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A chronometric and electromyographic approach to the effect of exercise on reaction time

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In many sports, competitors are under time pressure and must make tactical decisions very quickly. Especially in team sports, fighting sports and racket sports, the ability to give an accurate and appropriate response in a short time determines success. Moreover, in the field of physical activity, athletes are faced with physiological and cognitive demands and must simultaneously deal with both of these requirements in order to achieve a good result. Thus, the improvement of the knowledge concerning the interactions between physiological and cognitive processes appears to be particularly relevant to the framework of cognitive psychology, and sport and exercise sciences. In the following paragraphs, we will focus our attention on how exercise alters decision-making performance under time pressure.

The effects of exercise on decision-making performance have been studied using a wide variety of cognitive tasks and many physiological interventions during recent years. Unfortunately, the diversity of the protocols has led to many equivocal results and considerable differences in experimental protocols have made the synthesis and the comparison of results difficult. However, this multitude of experiments gives the opportunity to identify the weakness of such protocols and to point out the necessity of using a rigorous methodology to avoid interfering variables (e.g. learning effect, exercise workload, number of trials, time on task). Presently, there is a consensus among researchers examining the effect of exercise on cognitive function.

The mental chronometry method is certainly the most widespread method used to assess the effects of exercise on cognitive processes. The paradigm of mental

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chronometry takes into account the fact that the cognitive processes can be assessed through the measure of the duration of the information processing. Indeed, a number of inferences can be made using the measure of reaction time (RT). RT corresponds to the time that elapses between the onset of a stimulus and the occurrence of an overt response. The mental chronometry method consists of measuring RT in different conditions and, all other things being equal, the RT modulations are used to make inferences. Most authors agree that RT corresponds to the time necessary to perform a series of stages (a stage being a functional set of elementary operations), which begin at the onset of the response signal and which end at the occurrence of the response. Thus, RT can be broken down into a series of stages (Anderson, 1980). Van der Molen *et al.* (1991), for instance, proposed a six-stage breakdown of information processing: three perceptual stages (stimulus pre-processing, feature analysis and stimulus identification); a central stage (response selection); and two motor stages (motor programming and motor adjustment).

In the context of exercise and cognitive processes, despite the fact that results are not unequivocal, several studies suggest that RT is shorter when the participants perform an RT task while simultaneously undertaking sub-maximal exercise than when they are at rest (e.g. Arcelin, Delignières and Brisswalter, 1998; Chmura *et al.*, 1998; Davranche *et al.*, 2005a; McMorris and Graydon, 1996a; Paas and Adam, 1991; Pesce *et al.*, 2002; Yagi *et al.*, 1999). However, the questions of how exercise exerts its influence on mental processing and what stages are affected by physical exercise are still unclear.

The nature of the stages altered by exercise has so far been addressed using the additive factor method (AFM, Sternberg, 1969a, 2001). The method is more extensively presented in Chapter 1 of this book. This inferential method relies upon the analysis of the pattern of statistical effects of factorially manipulated variables: if the effects on RT are additive, it is likely that the variables affect different stages; conversely, if the effects interact, it is likely that the variables affect at least one common stage. Using this logic, Arcelin, Delignières and Brisswalter (1998) and Davranche and Audiffren (2004) have shown that the effect of physical exercise is additive on mean RT, with effects on signal quality, stimulus-response compatibility and foreperiod duration. This suggests that physical exercise spares the stages of stimulus identification, response selection and motor adjustment. These results are, however, quite inconclusive because these experiments failed to unequivocally localize the effect of exercise on information processing. Indeed, the interpretation of a lonely additive statistical pattern is a little problematic because this interpretation is based on an absence of a significant interaction. The unsuccessful use of the AFM implies that more direct measures should be used in conjunction with mental chronometry to assess the influence of exercise on human information processing.

