# Influence of physical exercise on choice reaction time in sports experts: The mediating role of resource allocation

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# INFLUENCE OF PHYSICAL EXERCISE ON CHOICE REACTION TIME IN SPORTS EXPERTS: THE MEDIATING ROLE OF RESOURCE ALLOCATION.

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Abstract: This experiment was performed in the aim of analyzing the influence of physical exertion on decisional processing in sports experts. 40 subjects were involved in the experiment. The first group (N=20) was composed of fencers and fencing masters, the second (N=20) of subjects who practised sport but who had no expertise in decisional sports. The two groups did not differ in physical condition. While pedalling on a cycloergometer at relative powers corresponding to 20, 40, 60 and 80% of their own maximal aerobic power, the subjects had to perform two choice reaction time tasks (2-RT and 4-RT). Performance scores were collected, and for all conditions, subjects were asked to assess the difficulty of the reaction time task. The results showed, for the experts, a monotonic increase in performance, as physical exertion increased. On the contrary, the performances of the non-expert group deteriorated as exertion increased. The error rate remained stable for each group over all conditions. Finally, the experts assessed tasks as more difficult than the non-experts, especially at high levels of exertion. These results showed that the improvement of the experts' performances in decision tasks under high physical exertion was related to an additional resource investment.

Key-words: Physical exertion, information processing, resource allocation, perceived difficulty.

## 1. Introduction.

In many sports, especially team and combat sports, subjects have to make decisions rapidly and accurately, despite a great physical exertion. Much research has been carried out on the influence of physical exercise on cognitive processes efficacy. Using diverse protocols, having considered the nature and the intensity of the required exertion, as well as the nature of the cognitive task (perceptive discrimination, memorisation, mental calculation, problem solving, coincidence-anticipation,...), this research has provided divergent results: from one experiment to another, exertion did not have any effect on performance in the cognitive task (Bard & Fleury, 1978; Craft, 1983; Fleury *et al*., 1981, Lulofs *et al*., 1981; McGlynn et al., 1979), had a positive effect (Lacour *et al.*, 1988; McGlynn *et al.*, 1977) or a negative one (Flynn, 1972; Gutin & Digennaro, 1968). Tomporowki and Ellis, after a review on this question, explained this inconsistency mainly by the variety of the protocols, and an imperfect control of subjects' physical condition and motivation.

Nevertheless, some works which specifically focused on decisional tasks gave more consistent results (Levitt & Gutin, 1971; Salmela & NDoyle, 1986; Sjöberg, 1968). Generally organized according to a progressive exercise protocol, these experiments showed an inverted-U curve between exercise intensity and choice reaction time: firstly exertion improved performance, until an optimum corresponding approximately to a heart rate of 120 beats per minute. Beyond this optimum, increase of workload impaired performance monotonically. These results have supported the hypothesis that the influence of physical exercise on cognitive processes efficacy was mediated by the level of activation induced by exertion.

Some recent research could challenge part of this model. Legros *et al.* (1992) have examined the influence of a treadmill running exercise at 95 and 125% of VO2max on simple and binary-choice reaction time, in expert basket-ball players. Results showed an impairment of simple reaction time under exertion, but inversely an improvement of choice reaction time. Nevertheless, this improvement was accompanied by an increase in the error rate. Durand, Bourrier and Legros (1991) analyzed the effects of a cycling exercise at 35, 60 and 90% of VO2max on simple and choice reaction time, in a group of female physical education students. In general no effect of exertion on reaction time was shown. But an *a posteriori* analysis showed that the subjectswho were experts in team sports improved their choice reaction time at high exertion levels. This improvement was again associated with an increase in error rate. On the contrary exertion had no influence, either on reaction time, or on error rate, with those who were experts in other sports (gymnastics, athletics). These experiments tended to show that experts in sports which required a decisional activity under high energy expenditure, were able to improve their performances in choice reaction time tasks as exertion increased.

These results concerning choice reaction time were incompatible with the hypothesis of a mediation by activation level, as the inverted-U model could not account for an improvement of cognitive performance at high levels of exertion. We could propose the hypothesis that experts possess a specific skill, which allowed them to cope with high energy expenditure, and to maintain or improve their performances. The decrease in response accuracy tends to invalidate this proposition. Durand *et al.* (1991) suggested an alternative hypothesis, according to which team sports experts could adopt risky strategies, favouring speed rather than accuracy. This hypothesis, consistent with the increase in error rate, is without doubt partially valid. But we could not be sure that it totally accounts for the improvement in reaction time. For example with some subjects of Legros *et al.*'s (1992) experiment, an improvement in reaction time was observed, without significant variation in error rate. Paas and Adams (1991) also showed a significant improvement in performance in a decisional task, at exertion levels located between 75 and 85% of VO2max. This improvement was not associated with an increase in error rate.

