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Ventilatory responses to imagined exercise

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Abstract

We studied whether the ventilatory responses to imagined exercise are influenced by automatic processes. Twenty-nine athletes produced mental images of a sport event with successive focus on the environment, the preparation, and the exercise. Mean breathing frequency increased from 15 to 22 breaths/min. Five participants reported having voluntarily controlled breathing, two of them during preparation. Twenty participants reported that their breathing pattern changed during the experiment: 11 participants were unable to correctly report on the direction of changes in frequency, and 13 incorrectly reported changes in amplitude. This finding suggests that these changes were not voluntary in most participants and may therefore reveal automatic forebrain influences on exercise hyperpnea. However, these changes may also reflect nonspecific processes (e.g., arousal) different from those occurring during actual exercise.

Descriptors: Breathing, Control, Higher nervous centers, Exercise, Mental images

When they imagine themselves doing a muscular exercise, resting individuals tend to hyperventilate (Beyer, Weiss, Hansen, Wolf, & Seidel, 1990; Decety, Jeannerod, Durozard, & Baverel, 1993; Deschaumes-Molinaro, Dittmar, & Vernet-Maury, 1992; Wang & Morgan, 1992; Wuyam, Moosavi, Decety, Adams, & Lansing, 1995). For example, in the experiment by Decety et al. (1993), the participants imagined themselves pressing and releasing a loaded footplate. Breathing frequency increased from 11 to 32 breaths/min, and Pco_2 decreased from its resting value of 36 mmHg to about 21 mmHg. However, the intramuscular metabolites (phosphocreatine and inorganic phosphates) and pH did not change, thus showing that the ventilatory activation was not caused by peripheral but rather by central processes. This activation may reflect a feedforward control of breathing from higher centers. However, in actual conditions this feedforward control is difficult to analyze because it is combined with simultaneous motor control and metabolic feedback processes. For this reason, the paradigm of mental imagery has been considered a valuable tool to shed light on the contribution of higher nerve centers to exercise hyperpnea (Fink et al., 1995).

However, this line of reasoning is based on the implicit hypothesis that the changes in breathing during imagined exercise are not voluntary. Otherwise, experiments involving mental imagery would be clearly irrelevant for the analysis of exercise hyperpnea, which is basically an automatic response. Any experiment in which the functional characteristics of the respiratory controller are inferred from the breathing pattern of conscious individuals may be affected by the "voluntary bias" (Gallego, Perruchet, & Camus, 1991). This bias is particularly likely during imagined exercise because deliberately mimicking the breathing pattern that corresponds to a given action may facilitate imagination of this action. This crucial concern rarely has been addressed, with the notable exception of Wuyam et al. (1995). In their experiment, six competitive athletes and 6 nonathletes imagined a previously performed treadmill exercise. Large increases in breathing frequency and ventilation were observed during imagination of exercise in competitive athletes, confirming the data of previous studies. However, despite the care taken by the experimenters to disguise their specific interest in breathing, four of the six athletes and two of the six nonathletes reported that they used their breathing to facilitate imagination of exercise. This observation made the interpretation of the ventilatory changes difficult, and more generally it questioned the validity of the mental imagery paradigm to shed light on the forebrain influence on exercise hyperpnea.

Our purpose was therefore to examine further the role of automatic processes in the ventilatory response to imagined exercise. We asked competitive athletes to imagine themselves during a sport event in their discipline. Compared with previous experiments, two methodological changes were specifically designed to address the issue of automaticity. First, we attempted to prevent the participants from voluntarily controlling breathing. To do this, mental imagery of exercise was guided by verbal instructions to orient the individual's attention toward multiple contextual (therefore nonrespiratory) aspects of the imagined event. In particular, the imagination of exercise was preceded by imagination of the environment of the sport event and then by the preparatory period preceding the test itself. The second change concerned the assessment of the automaticity of

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the ventilatory response, which was based on the answers to the questionnaire and on the comparison between the changes in breathing pattern as described by the participants and the actual changes recorded during mental images. We posited that the participants who voluntarily controlled their breathing patterns during imagined exercise would be able to describe these changes with relative accuracy. Their reports would therefore correspond to the changes actually observed. By contrast, the participants would be unable to correctly report on these changes if they were automatic.

Methods

Subjects

Twenty-nine healthy competitive athletes participated in this experiment. Thirteen were swimmers (11 males, 2 females, mean age = 21 ± 2 years, mean height = 176 ± 6 cm, mean weight = 69 ± 8 kg) and 16 were judo athletes (15 males, 1 female, mean age = 23 ± 5 years, mean height = 174 ± 5 cm, mean weight = 70 ± 10 kg). All the swimmers intensively practiced crawl, although this was not necessarily their preferred style. These athletes had not been instructed to practice mental imagery as part of their training, although one swimmer used to do so. None was informed of the exact purpose of the experiment. Most were undergraduate students in physical education and had received basic training in physiology. Informed consent was obtained from all participants. Physiological recordings were accidentally lost for one swimmer.

