

EFFECT OF PHYSICAL EXERCISE DURATION ON DECISIONAL PERFORMANCE

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Summary.- The purpose of this study was to measure the effect of exercise duration concomitantly on energy expenditure and cognitive performance. The physical task was pedalling on a cycloergometer at an intensity of 60% Pmax (power reached with maximal aerobic power). The cognitive task was a visual choice reaction task (RT2). Twenty-two students without expertise in decisional activities participated over four sessions procedure during 10 treatment days. In a first session, individual Pmax was measured. The second session (session 2) was composed by RT tasks performed at rest. During the sessions 3 and 4 randomly presented, each subject completed a 10 min. bicycle ergometer test without or with a simultaneous RT task. Mean RT values, error RT values, pedal rate were collected in sessions 2 and 4 at the beginning (3-5 min) and at the end (8-10 min) of the exercise test. Heart rate was continuously recorded. The results showed a significant interaction effect between cognitive task and exercise duration for mean RT values ($p < .025$), heart rate values ($p < .025$) whereas it was not significant for the R T eITor rate and pedal rate. With exercise duration, mean RT presented higher decrease at the end of the exercise testing ($p < .01$). These results are discussed principally in terms of intermediaries factors as activation or investment of attentional resources induced by exercise duration.

INTRODUCTION

During the last decades, the physiological effects of exercise on cognitive performance have been well documented (Bashore & Goddard, 1993; Folkins & Sime, 1981; Gutin, 1972; Thomas et al, 1994; Tomporowski & Ellis, 1986). However, the often contradictory findings of experimental researches have led several authors to identify four methodological factors to control in such studies:

- i. the physical fitness of subjects,
- ii. the intensity and duration of physical exercise,
- iii. the nature of the psychological task and
- iv. the time at which the psychological task was administered to the subjects (Brisswalter & Legros, 1996a; Paas & Adam, 1991; Tomporowski & Ellis, 1986).

With regard to the last factor, divergent results were found when a cognitive task was performed during or immediately after exercise (e.g.. Flynn, 1972; Mc Glynn et al, 1977; Legros et al. 1992). But, surprisingly, very few studies focused on the comparison between the same cognitive task performed at different periods of a single bout of exercise.

The physiological effects of exercise duration are relatively well known. Numerous studies have shown an upward VO₂ drift related to several factors such as the thermal stress, an enhanced cardiac work or a change in metabolic events (e.g.. Brisswalter & Legros, 1996b; Casabury et al, 1987; Hagberg et al, 1978). However, controversies could exist over the effects of an increase in these energetical constraints on cognitive performance according to different experimental hypothesis.

For the one hand, when the cognitive performance was performed during exercise, subjects are classically confronted with a principal physical task of locomotion such as walking, running, or cycling and an added cognitive task such as reaction time (RT). Within this framework, some consistent results have been observed showing a decrement of simple reaction time (SRT) performance during moderate exercise (e.g.. Brisswalter et al. 1995; Delignières & Brisswalter, 1995; Legros et al, 1992). In regard to the imposed physical task, the result may be interpreted in terms of the allocation of attention during dual task performance (Abernethy. 1988; Posner & Keele. 1969). Within this framework, Brisswalter et al (1995) have shown a linear relationship between VO₂ and reaction time performance suggesting that the dual task effect was strongly related to the energetical task constraints. The greater the energetical demand the more attention is mobilised to control movements.

For the other band, using a complex decisional task, some simultaneous tasks studies provided clear support for an improvement of cognitive performance during exercise (Arcelin et al, 1995; Delignières et al, 1994; Paas & Adam, 1991). Diverse contributing factors have been evoked to interpret this enhancement of cognitive efficacy. Firstly, an increase of the nervous activation level related to physical exertion is classically, often a posteriori (e.g.. Levitt & Gutin. 1971; Mc Morris & Keen. 1994; Sjoberg. .1968), but sometimes in an a priori fashion (Arcelin et al. 1997), suggested. According to the inverted-U hypothesis (Yerkes & Dodson. 1908), maximal levels of cognitive performance could be associated with optimal arousal states induced by exercise (Martens et. al. 1990; Gould & Krane. 1992). Secondly, recent studies have evoked the mediating role of resources allocation to explain an improvement of cognitive performance during exercise (Delignières et al, 1994; Paas & Adam, 1991). Within this framework, Delignières et al (1994) explained the improvement in

decisional performance by an increase in the amount of effort invested in the task as a function of exercise workloads (i.e. energetical constraints).