Paas and Adams (1991) suggested an other framework for interpreting this. They considered that such results might be analyzed by taking into account the amount of resource allocated by subjects to the cognitive task. Durand *et al.*'s (1991) explanation, assuming a speed-accuracy trade-off, is based on the idea of the stability of the processing capacity allocated to the task, under all effort conditions. Now, if we consider that there was a real improvement in performance at high levels of energy expenditure, it could be supposed that the amount of resource allocated to the reaction time task had been increased.

This proposition raises some problems: as the instruction given to subjects was, under all exertion conditions, to respond as quick as possible without errors, we could suppose that they used all of their processing capacity. Nevertheless, some theories could explain a variation in the available capacity. Kahneman (1973) thinks that the resource capacity is variable, and related to an estimation of task requirements: the more difficult the task is perceived as being, the more the subject release processing capacity to be used. Kantowitz and Knight (1976) suggested another hypothesis, and consider the processing system as fundamentally conservative: even if resources are, in the absolute, limited, the system would never allocate them all, conserving a residual capacity. An improvement in performance could be explained by the subject using this resources reservoir as a last resort.

Paas and Adams (1991) consider that such a model could not easily be tested, as no valid procedure is available to assess the allocated amount of resource. Recent works on perception of difficulty seem to allow for this kind of assessment. Delignières (1993a, 1993b) has shown that perceived difficulty (i.e. the sensation of difficulty which is perceived by the subject while performing a task) is related neither to the objective difficulty of the task, nor to the effective performance, but to the amount of resources invested. This result, consistent with the findings of Vidulich (1988) and Yeh and Wickens (1988) on the dissociations between performance and subjective workload, allows for a new experimental approach to resource allocation.

The aim of this experiment was to observe and to analyze the effect of different levels of physical exertion on choice reaction time, in combat sports experts and non-experts. We expected, in accordance with the previous results, an improvement in performance for the experts, as the level of exertion increased. Conversely, the performance of the non-experts would stagnate or decrease.

The diverse hypotheses previously raised allowed us to put forward the following predictions:

- If experts possess a specific skill, then the improvement in performance would not be associated with a significant increase in error rate. In addition, as skill is characterized by the efficiency of the processing, experts should assess tasks as being easier than non-experts.

- If experts adopt risky strategies at high levels of exertion, we should observe a significant increase in error rate. On the other hand, as these strategies diminish demands in information processing, experts should assess tasks as being easier than subjects who do not adopt such strategies.

- If the improvement in performance for the experts is due to an increase in resource allocation, then these subjects should assess the tasks as being more difficult than non-experts. On the other hand, no significant increase of error rate could be expected.

The present experiment was organized with the aim of testing these diverse predictions.

## 2. Method.

### 2.1. Subjects.

40 subjects were involved in the experiment. They were divided into two groups: the first one was composed of 20 expert fencers and fencing masters (17 males and 3 females, mean age 24.0, s.d.: 8.3). This group was considered as being composed of experts in choice reaction tasks under high energy demands. The second group was composed of 20 subjects, who had no expertise in such decisional sports (11 males and 9 females, mean age 23.3, s.d.: 5.5.). These latter subjects had nevertheless been chosen from a sportive population, in the aim of controlling a possible bias related to physical condition. Maximal oxygen uptake and maximal heart rate were individually determined in a preliminary protocol. Mean maximal oxygen uptake was 50.14 $ml.min^{-1}.kg^{-1}$ (s.d. 18.11) for the expert group, and 49.61 $ml.min^{-1}.kg^{-1}$ (s.d. 17.88) for the non-expert group. The difference between groups was not significant ($t_{38}$=.14, NS). There was no difference between mean maximal heart rates (191.60 (s.d. 58.37) *vs* 188.35 (s.d. 42.71), $t_{38}$= 1.54, NS).

### 2.2. Apparatus.

The pedalling task was performed on a cycloergometer *Ergomeca*. Workload was increased by increments both in pedalling frequency and in resistance strength. To provide subjects with feedback regarding pedalling rate, a screen displaying the number of revolutions per min was positioned in front of the subjects. The experimental device could be adapted to the morphology of each subject, in the aim of a maximal standardization of the test.