Apparatus

A respiratory inductive plethysmograph (Respitrace Plus, Non-Invasive Monitoring Systems [NIMS], Miami Beach, FL) provided with a cardiac monitor was used for respiratory and cardiac measurements. The coils of the Respitrace were placed on the chest above the nipple line and on the abdomen at the umbilical level, providing the thoracic motion (Vth) and the abdominal motion (Vab) signals. The proportionality constant between Vth and Vab amplifiers was determined by the qualitative diagnostic calibration method (QDC) carried out during a 5-min period of spontaneous breathing (Sackner et al., 1989; Sartène, Dartus, Bernard, Mathieu, & Goldman, 1993). Tidal volume (VT) was calculated as the sum of Vth and Vab and expressed as a percent change from this 5-min calibration period. The ventilatory signals by the Respitrace were processed by a computer (Software Respi-Events, NIMS) to produce total breath duration (TT, expressed in seconds), breathing frequency (f, in breaths/min), the inspiratory duration (TI in seconds), and the inspiratory/total breath duration ratio or duty cycle (TI/TT, dimensionless). The thoracic contribution to tidal volume was calculated as the Vth/VT percent ratio. This variable possibly reflects emotional changes caused by mental images (Boiten, Frijda, & Wientjes, 1994). The cardiac signal was also processed by the Respitrace to provide cardiac frequency in beats/min. After cleaning the skin, electrodes for electrocardiogram were placed near the right and left midclavicular line, directly below clavicle, and between the sixth and seventh intercostal space on the left midclavicular line.

Procedure

The expected ventilatory effects depend on the ability to perform mental images. This ability was assessed by using the Vividness of Movement Imagery Questionnaire (VMIQ; Isaac, Marks, & Russell, 1986) before the experiment. This questionnaire identified individual differences in imagery of movement and imagery of kinesthetic sensations associated with these movements. Twenty-four items refer to common motor acts (e.g., drawing a circle on paper or balancing on one leg). The visual and the kinesthetic qualities of images were separately assessed by asking the participants to imagine somebody else doing the movement and then to imagine doing the movement themselves. The participants rated the vividness of the each image on a scale of 1 to 5, ranging from "perfectly clear and as vivid as normal vision" (1) to "no image at all, you only know that you are thinking of the skill" (5). The test–retest reliability of this test was established over a 3-week intertest interval by Isaac et al. (1986). According to these authors, Pearson's product-moment correlation coefficient was .76. The stability of the questionnaire was assessed over a 6-month period. No significant differences among multiple administrations of the questionnaire were found. The validity was established with respect to another questionnaire, the VVIQ (Marks, 1973), with $r = .81$.

Because personality traits are linked with variables that influence breathing, such as arousal or emotional stability, we used the Eysencks' Personality Inventory (EPI; Eysenck & Eysenck, 1968) for each participant. EPI describes personality along two dimensions: introversion–extraversion (E) and neuroticism–stability (N). Each of these two traits is assessed by 57 questions to which the participants answered "yes" or "no." We suspected extraversion to be related to breathing, because it is related to several other indices of physiological arousal (Bullock & Gilliland, 1993).

All physiological recordings were carried out in a sound-protected experimental chamber. Participants were installed on a reclining chair in a standard position. Participants were instructed to close their eyes and to avoid any body movement and were informed that the experiment would consist of creating mental images of a sporting event and that each person would be questioned on this mental image after the experiment. By warning the participants that the imagination task would be followed by questions on these contextual aspects, we attempted to suggest that our interest was specifically oriented toward the quality of mental images rather than its ventilatory correlates. After a 5-min rest for adaptation, a 5-min period for autocalibration of the Respitrace, and 5 min for recording of cardiorespiratory variables (reference phase), the mental imagery phase began. The entire session lasted about 45 min. The participants were then asked to fill in a written questionnaire. No comments were made by the experimenters to avoid biasing answers.

Mental Imagery

All instructions for mental imagery were given by a prerecorded voice through headphones (Appendix 1). The participants had to imagine an actual past sporting event. To facilitate imagery, a background noise recorded during a swimming event or a judo event was delivered during each image. Participants were first trained to create three mental images: (a) observation of the environment, (b) preparation to compete, and (c) exercise (the sporting test itself). The preparation phase chronologically corresponded to the race or fight immediately preceding their own engagement. Attention was drawn toward several specific aspects of each image (environment, movements, adversaries, coaches) to distract participants from focusing on breathing. After this training, the participants created each of the three images with no other instruction than the beginning and the end of each image. The observation, preparation, and judo exercise images lasted 90 s. The image phase ended when participants raised their hands and lasted for a maximum of 90 s.

Postexperimental Questionnaires

After the recording session, the participants were asked to fill out a questionnaire without reading the questions in advance (Appendix 2). The questionnaire contained open questions (e.g., "What are your impressions on the experiment?"), self-ratings of the vividness and the duration of images, and questions specifically directed toward ventilatory changes (e.g., "Did you breathe faster?" and "Did you voluntarily modify your breathing?"). We adopted a 20% change from baseline to assess the correctness of responses to the questions on changes in breathing pattern. If a participant failed to correctly report a perceptible change, this change probably was automatic. Because changes in ventilation are judged on the basis of either tidal volume or frequency changes (Katz-Salamon, 1984b), the postexperiment questionnaire referred only to these two variables. In addition, previous studies have shown that the just noticeable difference between two successive breaths is between 23% and 28% of the reference volume (Katz-Salamon, 1984a). On this basis, we took the conservative threshold 20% as the minimum noticeable change in breathing frequency or tidal volume. In addition, the participants were asked whether their images were continuous or intermittent and to estimate the duration of the images in relation to the total duration requested from 0% to 100%.

