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CARDIOVENTILATORY RESPONSES DURING REAL OR IMAGINED WALKING AT LOW SPEED

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INTRODUCTION

There is now evidence that mental representation of willed motor actions involves to a large extent the same cortical areas that are activated during motor preparation and execution, respectively (see refs. in 7, 10, 14), including the primary motor cortex (6, 15, 16). These changes are conceivably related to conscious rehearsal of neural circuits involved in motor programs (10). Less consistent increases of activity in primary sensorimotor cortical areas have been found in neuroimaging studies during imagination of standing, walking or cycling, motor acts which are primarily based upon automated subcortical and spinal programs (8, 12, 17).

An interesting issue regards the extent to which vegetative changes, physiologically occurring during actual exercise, are also present during inner representations of motor acts. Previous studies have shown that heart rate and ventilation parameters are affected by imagination of exercise in healthy controls (e.g., 3), more so under hypnosis (17). These vegetative responses are likely to be of central origin, because no evidence for changes in muscle metabolic activity during imagined exercise was found using nuclear magnetic resonance spectroscopy (4). Watching a rowing race leads to an increase of ventilation and heart rate in normal volunteers and in athletes (2); moreover, during observation of locomotion breathing rate increases were related to the actor's running speed, suggesting the activation of central mechanisms related to action performance (13). The above mentioned data were obtained for observed or imagined exercise of moderate to medium intensity. They have shown a significant increase of breathing frequency, leading to an increased ventilation, essentially unchanged gas exchange, and hence a decreased alveolar PCO_2. In the present study we investigated cardioventilatory variables during imagined exercise, with the aim of extending its range towards the low to very low end of the intensity spectrum.

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METHODS

Fourteen healthy volunteers (22-44 years old; 8 females, 6 males) were studied after informed consent and approval of the local Committee on Ethics. All of them practiced physical activities at regular intervals, but none at agonistic levels.

The walking test was performed on a treadmill (Saturn, Germany). Throughout the exercise, the subjects were holding themselves at the life-belt and wore a nose-clip: they breathed through a mouthpiece into a two-way breathing valve (dead space, 71 ml). Oxygen consumption (VO_2), CO_2 production (VCO_2), ventilation (VE), as given by the product of tidal volume (VT) and respiratory rate (R-R), and heart rate (HR) were measured utilising a telemetric portable system (K4 RQ, Cosmed, Rome, I) on a 15 seconds time basis. The VO_2 was expressed at STPD, and VE at BTPS conditions. $PACO_2$ was calculated from the ratio of VCO_2 to alveolar ventilation (VA) according to the formula: $PACO_2 = VCO_2$ (STPD)/VA (BTPS) *K; where the constant K accounts for the different conditions used to report the ventilatory and gas exchange volumes (18). In turn, VA was obtained subtracting from VE the dead space ventilation (= VD * R-R) where the dead space (VD) was assumed to be equal to the sum of the subjects' anatomical dead space (2 ml/kg) and the apparatus dead space (71 ml).

At the beginning of the experiment, physiological variables were measured at rest during sitting and standing (S); then the treadmill was started and the subjects walked in different blocks (5-6 min each) at 2.0 km/h, 3.5 km/h and 5.0 km/h. Block (walking speed) order was randomised between subjects. At the end of each walking step, subjects were placed on a wood-board, suspended about 5 cm above the treadmill, and they were instructed to 'imagine themselves walking at the speed performed immediately before, without actually moving' (imagined locomotion session). To facilitate motor imagery, task order was not randomized, the imagined exercise always following the real one, and the treadmill was moving at the same speed as the immediately preceding walking test. The instructions emphasized that subjects had to perform kinaesthetic (first person), but not visual (third person) imagery (9).

The 5-6 minutes block duration for each walking speed was chosen to ensure that steady state conditions were reached; during the mental locomotion session, each imagined walking step lasted 3 minutes. Each step, either involving actual or mental locomotion, was separated from the next by an interval of 4-6 min, for return of cardioventilatory parameters to the resting level.

Statistical analysis was performed by repeated-measures analysis of variance (ANOVA), with Task (Actual or Imagined walking) and Walking Speed (0, 2, 3.5, 5 km/h) as the within-subjects factors. Paired comparisons were performed by the Student's t test. A P value less than 0.05 was assumed as the significance level. Unless otherwise stated, all values are expressed as mean ± SD.

RESULTS

No significant difference was found in any measured variable between values during sitting or standing baseline conditions, with the exception of HR which changed from 74 ± 9 to 80 ± 8 beats/min ($t = 4.3$, $P < 0.001$). The other values were: 4.33 ± 1 *vs.* 4.47 ± 1.5 ml/min/kg (VO_2), 9.99 ± 1.8 *vs.* 9.66 ± 2.2 l/min (VE), 0.81 ± 0.2 *vs.* 0.81 ± 0.2 l (VT), 13.58 ± 3.5 *vs.* 13.25 ± 2.6 breaths/min (RR), 29.65 ± 3.1 *vs.* 28.83 ± 4.5 mm Hg ($PACO_2$).