Reaction time tasks were performed on a computer, connected to two joysticks, held in front of the ergometer handlebar. The subject placed his forearms on special supports on the handlebar (Figure 1). Subjects had to respond to a signal appearing on the screen, by tilting the appropriate joystick in the appropriate direction. Depending on the level of difficulty, 2 or 4 empty squares horizontally aligned were on the screen, drawn in yellow on blue. The subjects had to respond when one of the squares became filled with red. At the first level of difficulty (2-RT), the subjects responded to the right signal by tilting the right joystick to the left, and to the left signal by the tilting the left joystick to the right. At the second level (4-RT), the subjects responded to the two left signals by the tilting the left joystick to the left or to the right, and conversely for the two right signals with the right joystick. Response time and errors were recorded by the computer.

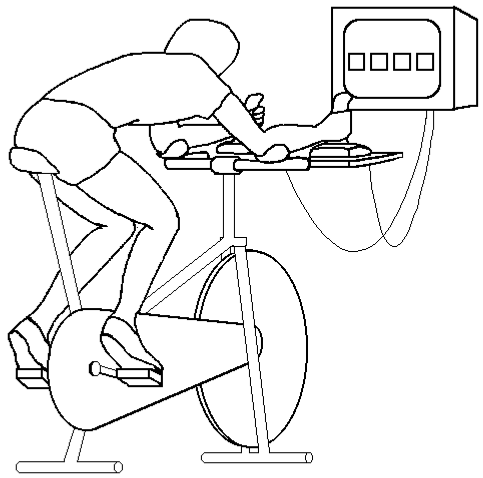

*Figure 1: Experimental device.*

Perceived difficulty was assessed according to the DP-15 scale (Delignières, Famose & Genty, 1993), a 15-points category scale, with 7 labels, from "extremely easy" to "extremely difficult", symmetrically placed around a central label "somewhat difficult" (Figure 2).

2.3. Procedure.

Subjects performed in succession four exercise sessions of four minutes. The workload for each stage was determined as a percentage of individual maximal aerobic power (MAP), respectively 20, 40, 60 and 80%. For each workload, pedal frequency was chosen as the optimal energetic frequency, determined for one workload and one level of physical fitness (Coast, Cox and Welch., 1986, Gregor and Broker, 1991). The duration of the pause between successive exercise stages was determined on the basis of the subject's heart rate so that a new stage was started when the resting level was reached.

| | |
|---|---|
| 1 | |
| 2 | Extremely easy |
| 3 | |
| 4 | Very easy |
| 5 | |
| 6 | Easy |
| 7 | |
| 8 | Somewhat difficult |
| 9 | |
| 10 | Difficult |
| 11 | |
| 12 | Very difficult |
| 13 | |
| 14 | Extremely difficult |
| 15 | |

*Figure 2: The DP-15 category scale for the perception of difficulty.*

The reaction time tasks were performed just before the first session, and in the last minute of each session, after stabilization of the heart rate. Subjects performed 20 successive trials for each level of difficulty. They were instructed to respond as quickly as possible, but without any error. At the end of the 20 trials, they were asked to rate the task difficulty, according to the DP-15 scale. The order of the two levels of difficulty is systematically varied between sessions and subjects.

### 2.4. Analyses

Performances faster than 160 ms were considered as anticipated responses and therefore as errors. The effect of workload on error rate was analyzed, for each group and each level of difficulty, by a one-way analysis of variance, with repeated measurements. The effects of expertise and workload on performance were analysed, for each level of difficulty, by a two (expertise) by five (workload) two-way analysis of variance, with repeated measurements on the workload factor, including resting condition. The effects of expertise and workload on perceived difficulty were analyzed, for each level of difficulty, by a two (expertise) by four (workload) two-way analysis of variance, with repeated measurements on the workload factor.

