breathing in man. *Journal of Applied Physiology*, 2, 592-607.

PEARSON, S. B., & CUNNINGHAM, D. J. C. (1973) Some observations on the relation between ventilation, tidal volume and frequency in man in various steady and transient states. *Acta Neurobiologiae Experimentalis*, 33, 177-188.

PRIBAN, I. P. (1963) An analysis of some short term patterns of breathing in man at rest. *Journal of Physiology*, 166, 425-434.

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