During actual exercise, HR increased from 80 ± 8 (S) to 85 ± 8 (2 km/h), 90 ± 10 (3.5 km/h), 101 ± 13 (5 km/h) beats/min ($F = 33.74$, $P < 0.001$). By contrast, no significant increase was found during imagined walking, mean HR being 83 ± 11 (2 km/h), 84 ± 11 (3.5 km/h), 84 ± 10 (5 km/h) ($F = 1.77$, ns). The Task difference was significant ($F = 14.84$, $P < 0.002$).

Oxygen consumption increased as a function of actual walking speed, as expected, from 4.47 ± 1.50 ml/min/kg (S) to 9.20 ± 1.0 (2 km/h), 11.13 ± 1.3 (3.5 km/h), 14.77 ± 1.6 (5 km/h) ($F = 223.8$, $P < 0.001$). During imagined exercise, a small increase was also found ($F = 3.17$, $P < 0.05$), which was independent of imagined speed: 4.72 ± 0.8 (2 km/h), 4.91 ± 0.8 (3.5 km/h), 4.88 ± 0.8 (5 km/h); the Task difference was significant, with higher values during real exercise ($F = 551.68$, $P < 0.001$).

Ventilation increased according to actual walking speed, as expected, from 9.66 ± 2.20 l/min (S) to 15.57 ± 2.5 (2 km/h), 18.46 ± 2.7 (3.5 km/h), 24.05 ± 3.7 (5 km/h) ($F = 104.91$, $P < 0.001$). During imagined exercise, a small increase was also found ($F = 3.71$, $P < 0.05$), which was significant at the higher imagined speed: 10.34 ± 2.0 (2 km/h), 10.42 ± 1.8 (3.5 km/h), 10.91 ± 2.1 (5 km/h); again, the Task difference was significant, with higher values during real exercise ($F = 314.43$, $P < 0.001$) (Fig. 1).

Mean percentage changes of respiratory rate, tidal volume and $PACO_2$ are shown in Figure 2.

Respiratory rate increased both during actual ($F = 23.57$, $P < 0.001$) and imagined ($F = 3.39$, $P < 0.05$) walking: significantly higher changes were found during actual exercise ($F = 23.27$, $P < 0.001$). By contrast, VT increased during real ($F = 12.29$, $P < 0.001$), but not during imagined walking ($F = 1.04$, ns): the difference between the two tasks was significant ($F = 18.30$, $P < 0.001$), as was the Task x Speed interaction ($F = 19.73$, $P < 0.001$). The estimated $PACO_2$ values showed no difference with respect to baseline during imagined walking ($F = 1.68$, $P > 0.15$); during actual exercise, $PACO_2$ values were higher both with respect to baseline ($F = 14.78$, $P < 0.001$) and to values during the imagination task ($F = 24.30$, $P < 0.001$). No significant $PACO_2$ difference related to walking speed was found in either condition ($F = 2.77$, ns).

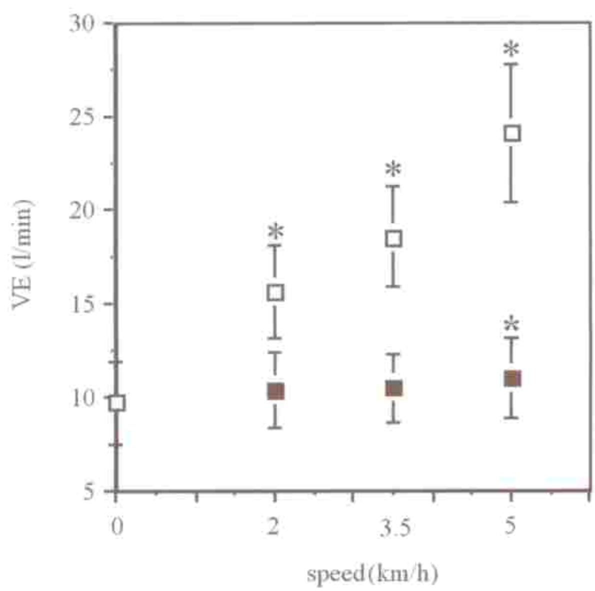

Fig. 1. - *Pulmonary ventilation (VE, l/min, BTPS) ± S.E. (n = 14) is reported as a function of walking speed (km/h): 0 km/h = standing on the treadmill.*
Open squares, real walking; full squares, imagined walking.
*: significant differences from standing rest, $P < 0.05$.