To this aim, electrophysiological techniques (e.g. single neuron activity, electrical and magnetic stimulations, Hoffman reflex) can be used to make inferences based on the observation of physiological changes. The general principle is to combine electrophysiological and mental chronometry techniques in order to record new indices related to the nature and the organization of the cognitive processes. Thus, the locus of the effect of an experimental factor can be addressed using fractionated RT

with respect to the changes in electrophysiological activity (Hasbroucq *et al.*, 2002). Note that this chronometric method cannot be used with all physiological indices. Indeed, because of the way in which the electrophysiological changes are measured, the onset of the physiological activity must be estimated using a trial by trial detection. This method, for example, cannot be applied to the electroencephalography technique when the detection of the event related potential, trial by trial, is impossible because of the background brain activity. Indeed, given the fact that the amplitude of an event-related potential evoked during a trial is weak and variable, it is necessary to make an average of several tens of trials to highlight an event-related potential. The time onset to the physiological change is then estimated, more or less precisely, by using the onset of the physiological change observed on the average curve. However, this estimation is not obviously identical to the average of the onset of the physiological changes that could be observed during a trial by trial analysis.

The electromyographic (EMG) activity of the response agonists allows such a fractioning. The time interval between the onset of the response signal and the onset of EMG activity is termed premotor time (PMT), while the time interval between the onset of EMG activity and the onset of the required motor response is termed motor time (MT) (see Figure 7.1).

MT reflects the duration of the actual execution of the response, which constitutes the neuromuscular component of the motor adjustment stage, whereas PMT reflects the duration of all preceding processes (i.e. perceptual and central stages). By examining the effect of an experimental manipulation on PMT and MT, it is possible to determine whether the manipulation's effects on RT occur after or before EMG onset and, therefore, whether it affects response execution and/or processes occurring upstream in the information flow.

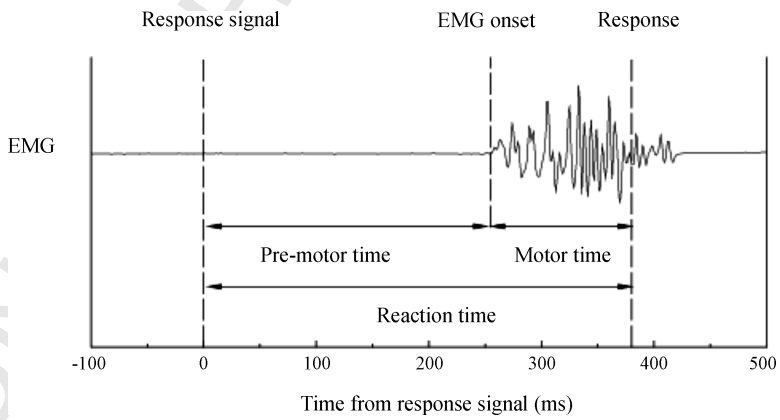

Figure 7.1 Electromyographic activity in the agonists muscle involved in the task as function of time (in ms) from the presentation of the response signal. The reaction time corresponds to the time between the response signal and the onset of the required motor response, the premotor time to the time elapsed from the response signal to the electromyographic (EMG) onset, and the motor time to the time elapsed from the EMG onset to the onset of the required motor response.

Based on this framework, two RT experiments (Davranche *et al.*, 2005a, 2006b), one using a choice RT test and the other using a simple RT task, were carried out and the EMG activity of the response agonist muscle was used to sub-divide the RT into PMT and MT. The purpose of both studies was to decipher whether sub-maximal physical exercise alters the later processes related to the response execution and whether it alters the processes located upstream from the neuromuscular level.

7.1 Research

Methods

During each experiment, 12 subjects, who regularly practised sport, were tested. The subjects performed three consecutive blocks while cycling at 50% of their maximal aerobic power with a freely chosen pedal rate and three consecutive blocks at rest. The order of exercise and rest was counterbalanced across subjects in order to avoid any eventual learning effect. The three consecutive blocks (204 trials) lasted about 15 minutes and a resting period (about 10 minutes) was given to the subject between the exercise conditions.

Subjects were seated on a cycle ergometer, their arms rested on a foam rubber support. In front of the subject, a row of light emitting diodes (LEDs) were positioned at a distance of 60 cm. Two response keys were fixed on the handlebars of the cycle ergometer, one on the right and one on the left, and subjects were asked to respond as quickly and accurately as possible to the visual stimulus by pressing the appropriate key with their thumb. During the choice RT task, the left key was to be pressed in response to the illumination of the left stimulus and the right key in response to the right stimulus. During the simple RT task, only one central stimulus appeared and the response was given by pressing the right response key.