Therefore, the aim of the present study was to investigate the effects of exercise duration on decisional performance in a cycling task. With regards to the dual task paradigm, we should observe a decrease in performance. However, according to previous studies using a complex decisional task, we made the assumption that exercise duration would lead to an improvement in a choice reaction time performance mediated by an activation increase, and/or motivational factors.

METHOD

Subjects. 22 volunteers took part in this experiment. Detailed physical characteristics are summarised in Table 1. Participants had been chosen as non-expert in decisional sports. Furthermore, to control a possible methodological effect of physical fitness on cognitive performance, subjects were selected after a maximal test of VO₂max determination, to be homogeneous in physiological capacities required by the physical task (Brisswalter et al, 1994). Mean values of VO₂ max (ml.min.⁻¹.kg⁻¹), FCmax (bpm) and maximal power reached with VO₂max (Pmax. in watts) were reported Table 1.

TABLE 1: Physiological characteristics of subjects recorded during the maximal test of VO₂max determination.

	Age (yrs)	Weight (kg)	Pmax (watts)	VO ₂ max (ml kg ⁻¹ .min ⁻¹)	Max Heart Rate (bpm)
Females	21.55 ± 1.75	61.78 ± 7.25	261.82 ± 22.61	47.92 ± 3.77	182.50 ± 7.50
Males	26.00 ± 7.87	77.30 ± 16.50	371.25 ± 14.36	61.78 ± 11.15	184.18 ± 8.50

Note: mean scores and ± standard deviation

Apparatus. For all experimental sessions, a cycloergometer Miditronic was used. in the aim of maximal standardization of the protocol, the experimental device could be adapted to the morphology of each subject. The luminosity, the heat and the moistness (Delignières & Brisswalter, 1995) were controlled during all sessions.

A screen displaying the number of revolutions per minute and power output was positioned in front of the subject to provide with feedback regarding pedalling rate. Heart rate was measured continuously during experimental sessions with a Sport tester PE 3000 system (polar). RT experimental device was the same as those described previously by Delignières et al (1994). Participants had to perform 2 x 20 trials separated by a 1 min rest. Each warning signal appeared 1200 msec after the preceding response. In the aim of controlling a possible bias related to anticipated responses (Sanders, 1983), a mixed foreperiod duration (from 5.5 to 9 sec) was proposed. When the response signal appeared in the center of the computer screen,

subjects had to respond by tilting on the appropriate joystick. Choice RTs under 160 msec were considered as error responses. Errors and latencies were recorded continuously by the computer.

Procedure. Each subject performed four experimental sessions during 10 treatment days. In order to allow comparison of physiological requirements between the different tests, all sessions took place, for each subject, at the same time of the day (Becque et al, 1993). No cognitive performance feedback was given (latency, accuracy of RT responses), whereas information about energetical performance was displayed (pedalling rate, mechanical power, exercise duration).

The first session was composed by a VO₂max determination test conducted at 60 rpm to volitional exhaustion (adapted from the test proposed by Storer et al, 1990). VO₂max was adjudged by the presence of a plateau in VO₂ uptake towards the end of the incremental maximal protocol, a maximum age-predicted heart rate, a respiratory exchange ratio (RER) above 1:1. Expired gases (Oxycon) and heart rate were collected continuously. The maximal power reached with VO₂max was called P_{max}. During this session, before exercise, subjects were familiarized with RT procedures in order to determine individual baseline performances (Sanders 1983).

The second session was the resting condition. During this test, after a period of accommodation to the RT tasks (2 x 20 trials), each subject completed the choice RT tasks sitting on the cycloergometer (without pedalling) at the beginning (3-5min) and at the end (8-10min) of a 10 min period. Heart rate was continuously monitored.

