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The effect of mental workload on the intensity and emotional dynamics of perceived exertion

David Cárdenas[1*], José C. Perales[2], Luis J. Chirosa[1], José Conde-González[3], Daniel Aguilar-Martínez[1] y Sergio Araya[4]

1 Department of Physical Education and Sport. Faculty of Sport Sciences. University of Granada. Spain
2 Department of Experimental Psychology. Faculty of Psychology. University of Granada. Spain
3 Department of Physical Education and Sport. Faculty of Education Sciences. University of Sevilla. Spain
4 Department of Physical Education and Sport. University Arturo Prat. (Iquique) Chile

Título: El efecto de la carga de trabajo mental en la intensidad y la dinámica emocional del esfuerzo percibido.
Resumen: El esfuerzo percibido, medido por escalas psicométricas, ha demostrado ser una herramienta válida para evaluar la carga de entrenamiento, que correlaciona altamente con dimensiones fisiológicas y mecánicas del esfuerzo físico. Sin embargo, poco se sabe sobre los correlatos emocionales del esfuerzo, y cómo la percepción del esfuerzo es influenciada por la carga de trabajo mental. En los dos experimentos descritos, se encontró que la valoración del esfuerzo percibido (RPE) estaba significativamente influenciada por la carga mental (generada por medio de una tarea cognitiva, sin relación, pero temporalmente superpuesta con la tarea física) durante la recuperación activa después de haber alcanzado el agotamiento durante el ejercicio, pero no durante el ejercicio incremental. Es importante destacar que el esfuerzo percibido correlacionó fuertemente con los valores emocionales / hedónicos de valencia, pero no así con los valores de la activación. Estos hallazgos refuerzan el valor motivacional del esfuerzo percibido y su vinculación con otros constructos psicológicos.
Palabras claves: Carga mental; esfuerzo percibido; esfuerzo físico; fatiga; ejercicio; motivación.

Abstract: Perceived exertion, as measured by psychometric scales, has been proven to be a valid tool to assess training load, and to highly correlate with physiological and mechanical dimensions of physical effort. However, little is known about the emotional correlates of exertion, and how perceived exertion is influenced by mental workload. In the two experiments reported here, ratings of perceived exertion (RPE) were found to be significantly influenced by mental workload (generated by means of a cognitive task, unrelated to, but temporally overlapping with the physical task) during active recovery after exhausting exercise, but not during incremental exercise. Importantly, perceived exertion was found to strongly correlate with reported emotional/hedonic valence, but not so tightly with reported arousal. These findings strengthen the motivational value of perceived exertion, and its linkage to other psychological constructs
Key words: Mental workload; perceived exertion; physical effort; fatigue; exercise; motivation.

Introduction

Perceived exertion is a key concept in the psychology of exercise, and may be defined as the subjective intensity of effort, strain, discomfort, and/or fatigue that is experienced during physical exercise (Robertson & Noble 1997). For example, let us imagine an athlete running a marathon. During the race, the marathoner will continuously monitor her sense of effort, and will decide on-line how fast to run in order to reach the finish line shortly before exhaustion. In general, people use perceived exertion to decide when to stop exercising. Our marathoner will probably run beyond the point at which she would have stopped in circumstances other than competition. Moreover, effort tolerance depends on psychological factors such as mood (Arruza, Balagué & Arrieta, 1998), arousal, and concomitant *mental workload*. Consequently, understanding these factors is crucial to improve decision making in athletes (Schomer, 1986). Unfortunately, despite the fact that perceived exertion is a psychological construct, little research has been done on how these factors influence perceived exertion, or on the relationship between perceived exertion and other psychological constructs, including those that define the subjective affective/emotional state (e.g. Baden, McLean, Tucker, Noakes, & Hunter, 2005; Beniscelli & Torregrosa, 2010).

*** Dirección para correspondencia [Correspondence address]:**
David Cárdenas Vélez. Carretera Alfacar s/n CP: 18071 Granada (Spain).
E-mail: dcardena@ugr.es

In face of the importance of perceived exertion, several psychometric scales have been developed to measure it. Actually, the relationship between mechanical and physiological measures of effort (mainly power output, lactate concentration, oxygen consumption, and cardiovascular indices), on the one side, and subjectively perceived exertion, on the other, constitutes a discipline by itself: the *psychophysics of effort* (Borg, 1982; Noble & Robertson, 1996; Borg & Borg, 2002; Borg & Kaijser, 2006; see Faulkner, Parfitt & Eston, 2008, for a recent review). The precise characterization of the functions that relate the objective and subjective dimensions of exertion has helped sportpeople to better understand and to improve training methods (see, for example, Marriot & Lamb, 1996; Sweet, Foster, McGuigan, & Brice, 2004; Foster et al., 2001).