Data Analysis

Dependent variables were T_T, f, T_I/T_T, V_T, the thoracic contribution to tidal volume, and cardiac frequency. We also analyzed the coefficient of variation of these variables, which may be influenced by mental activity (Mador & Tobin, 1991). Each dependent variable was analyzed using a separate analysis of variance (Superanova Software, Abacus Concepts) with image (four levels: reference [no image], observation, preparation, exercise) as repeated measures and sport (swimming vs. judo) as a between-subject variable. To take into account 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. Within-subject main effects and interactions are presented along with *p* values based on these adjusted degrees of freedom (Crowder & Hand, 1991).

Results

Breathing Variables

Significant changes in T_T were observed across the different phases (Figure 1), main effect for image, $F(3,78) = 13.59$, $p < .001$, $\epsilon = 0.880$. Mean T_T for all the participants decreased from 4.30 ± 0.09 s during reference to 3.20 ± 0.09 s during imagery of exercise. The T_T values for each of the three images (observation, preparation, exercise) were lower than those for the Reference period, $F(1,78) = 11.85$, $p < .002$; $F(1,78) = 7.11$, $p < .012$; and $F(1,78) = 40.15$, $p < .0001$. This finding suggests that mental imagery per se had a significant effect on T_T. Pairwise comparisons of successive phases over all participants yielded a significant decrease in T_T from reference to observation, $F(1,78) = 11.85$, $p < .0009$, and from preparation to exercise, $F(1,78) = 13.46$, $p < .0008$ (observation and preparation data were not significantly different). T_T was lower during exercise than during observation, $F(1,78) = 8.37$, $p < .007$. These data suggest that the specific content of each mental image significantly influenced T_T. Mean T_T value for exercise was lower than those obtained for pooled observation and preparation, $F(1,78) = 14.35$, $p < .001$, suggesting that imagination of exercise had a particularly strong effect.

The main effect for sport was not significant. In swimmers, T_T was higher during preparation, as confirmed by a significant contrast between this phase and pooled observation and exercise, $F(1,33) = 6.82$, $p < .033$. However, the overall interaction of Sport × Image was not significant.

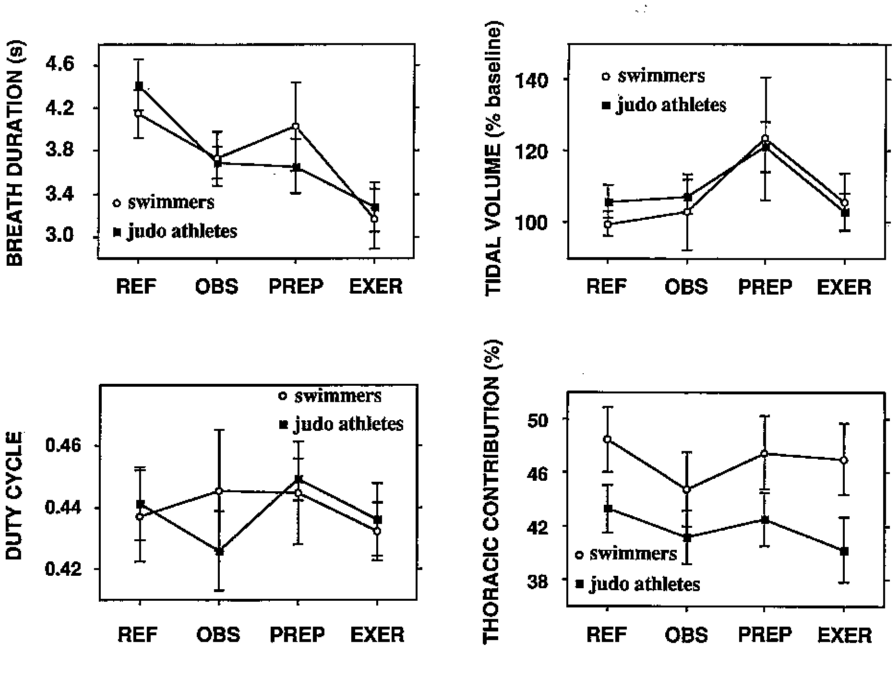

Figure 1. Breath duration (T_T), tidal volume (V_T), duty cycle (T_I/T_T), and thoracic contribution (V_{th}/V_T) averaged over the reference period (REF) and the three consecutive mental images: observation of the environment (OBS), preparation (PREP) and exercise (EXER). Duty cycle is dimensionless. Values are group $M \pm SEM$ ($N = 12$ swimmers and 16 judo athletes).

The decrease in T_T from reference to exercise corresponded to an increase in breathing frequency from 15 to 22 breaths/min (Figure 2). Breathing frequency displayed the same statistical features as T_T and they are not reported here.