TABLE 2: Means and standard deviation (+/-) values for Δ heart rate (bpm) and pedal rate (rpm) recorded during session 3 and 4.

Task	Period	
	3' -5'	8' -10'
	Δ . HR (bpm)	
Session 3	67.7 +/- 10.6	75.8 +/- 11.9*
Session 4	67.3 +/- 10.9	72.4 +/- 10.5*
	Pedal rate (rpm)	
Session 3	64.9 +/- 5.6	66.2 +/- 5.4*
Session 4	67..7 +/- 5.5#	69.4 +/- 5.6*#

Note: a significant difference was found between the period for *P<.01 and between the tasks conditions for #P<.025

The two other sessions (sessions 3 and 4) were randomly presented. During these tests, subjects had to perform a submaximal pedalling exercise on a cycloergometer. After a 3 min. warming up at 30 watts, the intensity was fixed at 60% of P_{max}, during 10 min. According to a previous work on interactions between energetical and cognitive processes, pedal rate was freely chosen, in order to minimize bath energy cost and/or dual task effect on cognitive

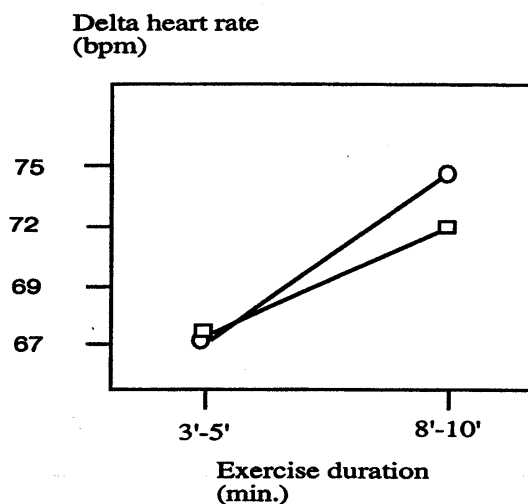
performance (Brisswalter et al, 1995). The cognitive task was proposed only during session 4 at the beginning (3-5min) and at the end of the exercise (8-10min). During all these tests, heartrate was measured and expressed as delta heart rate: $DBR = BR_{Work} - HR_{Rest}$ (Karvonen & Vuorimaa, 1988). Furthermore, pedal frequency (mean values and variability calculated from 24 rotations for each period) was continuously monitored.

Statistical analysis. Firstly, daily reliability of physical parameters collected during sessions 2, 3 and 4 was analysed using Student's t test (Becque et al, 1993). Secondly, a two way analysis of variance with repeated measure (period) was performed on cognitive performance values and physical parameters. The effect of exercise on error rate was analysed after arcsinus transformation (Winer, 1962). The Newman-Keuls test was used for posthoc comparisons of mean differences between levels. Reliability of physical and cognitive parameters was studied by calculating the coefficient of variation $CV = (sd.mean^{-1}) \times 100$ (Brisswalter et al, 1995).

RESULTS

Reproductibility and energetical requirement of pedalling tasks

Mean DHR and pedal rate values collected during sessions 3 and 4 are reported in Table 2. No significant differences between all the tests (sessions 1, 2, 3, 4) have been found for heart rate at rest ($p > .05$), and between session 3 and 4 during exercise. The DHR values collected at the beginning of the pedalling task were respectively: 66.9 vs 66.2 bpm, ($p > .05$). A significant effect of exercise duration was observed on BR values ($F_{1,18} = 129.40$, $p < .01$), whereas no significative main effect of task condition was found ($F_{1,18} = .40$, $p > .05$). Furthermore, a significative task by exercise duration interaction was found ($F_{1,18} = 6.82$, $p < .025$). Post-hoc analysis indicated that the increase of DHR values with exercise duration was lower in simultaneous task than in the single exercise (Figure 1).



*FIGURE 1: Mean Δ heart rate values related to exercise duration.
circles - during exercise condition
squares - during simultaneous task*

For pedal rate, no differences were found between session 3 and 4 during the first minutes of exercise ($p > .05$). A significant effect of exercise duration was found ($F_{1,18} = 8.30$, $p < .01$), but no significant task by exercise duration interaction was observed ($F_{1,18}$

=.26, $p > .05$). Furthermore, a significant main task effect was found on mean pedal rate values ($F_{1, 18} = 7.68$, $p < .025$), whereas pedal rate variability was not significantly different among task conditions ($F_{1, 18} = 2.17$, $p > .05$) or exercise duration ($F_{1, 18} = 1.06$, $p > .05$).