The present work is aimed at investigating (1) whether, and how, perceived exertion is affected by mental workload during exercise (cycling) up to volitional exhaustion, and during active recovery. In other words, we intend to test the common intuitions that physical tasks involving concomitant complex information processing (as, for example, planning or decision-making) are subjectively perceived as more effortful than plainly physical tasks, and that cognitive effort can hinder recovery after exercise. And, (2) we explore how the subjectively estimated affective state of the exerciser is affected by effort, and modulated by mental workload.

In operational terms, mentally loading tasks are those requiring the management of significant amounts of information in a non-automatic way. These tasks have been claimed to require attentional resources and to interfere with other cognitive tasks (Kahneman, 1973), to mobilize central resources (Wickens, 1984), or to require the involvement of the central executive system (Baddeley, 2003) –the cognitive mechanism necessary for planning activities when the task cannot be automatized, or generates response conflict (Miyake & Shah, 1999) –. In addition, cognitive workload has emotional correlates: the effort associated with cognitive workload is hedonically negative, and increases arousal (Baumeister, Vohs & Tice, 2007; Wallace & Baumeister, 2002).

The interest on the interaction between cognition and physical effort is not new. A few studies have investigated the role of mental fatigue[1] on perceived exertion, in consecutive mental-physical tasks (Marcora, Staiano, & Manning, 2009). Relatedly, some studies have focused on the opposite causal direction, that is, on the effect of physical effort and fatigue on cognitive performance (Sanabria et al., 2011). To our knowledge, however, our study is the first to experimentally manipulate the magnitude of mental workload during and after exercise, and to check its effect on perceived exertion (and related emotional dimensions).

To sum up, our aims are: (1) to quantify the degree to which mental workload contributes to perceived exertion during exercise and recovery; and (2) to analyse the emotional dynamics resulting from the combined effects of physical and cognitive load. In Experiment 1, mental workload was manipulated by presenting participants with cognitive tasks during exercise, until exhaustion, and during recovery. *N-back* and *Go/No-go* tasks were used to generate either high or low mental workload. Load was manipulated across sessions, and compared to a control session without any concomitant mental task. Ratings of perceived exertion were registered during each session, and compared across sessions with different mental workload levels. In Experiment 2, two mental workload conditions, and one condition without mental workload were compared. This second experiment was carried out to dissociate the potential effect of mental workload from the effect of cognitive performance feedback. Simultaneously to RPE (Rating of Perceived Exertion; Borg, 1982), we recorded two emotional dimensions (arousal and hedonic valence) during the whole of each session, with the aim of investigating the emotional features of concomitant physical and mental workload.

[1] Cognitive workload is directly proportional to the amount of information to be managed, and the complexity of the operations performed on it. We assume that subjectively perceived cognitive effort parallels cognitive workload, in a way similar to how perceived exertion parallels physical load. Following the analogy, we distinguish between mental fatigue (namely, a reduction in mental performance, mainly, but not only, attributable to sustained cognitive effort) and cognitive effort. Recent studies have actually dissociated mental effort from mental fatigue, by measuring their differential effects on eye motility (Di Stasi, Antolí, & Cañas, 2011; Di Stasi, Renner, Staehr, Helmert, Velichkovsky, Cañas, Catena, & Pannasch, 2010).

Experiment 1

Two alternating executive function tasks were used to directly manipulate cognitive workload, at three levels (High load, Low load, No load), during exercise. Perceived exertion and oxygen consumption were monitored during mounting exercise, at volitional exhaustion, and during active recovery. The main working hypothesis was that the sense of physical effort (RPE) during exertion and/or recovery would be directly modulated by the level of cognitive workload.

Method

Participants

18 participants (4 women and 14 men; average age 21.17 years; age range 19-26 years) took part in Experiment 1. All of them were Sport Sciences students at the University of Granada. In accordance with ethical standards, all of them were informed of the experiment's aims and conditions, and signed an informed consent form. In addition, a medical doctor was available in the building during the whole duration of each experimental session, and was informed when such an experimental session was being carried out. A defibrillation device was also at reach.

Two participants did not report reaching 18 points in the reported exertion scale and were excluded from further analyses (as this was a maximum effort test, we considered that not reaching a perceived exerted effort close to the maximum implied not having understood the logic of the scale, or not having exerted the maximum possible effort during the test).