A significant main effect of image for V_T was found, $F(3,78) = 6.10, p < .006, \epsilon = 0.604$. V_T was significantly higher during preparation than during reference, $F(1,78) = 13.55, p \leq .003$. Reference and exercise data were not significantly different. Pairwise comparison between successive images for all participants yielded a significant increase in V_T from observation to preparation, $F(1,78) = 10.85, p < .006$, and a significant decrease from preparation to exercise, $F(1,78) = 11.87, p < .006$. No significant difference was observed between reference and observation. As for T_T, the main effect for groups was not significant (Figure 1).

Percent thoracic contribution to V_T was not significantly different across images, but it was slightly higher in swimmers, 47% ± 9% versus 42% ± 8%, $F(1,78) = 3.25, p < .084$, *ns*. Neither sport nor image had significant effects on duty cycle (Figure 1), which showed that the decrease in T_T was not achieved by a specific shortening of inspiration or expiration.

The correlation between the ventilatory variables over the four experimental phases were calculated individually (four observations per participant). The pairwise correlation coefficients were computed for the four variables displayed in Figure 1, which gave rise to six sets of individual correlation coefficients. After transformation from Fisher's r to z, we performed a one-sample t test to test whether these correlation coefficients were significantly different from zero. The only significant difference was found for the correlation coefficients between thoracic contribution and breath duration (T_T), $z = 0.404 \pm 1.006$, $t(27) = 2.126, p < .043$. The correlation between V_T and T_T was marginally significant, $z = 0.393 \pm 1.082, t(27) = 1.921, p < .065$.

No significant difference in breathing variability was observed between swimmers and judo athletes, and these data were pooled together (Figure 3). Significant main effects for image were found for T_T, V_T, T_I/T_T, and Vth: $F(3,81) = 3.38, p < .043, \epsilon = 0.649$; $F(3,81) = 5.62, p < .002, \epsilon = 1.002$ (probability was not corrected for this $\epsilon > 1$), $F(3,81) = 3.57, p < .02, \epsilon = 0.923$, and $F(3,81) = 5.17, p < .004, \epsilon = 0.873$; respectively. A contrast analysis showed that variability was higher during reference than during the mental images for V_T, T_I/T_T, and Vth, $F(1,81) = 14.38, p < .0003$, $F(1,81) = 9.59, p < .003$; $F(1,81) = 13.44, p < .0008$, respectively. By contrast, T_T displayed significantly higher variability during exercise, $F(1,81) = 6.99, p < .020$.

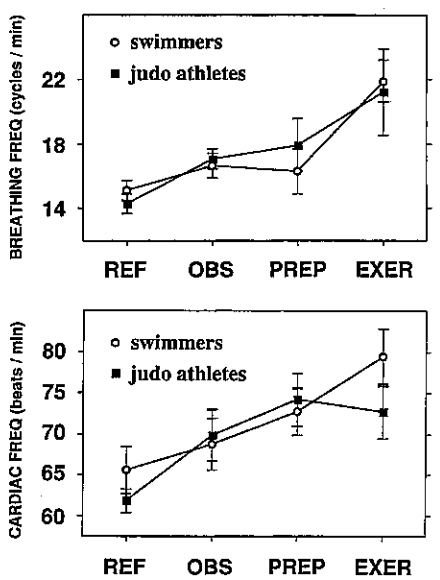

Figure 2. Breathing frequency (f) and cardiac frequency in swimmers ($N = 12$) and judo athletes ($N = 16$) during the reference period (REF) and the three consecutive mental images: observation of the environment (OBS), preparation (PREP), and exercise (EXER). Values are group $M \pm SEM$.

Cardiac Frequency

Cardiac frequency significantly changed in the two groups, as shown by the main effect for image: $F(3,78) = 45.47, p < .0001, \epsilon = .758$ (Figure 2). Cardiac frequency was lower during the reference period than during any of the three images: $F(1,78) = 26.10, p < .0001$; $F(1,78) = 75.01, p < .0001$; and $F(1,78) = 119.8, p < .0001$; respectively. Pairwise comparison for all participants over successive images yielded a significant increase in cardiac frequency from reference to observation, $F(1,78) = 26.10, p < .0001$, from observation to preparation, $F(1,78) = 12.62, p < .002$, and from preparation to exercise, $F(1,78) = 5.22, p < .035$. However, swimmers and judo athletes displayed a different pattern of variation between preparation and exercise. Cardiac frequency increased in swimmers, $F(1,33) = 24.35, p < .0001$, whereas it decreased in judo athletes (*ns*). This difference was confirmed by the interaction tests: the Sport × Image interaction was significant, $F(3,78) = 5.39, p < .005, \epsilon = 0.758$, as was the interaction restricted to preparation and exercise, $F(1,26) = 19.80, p < .0001$. However, the interaction for the remaining levels of the image variable (reference, observation, preparation) were not significant.