The EMG of the flexor pollicis brevis of each thumb was recorded by means of paired surface Ag–AgCl electrodes, 11 mm in diameter, fixed 2 cm apart on the skin of the thenar eminence. This activity was amplified (gain 10 000), filtered (low frequency cut-off 10 Hz, high frequency cut-off 1 kHz) and digitized on-line (2 kHz). The experimenter continuously monitored the EMG signal in order to avoid background activity as much as possible. If the signal became noisy, the experimenter asked the subject to relax his/her muscles. During the data treatment the EMG traces were inspected off-line, trial by trial, as displayed on a computer screen. Since human pattern recognition processes are superior to automated algorithms (van Boxtel *et al.*, 1993), we hand-scored the EMG onsets. Importantly, at this stage the experimenter was unaware of the exercise condition and of the signal intensity condition he was looking at.

Results

As we might expect, RT was faster in the exercise condition than in the rest condition in both choice and simple RT tasks (Table 7.1). Additional analyses on the percentage of decision error showed that the differences observed on RT are not explained by a

Table 7.1 Mean and standard deviations (SD) of heart rate, overall reaction time and percentage of decision error at rest and during exercise in the choice reaction time (CRT) and simple reaction time (SRT) tasks.

Variable	Mean (SD)			
Task	CRT		SRT	
Condition	Rest	Exercise	Rest	Exercise
Heart rate (bmp.min^{-1})	75 (11)	141 (15)	75 (13)	137 (17)
Reaction time (ms)	275 (26)	262 (28)	226 (19)	217 (22)
Error (%)	0.09 (0.01)	0.17 (0.01)	0.13 (0.01)	0.26 (0.02)

possible shift in the speed–accuracy trade-off. Note that in the simple RT task, decision errors corresponded to responses given in catch trials during which no movement was required.

The fractionating of RT into PMT and MT with respect to the onset of EMG activity of the response agonist shed light on the processes affected by exercise. Indeed, both experiments showed that exercise improved late motor processes (Figure 7.2). These findings suggest that sub-maximal exercise affects response execution and, thus, the neuromuscular component of the motor adjustment stage. This conclusion is strengthened by closer analysis of the EMG activity of the response agonists.

The EMG burst measured through the α angle, which corresponds to the angle comprised by the EMG activity baseline and the line that joins the onset and peak of the rectified EMG activity waveform, was steeper during exercise than at rest

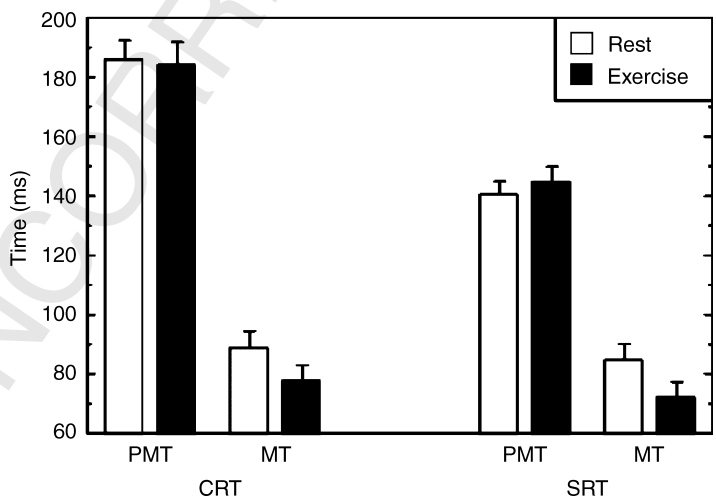

Figure 7.2 Effect of exercise (ms) on premotor time (PMT) and on motor time (MT) during choice reaction time (CRT) and simple reaction time (SRT) tasks. White bars correspond to the performances at rest and black bars to the performances during exercise.