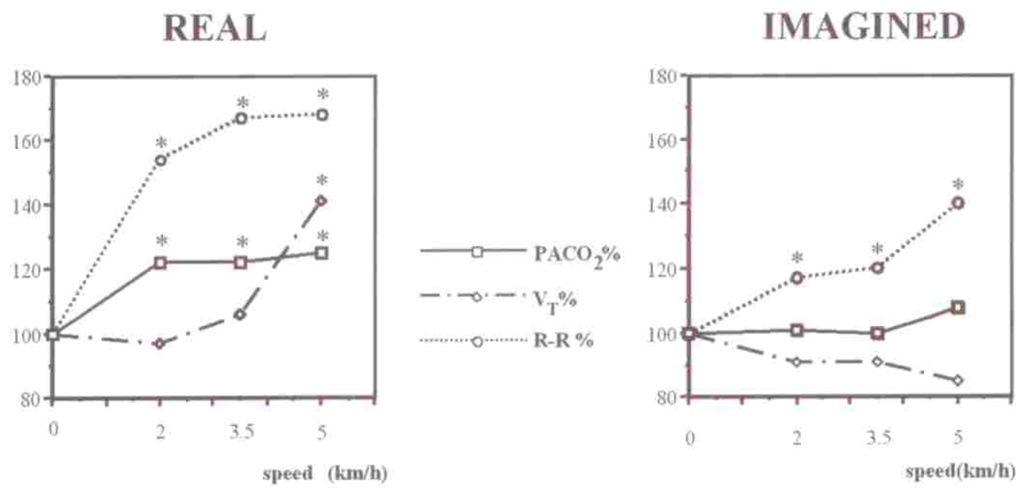

Fig. 2. - *$PACO_2$, VT and R-R are reported as a percentage of the value observed when standing on the treadmill, as a function of the walking speed during real or imagined walking.*
*: significant differences from standing rest, $P < 0.05$.

DISCUSSION

Our results unravel the pattern of ventilatory changes during imagined walking at low speed, confirming and extending the results of previous studies (see Introduction) on vegetative correlates of imagined exercise.

The low baseline $PACO_2$ values, both in sitting and standing conditions, are likely to be due to a mild anxiety level and anticipatory effect, leading to hyperventilation.

As for imagined exercise, the very mild increase in oxygen consumption (see also 3), which was independent of the imagined speed, cannot be fully explained at present. It may be hypothesized that it is due at least in part to an involuntary increase in muscle tone to maintain upright posture, presumably induced by the treadmill movement below the subjects' feet. Our data suggest that ventilatory responses are more sensitive to the imagined exercise than cardiocirculatory ones. Indeed, we observed a mild increase in ventilation, brought about exclusively by an increase in respiratory rate, with no change in heart rate.

During real walking, the increase in ventilation was much larger and speed-dependent, and brought about by an increase of both tidal volume and respiratory rate. Already at low walking speed, $PACO_2$ values increased by about 6 mm Hg over the low baseline values; at the two greater speeds, it remained unchanged. These findings can be due to the well-known decay of the anticipatory hyperventilation at the beginning of exercise (1). The other cardioventilatory responses to actual walking at low speed were fully consistent with published data (11).

The mechanisms underlying ventilatory adjustments during exercise are still somehow controversial, especially concerning the dual role of peripheral metabolic signals and descending influences from brain circuits involved in motor programming (5, 17, 18). Our data show that the breathing frequency increased both in real and imagined walking, the increase being larger in the former case. On the contrary, tidal volume increased during real walking, whereas it decreased slightly, albeit not significantly, in imagined walking. Therefore our and previous (17) data suggest a differential control on respiratory rate and tidal volume, with a more pronounced centrally-mediated effect on breathing frequency. Indeed, conscious access to central motor programs during imagery yielded an increase of respiratory frequency alone: this effect was conceivably attenuated by a subsequent adjustment of tidal volume in order to maintain $PACO_2$ close to pre-exercise values. A peripheral determinant in increased breathing frequency during imagery is unlikely, inasmuch as increased pulmonary ventilation during light to moderate exercise intensity is mainly due to increases in tidal volume (1).

In conclusion, the pattern of imagery-related ventilatory changes summarised above appears a rather general characteristic of imagined exercise, over a wide intensity spectrum.

SUMMARY

There is increasing evidence that motor imagery involves at least in part central processes used in motor control. In order to deepen our understanding on the neural mechanisms underlying vegetative responses to real and imagined exercise, we determined cardioventilatory variables during actual or imagined treadmill walking on flat terrain at speeds of 2, 3.5 or 5 km/h, in a group of 14 healthy volunteers. During actual walking, as expected, a comparable intensity-dependent increase was found in ventilation, oxygen consumption, tidal volume and respiratory rate. Imagined walking led to a significant, albeit small (less than 10%), increase in ventilation and oxygen consumption, and to larger increases (up to 40%) in respiratory rate, which was paralleled by a non significant trend towards a decline of tidal volume. These results confirm and extend previous observations showing that motor imagery is accompanied by centrally induced changes in vegetative responses, and provide evidence for a differential control on respiratory rate and tidal volume.

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