Personality Traits and Ability to Create Mental Images

The ability to create mental images was significantly better in swimmers, as shown by their smaller visual scores (1.65 ± 0.52 in swimmers vs. 2.15 ± 0.64 in judo athletes, $p < .038$) and kinesthetic scores (1.58 ± 0.50 in swimmers vs. 2.15 ± 0.70 in judo athletes, $p < .024$). Personality traits (introversion–extraversion

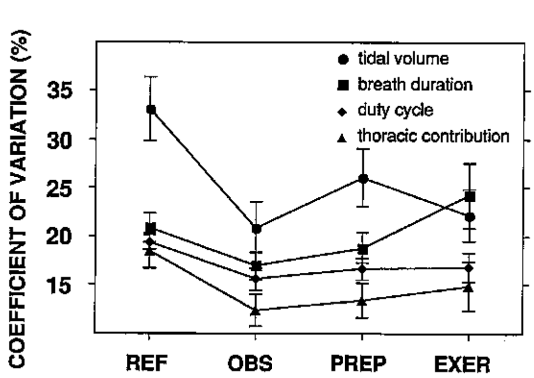

Figure 3. Variability in breath duration (T_T), tidal volume (V_T), duty cycle (T_I/T_T) and thoracic contribution (Vth/V_T) during the reference period (REF) and the three consecutive mental images: observation of the environment (OBS), preparation (PREP), and exercise (EXER). Values are group $M \pm SEM$. Swimmers and judo athletes were pooled together ($N = 28$) because they were not significantly different with respect to variability variables.

and neuroticism–stability) assessed by EPI scores were not significantly different between the two groups and were not significantly related to visual and kinesthetic scores. The magnitude of changes in cardiorespiratory variables was not significantly related to the VMIQ scores or to personality variables.

Postexperimental Questionnaires

Quality of mental images. Self-estimation of the percent duration of imaging was nearly identical in swimmers and judo athletes and did not significantly change across the three images (swimmers: 82% ± 15%, 85% ± 11%, and 83% ± 15%; judo: 80% ± 21%, 82% ± 17%, and 83% ± 15%). Mean self-estimation of the vividness of images for environment was similar in the two groups (2.42 ± 0.77 vs. 2.30 ± 0.56, respectively). Swimmers reported slightly more vivid images of exercise, but this difference was not significant (1.74 ± 0.24 vs. 2.20 ± 0.74, $p < .072$). The duration of the imagined race in swimmers was longer their actual best performance (73.25 ± 14.66 s vs. 62 ± 6.69 s).

Open questions on thoughts and impressions during mental images. The participants did not mention breathing in their comments, with two exceptions. One swimmer reported thinking of breathing before listening to the soundtrack. In addition, one judo athlete mentioned having concentrated on breathing, although the same person denied having voluntarily controlled it when explicitly asked whether he did so.

"Did your breathing change at certain moments during the experiment?" Twenty participants answered affirmatively: 16 reported that change occurred during the exercise phase and 4 were not able to say when this change occurred. Among the 9 participants who did not answer affirmatively, 4 answered that they did not think so, and the remaining 5 did not answer this question. The comparison between reported and actual changes for frequency and amplitude is summarized in Table 1. A 20% change from reference was arbitrarily taken as an inferior threshold for actual changes (the same calculations with 15% changes yielded nearly identical results). Seventeen participantes who correctly reported the changes in breathing frequency (13 correct reports of actual changes and 4 correct reports of no change). Fifteen participants correctly reported amplitude changes (3 correct reports of actual changes and 12 correct reports of no change). Thus, a relatively high proportion of participants had some perception of their ventilatory response during the test. However, 11 participants either did not answer or gave an erroneous estimation of frequency changes; 13 were incorrect regarding amplitude. The hypothesis of independence between observed and subjective ventilatory changes was not rejected by a chi-square test.

Table 1. *Number of Participants With Actual and Reported Changes in Breathing Frequency and Amplitude*

Actual changes from baseline	Reported changes					
	Frequency			Amplitude		
	Yes	No	NA[a]	Yes	No	NA
>20%	13	4	2	3	3	2
<20%	3	4	2	5	12	3

[a]NA = no answer.

"Did you voluntarily modify your breathing during this experiment?" Five participants (one judo, four swimmers) answered positively, and two out of these five located this control during preparation, not exercise. These five participants were not significantly different from the remaining sample with respect to EPI and VMIQ.

Comparison Between Participants Who Reported Having Controlled Breathing and Those Who Did Not

Ventilatory and cardiac variables were compared between the five participants who reported having voluntarily controlled breathing (hereafter designed *voluntary controller*) and the 23 subjects who reported not having done so (*nonvoluntary controller*; the individual whose files were lost was a nonvoluntary controller). The difference between these two groups was significant for V_T, $F(1,78) = 5.23$, $p < .031$, and nearly significant for T_T, $F(1,78) = 3.69$, $p < .066$. For V_T and T_T, the interactions between the voluntary–nonvoluntary variable and phase were significant, $F(3,78) = 9.30$, $p < .0003$, $\epsilon = 0.686$; $F(3,78) = 3.89$, $p < .016$, $\epsilon = 0.889$; respectively. In fact, voluntary controllers had higher T_T and V_T than nonvoluntary controllers only during preparation (5.05 ± 1.95 s vs. 3.55 ± 0.81 s, and 172% ± 81 vs. 111% ± 21, respectively). No significant difference was observed during exercise.