Choice RT performance

Mean reaction times (RT), error rates (ER) and intra-individual variability (RTvar) in reaction time are reported in Table 3. No effect of duration on RT, ER or RTvar was found during session 2 ($p > .05$). Furthermore, during sessions 2 and 4, no main effect of task ($p > .05$), exercise duration ($p > .05$) and no significant interaction ($F_{1,21} = .05$, $p > .05$) were found on ER. Similarly, no main effect of duration ($p < .05$) and no significant interaction ($p < .05$) were observed on RTvar, whereas a main effect of task condition ($F_{1,21} = 13.63$, $p < .001$) was found.

In contrast, a main effect of task ($F_{1,21} = 21.02$, $p < .01$) without effect of duration ($p > .05$) and a significant task by exercise duration interaction ($F_{1,21} = 6.78$, $p < .025$) were found on mean RT values. Compared with at rest condition, post-hoc analysis indicated a significant improvement of RT performance during exercise, respectively at the beginning ($F_{1,21} = 4.36$, $p < .05$) and at the end of the physical stage ($F_{1,21} = 30.35$, $p < .01$) (Figure 2).

DISCUSSION

The results of this experiment confirm the possibility of improving cognitive performance during physical exercise. This finding is in agreement with previous studies conducted during the same moderate exercise (Arcelin et al., 1995; Delignières et al, 1994; Paas & Adam, 1991). Furthermore in this study, this improvement could be seen as a function of the task constraints. However, several methodological factors have to be considered.

TABLE 3: Means and standard deviation (+/-) values for choice RT (msec) error rate (%) and intra-individual variability of choice RT performance recorded during session 3 and 4.

Task	Period	
	3'-5'	8'-10'
RT (msec)		
Session 2	265.9 +/- 20.4	267.1 +/- 26.3
Session 4	256.9 +/- 24.1#	245.3 +/- 29.1#
Error rate (%)		
Session 2	2.9 +/- 3.4	2.5 +/- 3.7
Session 4	2.3 +/- 2.4	2.5 +/- 3.3
Choice RT variation (CV)		
Session 2	10.6 +/- 3.3	11.6 +/- 2.7
Session 4	13.6 +/- 2.9###	13.0 +/- 4.1###

Note: a significant difference was found between the tasks conditions for # $P < .01$ and for ### $P < .001$

On the one hand, the validity of the experimental protocol is closely linked to the reproductibility of physiological solicitation across the different physical tasks. The analysis of physiological parameters (HR data) indicates that the energetical requirement for both the pedalling tasks (sessions 3 and 4) was similar. Furthermore, the relative values of HR (expressed in %HRmax) indicate that exercise was strictly aerobic (respectively for sessions 3 and 4 at the beginning and at the end of exercise, 60.55% vs 61.87% and 60.88% vs 61.54%). Thus, our results were in accordance with reproductibility criteria determined in a similar protocol with non experienced cyclists (Becque et al, 1993).

On the other hand, Durand et al (1991) had suggested that an improvement in cognitive performance could be linked to the adoption of risky strategies by subjects. In our study, no changes in error rate were observed between sessions 2 and 4 at the beginning nor at the end of the two tests (respectively, for sessions 2 and 4 : 2.88 vs 2.50% and 2.35 vs 2.50%). In agreement with recent studies (Delignieres et al, 1994; Paas & Adam, 1991), these findings invalidated Durand et al's hypothesis postulating that subjects under exercise could privilege speediness rather than accuracy.