## 3. Results.

### 3.1. Errors.

Error rates are reported in Table 1. The analysis of variance indicated a significant effect of workload on error rate only with the experts in 2-RT ($F_{4,76}$=13.02, p<.01). Nevertheless, it is impossible to describe, in this case, a monotonic relationship between workload and error rate. Generally, increase in workload was not related to increase in error rate.

| | | Percentage of MAP | | | | |
|---|---|---|---|---|---|---|
| Task | Group | 0% | 20% | 40% | 60% | 80% |
| 2-RT | Experts | 5.00 (4.52) | 6.00 (3.92) | 0.75 (1.92) | 0.75 (1.62) | 3.50 (3.50) |
| | Non-experts | 3.50 (4.13) | 6.00 (5.73) | 2.25 (3.57) | 5.00 (4.52) | 3.75 (3.73) |
| 4-RT | Experts | 7.50 (3.96) | 7.75 (4.29) | 6.50 (4.20) | 7.00 (4.26) | 6.00 (3.65) |
| | Non-experts | 6.50 (4.78) | 7.50 (6.24) | 5.75 (3.53) | 6.50 (6.21) | 5.75 (5.20) |

*Table 1: Error percentages (standard deviation in brackets).*

3.2. Reaction time.

Mean reaction times were computed for each group and each difficulty level from valid performance scores (Table 2). At rest, the experts had better performances than the non-experts (2-RT: $t_{38}$=2.18, p<.05; 4-RT: $t_{38}$=4.40, p<.01).

The analysis of variance showed a significant effect of expertise (2-RT: $F_{1,38}$=22.05, p<.01; 4-RT: $F_{1,38}$=42.57, p<.01), and of the interaction expertise-workload (2-RT: $F_{4,152}$=13.92, p<.01; 4-RT: $F_{4,152}$=13.41, p<.01). The analyses of simple effects showed a significant effect of workload, for the experts (2-RT: $F_{4,76}$=22.22, p<.01; 4-RT: $F_{4,76}$=12.38, p<.01) and the non-experts (2-RT: $F_{4,76}$=4.17, p<.01; 4-RT: $F_{4,76}$=4.62, p<.01). For the non-experts, a Newman-Keuls test indicated a significant decrease in performance, at 60 and 80% of MAP, as compared with the performances obtained at rest, 20 and 40%. With the experts, the Newman-Keuls test showed *a contrario* improvements in performance, between rest and 20% and between 40 and 60% for 2-RT, between rest and 40% and between 40% and 60% for 4-RT (Figure 3).

| | | Percentage of MAP | | | | |
|---|---|---|---|---|---|---|
| Task | Group | 0% | 20% | 40% | 60% | 80% |
| 2-RT | Experts | 270.35 (25.49) | 263.95 (27.69) | 260.70 (26.10) | 249.10 (24.80) | 250.30 (26.81) |
| | Non-experts | 286.30 (20.46) | 290.75 (42.20) | 292.25 (22.81) | 296.70 (26.38) | 307.85 (24.13) |
| 4-RT | Experts | 354.25 (21.96) | 348.65 (28.67) | 342.70 (30.50) | 329.85 (26.41) | 331.25 (26.02) |
| | Non-experts | 387.55 (25.74) | 393.20 (47.70) | 392.10 (32.96) | 401.50 (31.73) | 411.20 (30.26) |

*Table 2: Mean reaction time (standard deviation in brackets).*

3.3. Perceived difficulty.

Mean scores of perceived difficulty are reported in Table 3. The analysis of variance indicated, for the two levels of difficulty, a significant effect of expertise (2-RT: $F_{1,38}$=62.32, p<.01; 4-RT: $F_{1,38}$=29.54, p<.01), of workload (2-RT: $F_{3,114}$=415.96, p<.01; 4-RT: $F_{3,114}$=230.01, p<.01), and of the interaction expertise-workload (2-RT: $F_{3,114}$=90.95, p<.01; 4-RT: $F_{3,114}$=51.46, p<.01).