Cardiac and respiratory variables were completely reanalyzed for the 23 nonvoluntary controllers. The results for T_T were very similar to those obtained for all participants, with the same significant main effects and interactions. However, V_T no longer displayed significant changes during preparation because the most radical changes for this variable were displayed by voluntary controllers.

Discussion

The purpose of this experiment was to study whether or not breathing behavior during imagined exercise can be influenced by automatic processes. We observed a ventilatory activation during imagined exercise, which confirmed results of previous experiments. Only breathing frequency displayed consistent changes, which is consistent with the observations by Wuyam et al. (1995). Ventilatory questionnaire data suggested that these changes were generally automatic. All but 5 participants denied having voluntarily controlled breathing, and only 3 of these 5 among the 29 participants reported doing so during imagined exercise. Breathing pattern during imagined exercise in these five participants was not different from patterns observed in the remaining participants. The differences were observed during imagined preparation, probably because voluntary slow and deep breathing is a common behavior during preparation to compete. Four of these five participants were swimmers, which is not surprising given the importance of breath control in swimming technique.

The proportion of participants who reported having voluntarily controlled their breathing was lower than that in Wuyam et al.'s (1995) study (four of the six athletes). This difference was probably due to methodological differences between the two studies. First, in the present experiment, the participant's attention was experimentally oriented toward nonrespiratory aspects of mental images. Second, the short duration of images (90 s) was better suited to an intense continuous focusing than was the 9-min images designed by Wuyam et al. (1995). Third, we used recording belts rather than facial masks to avoid orienting attention toward breathing. The experiment questionnaires may have been biased by several artifacts (e.g., experimenter expectancies). For this reason, our conclusion on the automaticity of ventilatory changes was not based only on the number of participants who denied having controlled breathing but also on the comparison between actual and reported changes. The perception of the direction and the magnitude of the ventilatory changes were generally vague and actually incorrect in nearly one-third of the subjects. If they had deliberately modified their breathing pattern to mimic their actual ventilatory behavior during exercise, they would have been able to report on the direction of the ventilatory changes.

In the two groups of participants, the image of exercise yielded the shortest breath duration (Tt), in comparison with the observation and preparation images. The exercise image script was characterized by a relatively large number of response propositions in comparison with observation and preparation scripts. Therefore, the present data were consistent with Lang's (1979) view that the pattern of physiological activity during imagery is determined by the response propositions included in the image structure. However, in the experiments by Lang, Kozak, Miller, Levin, and McLean (1980), the image scripts contained both behavioral and physiological propositions, thus making it difficult to assess the independent effects of these two categories of propositions. By contrast, in the present experiment, the image script for exercise emphasized behavior ("repetitive arm movement," "your falls, your movements") while cautiously avoiding any mention of their cardiorespiratory correlates. Therefore, our data suggest that including physiological changes in the image script is not a necessary condition for these changes to occur. Participants may have deliberately made up the image of exercise by generating ventilatory propositions, but the automatic nature of the observed cardiorespiratory changes does not support this hypothesis.

In the present study, a systematic approach to the ventilatory differences between actual and imagined exercise was considerably hampered by the difficulty of collecting ventilatory data during normal practice of swimming or judo. No existing device allows the measurement of breathing variables during actual executions of these (and most) sport activities. Noninvasive respiratory devices (e.g., Respitrace) do not provide acceptable data when body movements are present. Available invasive devices (e.g, pneumotachographs) require breathing out of water, which would profoundly disrupt the breathing pattern normally adopted by swimmers (with the possible exception of backstroke). Although difficult to implement practically, underwater/overwater videotaping may provide an indirect assessment of inspiration and expiration durations. Physiology and sports literature does not seem to provide objective data on breathing during judo or swimming events, although numerous studies have dealt with swimming physiology under conditions adapted for physiological measurements (e.g., tethered swimming).

Breathing patterns during actual swimming or judo have some obvious characteristics that we attempted to identify in the ventilatory tracings during mental images. For example, during a 100-m race, swimmers necessarily have a several-second apnea on the start and on the flip turn. Apnea also generally occurs during the final sprint. In judo, attacks are generally accompanied by active expirations, and short apneas often occur during intense efforts, especially during immobilizations. We failed to observe any of these ventilatory events in the individual ventilatory tracings, even in those participants who reported having experienced them during imagined exercise. This finding further supports the idea that these participants did not voluntary mimic the breathing pattern corresponding to actual exercise. Seemingly, the ventilatory activation caused by imagined exercise was not influenced by the constraints of the actual activity on breathing pattern and was therefore qualitatively different from the actual breathing pattern. Similarly, the observed pattern of correlation between breathing variables departed from the habitual pattern. In trained and untrained participants, when ventilation is stimulated by actual exercise, Tt is negatively related to Ti/Tt and to Vt (Boule, Gaultier, & Girard, 1989). Our data displayed an opposite pattern, consistent with previous reports by Wuyam et al. (1995), that breathing frequency—but not tidal volume—was affected by imagery. In the same vein, different effects of conditioning on breathing frequency and tidal volume have been reported (Gallego & Perruchet, 1991; Van den Bergh, Kempynck, Van de Woestinje, Baeyens, & Eelen, 1995).