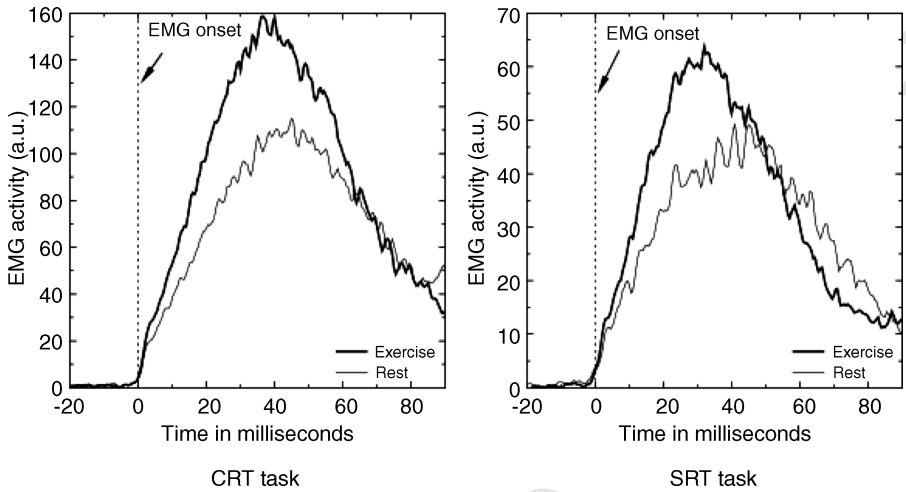

Figure 7.3 Grand average of electromyographic (EMG) activity for the choice reaction time (CRT) and simple reaction time (SRT) tasks during exercise (black lines) and rest (grey lines). The origin of the abscissa is set at the onset of the EMG activity (time 0). EMG is expressed in arbitrary units.

(see Figure 7.3). According to models of EMG and/or force production, the steepness of the EMG activity may be related to the variance of the motor unit onset time: the lower the variance, the more synchronized the motor unit discharges, and the steeper the EMG activity (Meijers, Teulings and Eijkman, 1976; Ulrich and Wing, 1991). In other words, the cortico-spinal command was more efficient during exercise than at rest, which accounts for the effect of exercise on the MT.

Further examination also showed that the surface under the averaged curve during the interval separating the onset and the peak of the EMG activity burst was larger during exercise than at rest. Since the force generated by a muscle is monotonically related to this index (Bouisset and Matton, 1995), the force produced during this time window was larger during exercise than at rest. Considered together, the whole pattern of results clearly converges in suggesting that physical exercise shortens RT by affecting late motor processes. At least three mechanisms could explain the effect of exercise on MT: (1) an increase in conduction velocity induced by an elevation of body and skin temperature; (2) a change in the motor command (firing rate or number of motor neurons involved in the command); and (3) an improvement in muscle contraction at the sliding-filament level.

Even if the effect of exercise is absent on the PMT component, one must note that an interaction between exercise and signal intensity was observed on mean PMT during both experiments. According to the AFM, this finding strongly suggests that physical exercise exerts an effect, although complex, on sensory processes. This interpretation should await further investigations, but the result is compatible with previous findings obtained with the critical flicker frequency (CFF) technique. Indeed, the CFF threshold, which is considered to reflect changes in sensory

sensitivity, has been reported to increase immediately after moderate (Davranche and Audiffren, 2004; Davranche and Pichon, 2005) and exhausting exercises (Davranche and Pichon, 2005).

7.2 Conclusion

These EMG studies confirm that RT performance is better when the task is performed while simultaneously undertaking sub-maximal exercise (50% of maximal aerobic power) than when it is performed at rest. The most important finding of these experiments is that fractionated RT sheds light on the processes affected by exercise.

Indeed, the fractionating of RT into PMT and MT, with respect to the onset of EMG activity of the response agonist, showed that most of the effect of exercise was exerted on the MT component but exercise exerts little influence on PMT. Previous studies using the same methodology have shown that some task variables, such as stimulus–response compatibility, affect only the PMT, while others, such as response repertoire or foreperiod duration, affect both PMT and MT. To our knowledge, exercise is so far the only task variable which affects mainly MT. This is an instance of a double dissociation, which suggests that the two variables are independent. Although relatively simple, the fractionating of RT, with respect to the EMG activity of response agonists, can provide useful information relative to the locus of RT effects and their functional mechanisms.

Finally, the EMG technique used in these experiments deserves some comments. Because the inferences are based on the observation of physiological changes, the main weakness of this technique is naturally the accuracy with which we are able to detect electrophysiological changes. The use of rigorous and systematic methods widely determines the relevance of the results. Moreover, particular precautions must be taken when the electrophysiological changes are observed during exercise because the experimental conditions are not optimal and the sweating function could disturb the EMG signal performed with such surface electrodes. Indeed, without a meticulous method to record EMG, the background activity induced by physical exercise could not allow an unequivocal determination of the beginning of the EMG activity.