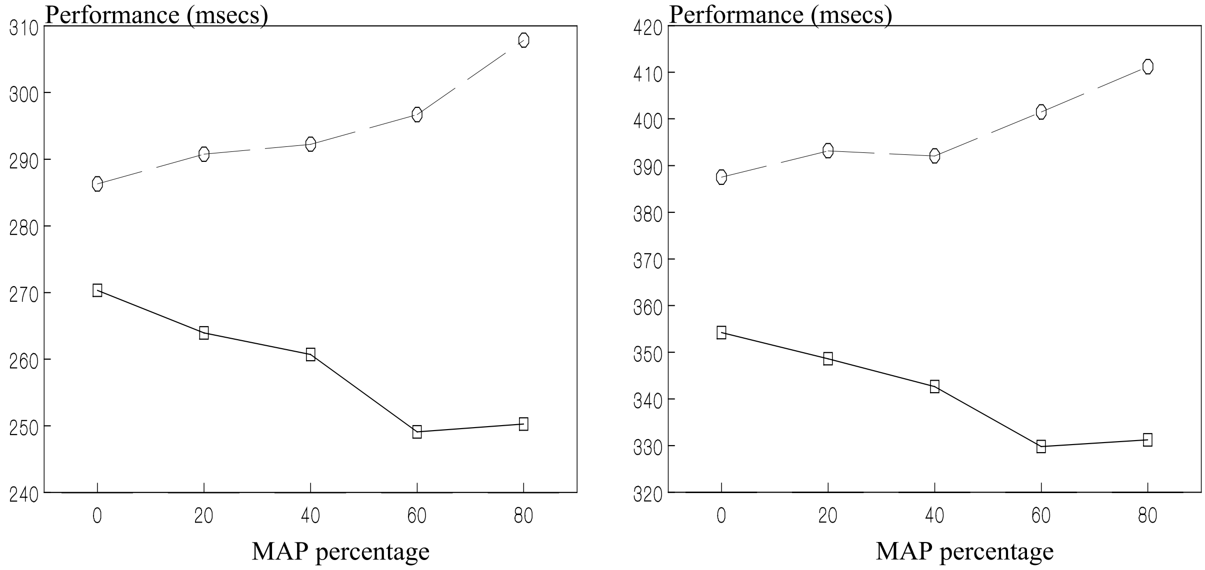


*Figure 3: Evolution of performance in RT tasks, as a function of pedalling workload. Left: 2-RT, right: 4-RT (squares: experts group, circles: non-experts group).*

| | | Percentage of MAP | | | |
|---|---|---|---|---|---|
| Task | Group | 20% | 40% | 60% | 80% |
| 2-RT | Experts | 3.70<br>(1.67) | 5.25<br>(1.19) | 7.85<br>(1.50) | 10.70<br>(1.73) |
| | Non-experts | 3.10<br>(0.74) | 3.90<br>(0.94) | 4.55<br>(0.62) | 5.70<br>(0.59) |
| 4-RT | Experts | 5.10<br>(1.33) | 5.55<br>(0.91) | 8.70<br>(1.73) | 10.55<br>(1.58) |
| | Non-experts | 4.75<br>(0.81) | 5.65<br>(0.69) | 5.80<br>(0.71) | 7.35<br>(1.01) |

*Table 3: Mean scores of perceived difficulty (standard deviation in brackets).*

The analyses for simple effects showed a significant effect of workload, for the experts (2-RT: $F_{3,57}$=354.35, p<.01; 4-RT: $F_{3,57}$=181.74, p<.01) and the non-experts (2-RT: $F_{3,57}$=80.54, p<.01; 4-RT: $F_{3,57}$=60.92, p<.01). Newman-Keuls tests indicated that generally perceived difficulty increased as workload increased, for the two groups (Figure 4): the only non significant differences between two successive conditions appeared in 4-RT, between 20% and 40% for the experts, and between 40% and 60% for the non-experts.

The analysis showed a effect of expertise, significant for the two levels of difficulty at 80% of MAP (2-RT: $t_{38}$=12.54, p<.01; 4-RT: $t_{38}$= 7.83, p<.01) and 60% (2-RT: $t_{38}$= 9.33, p<.01; 4-RT: $t_{38}$= 7.10, p>.01). At 40%, the effect was significant only for 2-RT (2-RT: $t_{38}$= 4.08, p<.01; 4-RT: $t_{38}$= -.40, NS) and there was no effect at 20% (2-RT: $t_{38}$= 1.51, NS; 4-RT: $t_{38}$= 1.03, NS).

In conclusion, the experts perceived higher levels of difficulty than the non-experts, and the difference increased as pedalling workload increased (Figure 3).

## 4. Discussion.

These results confirm that it is possible to obtain a significant improvement in performance in decisional tasks under high exertion conditions, with experts in combat or team sports. Conversely, with subjects who do not possess this kind of expertise, a deterioration of performance is observed, which is consistent with the results traditionally reported in the literature (Levitt & Gutin, 1971; Salmela & NDoyle, 1986; Sjöberg, 1968).

Contrary to the results previously obtained by Durand *et al.* (1991) and Legros *et al.* (1992), this improvement in response time is not associated with an increase in error rate. This result invalidates the hypothesis that improvement in response speed was solely due to the adoption of risky strategies, to the detriment of response accuracy (Durand *et al.*, 1991).