The similarity between swimmers and judo athletes raises the issue of whether ventilatory changes were specifically caused by imagination of exercise or by confounding factors such as mental activity, emotions, or arousal associated with this image. Several authors (Decety et al., 1993; Wuyam et al., 1995) have addressed this issue by varying the intensity of the imagined exercise (e.g., the speed of the treadmill or the load of the cycle ergometer) or by comparing the ventilatory effects of imagined exercise with those of nonexercise mental tasks (visualizing and counting letters). These authors found that breathing frequency during imagined exercise was correlated with the intensity of imagined exercise, and they concluded that these changes were specifically linked to the content of mental images. However, even assuming the automaticity of the ventilatory responses, mentally increasing the level of exercising may also have increased the mental load or arousal, which also influences breathing frequency (Caroll, Turner, & Hellawell, 1986). In the present experiment, the participants generated strong, vivid images, and the cognitive and emotional factors that influenced breathing during the actual challenge probably were also present during imagery of exercise. If so, the value of mental imagery would be to disentangle these effects from the exercise-induced metabolic processes. However, this argument should be considered with caution because the psychological and metabolic process may interact under actual exercise conditions, in contrast with imagined exercise. In particular, if actual performance levels off arousal, as suggested by anecdotal evidence from athletes and stage performers, the arousal effects during mental imagery may overestimate those occurring under actual conditions. The difference in breath durations between exercise and nonexercise images may have been caused by a higher mental load or arousal during imagined exercise.

Contrary to breathing frequency, cardiac frequency displayed a different pattern of variation in swimmers and judo athletes. In swimmers, cardiac frequency significantly increased from preparation to exercise. In contrast, in judo athletes, cardiac frequency decreased, although nonsignificantly from preparation to exercise. This interaction was significant and suggested that (a) changes in cardiac frequency were not caused by changes in breathing pattern (i.e., respiratory sinus arrhythmia) and (b) the decrease in cardiac frequency from preparation to exercise in judo athletes was not due to their lower ability to create mental images. Otherwise, a parallel decrease in breathing frequency would be expected.

This effect may be similar to the changes in cardiac frequency observed during tasks requiring an accurate processing of environmental stimuli (the intake tasks). Reaction time tasks in which a warning stimulus precedes an imperative stimulus (visual detection tasks) are typical examples of intake tasks. During these tasks, cardiac frequency decreases (Lacey & Lacey, 1978; Ray & Cole, 1985). Conversely, cardiac frequency tends to increase during rejection tasks, such as mental arithmetic, in which external stimuli are irrelevant. This differential effect on cardiac activity between intake and rejection tasks is not reflected by breathing frequency, digital blood flow, or palmar conductance (Lacey & Lacey, 1974, 1978). The intake–rejection dimension seems relevant for the present experiment. Judo fights require speeded responses to environmental and unpredictable stimuli. In swimming, environmental stimuli are much less relevant than the management of internal physiological processes. Therefore, in swimmers, the rejection effect may have acted synergistically with the activatory factors linked to imagery to increase cardiac frequency from preparation to exercise. By contrast, in judo athletes, the intake factor may have acted in a direction opposite to the activating factors linked to mental images. This hypothesis may explain why during the exercise image cardiac frequency significantly increased in swimmers, whereas it (nonsignificantly) decreased in judo athletes. Under actual exercise conditions, this effect on cardiac frequency would certainly be overwhelmed by cardiac effects of metabolic requirements.

In conclusion, the automatic increase in breathing frequency that accompanies imagined exercise may reflect the contribution of higher nerve centers to exercise hyperpnea. However, a possible limitation of this approach is that these ventilatory changes may be influenced by nonspecific processes (e.g., arousal) different from those occurring during actual exercise.

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APPENDIX 1: INSTRUCTIONS FOR MENTAL IMAGES

Instructions for Swimmers

This experiment consists—for you—of imagining a swimming competition in which you are one of the participants. It is a 100-m crawl race, carried out in a 50-m pool. Your task will include three images, of approximately 1 min each. Please try to produce the clearest mental images you can—the most vivid, accurate images possible. To help you, we will play a recording of sounds from a swimming competition. The beginning and end of each image period will be announced to you in due time.

First, we are goint to explain to you the content of the three images. This will allow you to practice producing these images right away.

The first image will be an observation of the premises. Please direct all of your attention to the place where the competition is to take place. You will imagine the pool, its lanes, its bleachers, and the public attending. You will think about the odors, the noise, the conversations. Train yourself for a few seconds with this mental image. (. . .) Good.

The second image concerns your preparation, just before the competition, during the minute that precedes your race. You are already familiar with the pool, you are already warmed up, and you have attained your usual pace. The lanes have already been assigned. You are in line behind the starting block, and you are getting ready to plunge. The signal for the departure of the race preceding yours will be given. The race preceding yours will last approximately 1 min. This is the minute—just before your race—that you will be imagining. Try to remember this minute of preparation. (. . .) Good.