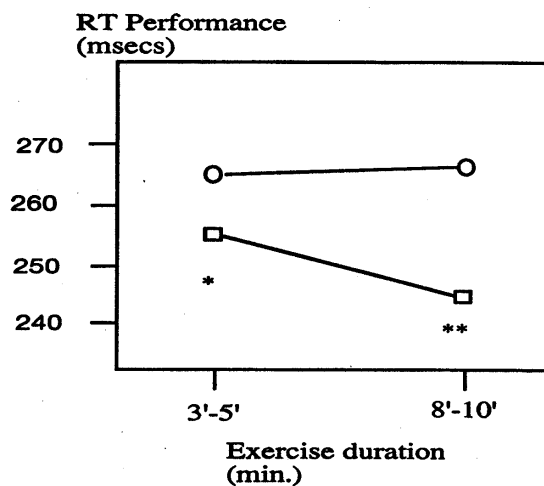


FIGURE 2: Influence of acute exercise on choice RT performance related to exercise duration. Circles - during exercise condition, squares - during simultaneous task
Significantly different at * $P < .05$ and at ** $P < .01$ (Newman-Keuls test)

Nevertheless, our results are not in agreement with dual task paradigm predictions. In this study whatever the period, we have observed an improvement in RT performance. This absence of a dual task effect can be interpreted in terms of a minimization of the attentional allocation during a cycling exercise especially, when it was performed with a freely-chosen pedal rate. In a recent dual task study, Brisswalter et al (1995) have shown that the lowest attentional demand was recorded for an optimal zone including freely-chosen and physiological optimal rates. Therefore, the improvement in RT could be seen as a result of intermediary factors such as activation, resources allocation or motivation (Tomporowski & Ellis, 1986).

On the one hand, our results seem to be compatible with the assumption of a mediation by activation level. As classically reported in physiological studies, we have observed an increase in energy expenditure with exercise duration (e.g., Casabury et al, 1987; Hagberg et al, 1978). This effect, concomitant with cognitive performance improvement, could be compared to the first hypothesis on the interactions between exercise and cognitive

performance organized according to an inverted-U curve between heart rate and cognitive performance (e.g., Tomporowski & Ellis, 1986). Furthermore, recent studies have assumed that the effect of exercise on cognitive performance was mediated by neuro-hormonal functioning (Brisswalter et al.1994; Dientbier, 1991; Lacouretal, 1988). Within this framework, in our study, we have reported that the increase in HR with exercise duration was lower during the simultaneous condition, despite the increase of pedal rate. This result can be compared to Takahashi and Arito 's study (1996) showing that heart rate variation during repetitive cognitive task is related to a balance of the sympathetic-parasympathetic system and thus, to neuro-hormonal factors. Therefore, if the actual effect of activation could not be easily tested in such experiment, it must be considered in further researches.

On the other hand, Delignières et al (1994) have assumed that the RT improvement during exercise is related to a higher involvement in attentional resources. Within this framework, the amount of resources invested is a function of constraints of the task. So in our study, exercise duration could introduce an alteration of the subject-task relation that increased the allocation of attentional resources. Such an alteration is classically evoked to explain the increase in pedal rate as a function of the cycling task constraints (Coast & Welch, 1985; Gregor et al, 1991). Consequently, the effect of exercise duration on RT could be compared to the increase of noise studied by Dornic et al (1974). These authors have reported that subjects were able to maintain cognitive performance under noise conditions but more effort was necessary in this situation.

Furthermore, a higher involvement in attentional resources could be related to the expectancy of benefits induced by exercise on cognition. Tomporowski and Ellis (1986) had reported that these motivational factors could explain divergent results in cognitive functioning during exercise. In this study, our fit volunteers could have a positive expectancy of benefits from exercise, specially because energetical constraints (moderate intensity, short exercise duration, freely chosen pedal rate) optimally challenged individual's own ability. Thus, beneficial effects of exercise on cognitive functioning would only be observed when participants felt optimally stimulated (e.g., Csikszentmihalyi, 1975).

In conclusion, this study belongs to the category of current experiments suggesting that cognitive functioning is sensitive to the short-term effects of exercise mediated by several intermediary factors. However, while it seems difficult to test these models, it is necessary to accumulate results by varying experimental conditions. Furthermore, according to activation or motivational hypothesis it remains unclear how long these effects last. Interestingly, future research should determine either the minimal or the optimal exercise duration required for achieving and maintaining significant cognitive functioning benefits.

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