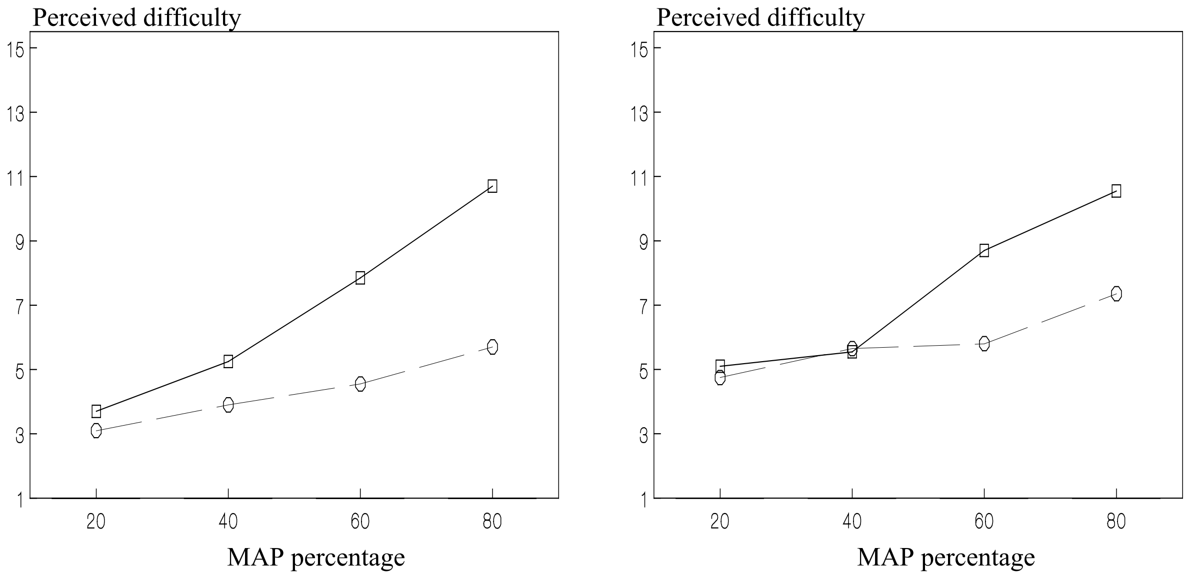


*Figure 4: Relationship between pedalling workload and perceived difficulty. left: 2-RT, right, 4-RT (squares: experts group, circles: non-experts group).*

The increase of perceived difficulty as workload increased invalidates the hypothesis that experts possess a specific skill, allowing them to cope with high energy expenditure while maintaining a stable level of performance. It indicates conversely that experts improve their performances because they invest more resources. Under all conditions where the experts obtained better performances than the non-experts, the former's scores of perceived difficulty were significantly higher than those of the latter. This interpretative framework is consistent with the hypothesis reported by Vidulich (1988) and Yeh and Wickens (1988), on the dissociations sometimes observed between performance and perceived difficulty: a long-term improvement in performance is generally associated with a decrease in subjective workload, due to the automatization of processing procedures, but a short-term improvement gives the inverse phenomena. This kind of improvement, related to motivational factors, is due to an increase in the amount of effort invested in the task, and results in an increase in subjective workload. Our results confirm the importance of motivational factors, in the relationships between exercise and cognitive processes (Tomporowski & Ellis, 1986).

An other interesting result is the progressive increase in perceived difficulty, objective difficulty remaining constant, as physical workload increases (Figure 4). This result could be compared with that obtained by Dornic *et al.* (1974). These authors studied the evolution of performance and perceived difficulty in four mental tasks, under three experimental conditions: in the first one, the tasks were performed in a quiet ambience. In the second one, the subjects were submitted to an intense non-significant noise (70-90db). In the last one, they were submitted to a significant noise (a conversation recorded on a tape). Results showed that subjects were able to maintain an equivalent level of performance under all conditions, but perceived difficulty was higher under noise conditions, and particularly when the noise was significant. According to the authors, this effect was due to the fact that more effort was necessary to realize the same level of performance in stressful situations.

In conclusion, we want to emphasize the fact that this experiment opens up some interesting perspectives for the study of time-sharing in double-task situations. The analysis of perceived difficulty in two concurrent tasks could give extra information, beyond just chronometrical data, on the manner in which individuals cope with the constraint systems they face.

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