The last image is of your race, from your stepping up onto the starting block to your arrival at the end of the race. It is a 100-m crawl in a 50-m pool. At the sound of the whistle, you will dive in. You'll imagine this dive, your surfacing to start swimming, your repetitive arm movements, the kicking action of your legs. You will try to relive all your sensations and thoughts during the race. You will try to remember what you see during the race, both in and out of the water. Think about the noise, the cheering. Please indicate to us your arrival at the end of the race by raising your hand at the exact moment you touch the edge of the pool in your mind. Try to image this race for a few moments. (. . .) Good.

After the experience, we will ask you a few questions on the contents of your three mental images: observation, preparation and action. Please concentrate as hard as possible so you can accurately answer these questions.

We are going to start the experiment now, starting with the observation phase. Try to imagine the pool. Go ahead! (. . .)

The first image period is over, now you are going to imagine the preparation phase. You are in line, and in 1 min you will be jumping in. Go ahead! (. . .)

The second image period is over. Now you are going to imagine your own race. Indicate your arrival at the end by raising your hand. Listen carefully to the orders of the starter. Go ahead! (. . .)

Thank you. The experiment is over.

Instructions for Judo Athletes

This experiment consists—for you—in imagining a judo competition in which you have participated. Your task will include three images, of approximately 1 min each. Please try to produce the clearest mental images you can—the most vivid, accurate images possible. To help you, we will play a recording of sounds from a judo competition. The beginning and end of each image period will be announced to you in due time.

First, we are going to explain to you the content of the three images. This will allow you to practice producing these images right away.

The first image will be an observation of the premises. Please direct all of your attention to the area where the competition is to take place. You will imagine the room, the tatami, and the public attending. You will think about the odors, the noise, the conversations. Train yourself for a few seconds with this mental image. (. . .) Good.

The second image concerns your preparation, just before the competition, during the minute that precedes your match. You are already familiar with the room, you are already warmed up, you are rehydrated, and you are rested. Your series has been called. You are near the tatami, and you are getting ready to start. The match preceding yours is about to begin. It will last a few minutes. This is the time, just before your match, that you will be imagining. Try to remember this preparation time. (. . .) Good.

The last image is of your match, from the moment you advance toward your adversary until the end of your match. On the order of your referee, the match is on. You will imagine the beginning, your kumikatas, your falls, your movements, the times when you are blocked. You will try to relive all your sensations and thoughts during the match. You will try to remember what you see during the match. Think about the noise, the cheering. Please indicate to us the end of the match by raising your hand. Try to image this match for a few moments. (. . .) Good.

After the experience, we will ask you a few questions on the contents of your three mental images: observation, preparation, and action. Please concentrate as hard as possible so you accurately answer these questions.

We are going to start the experiment now, starting with the observation phase. Try to imagine the room. Go ahead! (. . .)

The first image period is over; now you are going to imagine the preparation phase. You are near the tatami, and in 1 min you will be starting. Go ahead! (. . .)

The second image period is over. Now you are going to imagine your own match. Indicate the end of the match by waving your hand. Listen carefully to the orders of the starter. Go ahead! (. . .)

Thank you. The experiment is over.

APPENDIX 2: POSTEXPERIMENTAL QUESTIONNAIRE

(The questions for swimmers and judo athletes have been regrouped for clarity. The spaces left for answering are not represented.)

Please reply to the questions in order, without looking at the later questions.

What are your impressions of this experiment? What did you think about during the mental images?

1. Did you think about any given competition? If so, which one?

2. Were the mental images continuous or intermittent? Estimate the duration of these images in relation to the total duration requested (from 0% to 100%). Observation? Preparation? Action?

3. Swimmers: Evaluate from 1 to 5 (see enclosed scale) the quality of the mental image in relation to the following environmental aspects: the pool surroundings, the pool itself, the public, the starter, the trainer, your competitors, your lane, and the line on the pool floor?

3. Judo athletes: Evaluate from 1 to 5 (see enclosed scale) the quality of the mental image in relation to the following environmental aspects: the gymnasium, the public, the tatami, your position in the room, the safety zone, the referee, the coach, and your adversary?

4. Swimmers: Evaluate from 1 to 5 (see enclosed scale) the quality of the mental image in relation to the following activities: immobilization before starting, the impetus of the dive, contact with the water, your surfacing to start swimming, your repetitive arm movements, the kicking action of your legs, the somersault at the turn, and the thrust forward at the turn.

4. Judo athletes: Evaluate from 1 to 5 (see enclosed scale) the quality of the mental image in relation to the following activities: the salute, the first step toward your adversary, the first contact, your kimono being seized, your movements, the reactions of your adversary, your falls, and when you are blocked.

5. Did your breathing change at certain moments during the experiment? If so, can you specify these changes and when they came about? Observation phase? Preparation phase? Action phase?

6. Swimmers: Did you synchronize your breathing and the arm cycles during the mental image? If so, was it throughout the action phase? Exactly the same during the first and second length?

6. Judo athletes: Did you make hold your breath during the mental images of the action phase? During the combat while standing up? During the combat on the tatami? Upon initiating movements?

7. During the images of the action phase, did you breath faster (with a higher respiratory frequency than when at rest)? If so, when exactly?

8. During the images of the action, did you breath more deeply (that is, with a higher amplitude than when at rest)? If so, when exactly?

9. Did you voluntarily modify your breathing during this experiment? If so, when exactly? Why?