Apparatus and stimuli

A Cardioline® xr100 cycloergometer was used for the physical effort task. The stimuli for the cognitive load tasks were projected on a screen located approximately two metres in front of the participant. Stimuli presentation was controlled from a laptop located on the left of the participant. Responses for the cognitive task were recorded by using a wireless numeric keyboard attached to the cycloergometer handle, and connected to the laptop controlling the task. The participant could respond by pressing any key of the keyboard with her thumb, while grasping the handle. Each stimulus was a number or letter (depending on the task), and the participant was asked to respond to by pressing/not pressing any key of the keyboard. A distinctive sound was used as feedback for each response.

Procedure and design

Physical effort task. Each session consisted of three stages (see Figure 1). In the warming up stage, participants cycled on the cycloergometer without resistance for 5 minutes. In the second stage, participants were asked to cycle in incremental 2-minute-long exercise intensity levels (henceforth, effort levels) until volitional exhaustion. During this stage, participants were asked to cycle at a pace of 70 rpm. When pace deviated from that reference, one of the experimenters warned the participant to increase or decrease her pace. In the first effort level in this stage, the level of physical effort was set at a number of watts calculated as half the participant's weight (measured in kilograms). In other words, a person weighting 70 kilograms started the effort stage mobilizing 35 watts. In each successive level, the effort was increased *bodyweight*/2 watts. Following the same example, a person weighting 70 kg mobilized 70 watts in the second level, 105 in the third one, and so on. After exhaustion, resistance was removed, but the participant was asked to keep the pace at 70 rpm during 8 minutes more (recovery stage).

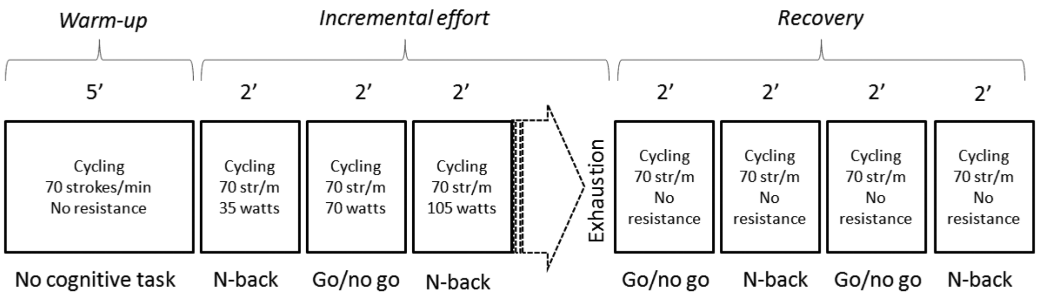

Figure 1. The three stages of the session.

Cognitive load tasks. In the load conditions, during incremental effort and recovery, participants performed two cognitive load tasks in an alternating fashion. The first one is known as the *N-back* task (see Owen, McMillan, Laird, & Bullmore, 2005). In our version of the task a series of digits appeared successively on the screen, at a rate of one digit every 2500 miliseconds (with a stimulus duration of 2000 ms), and the participant was asked to report whether the number on screen was the same as the one presented N positions earlier. Once the response was made ("press if yes, withhold response if no") and the following digit appeared, the previous comparison digit had to be discarded and the content of the working memory updated with the new one. Only digits 1 to 4 were used in the present version of the task. The digit appearing in each trial was randomly selected, which means that, on average, the present digit was the same as the one N positions earlier, and thus pressing was correct, in 25% of the trials.

The second task is called the *Go-No go* task (see Gómez, Ratcliff, & Perea, 2007; Perales, Verdejo-García, Moya, Lozano, & Pérez-García, 2009). In this task the participant is presented with one of two stimuli in each trial (for example, one of two letters), and is simply asked to respond when one of them appears on screen (one of the letters) and to withhold the response in presence of the other. The first stimulus is called the Go stimulus, and appears in 3 out of 4 trials; the other one is the No-go stimulus and appears in 1 out of 4 trials. The rate of appearance of stimuli and the duration of each trial were the same in the two tasks.

Both the N-back and the Go/No-go task require the involvement of the central executive system and thus generate significant cognitive workload. However, the degree of workload can be easily adjusted to the experimenter's needs. In the case of the N-back task, the larger N, the more demanding the task. Note that N determines how many digits the participant needs to keep in working memory and operate with. 1-back tasks are subjectively perceived as very easy, 2-back task as moderately demanding, and 3-back tasks as very difficult. Two levels of workload were used in the present experiment: 1-back (low load), and 3-back (high load).

Similarly, the workload generated by Go/No-go tasks can be varied by manipulating the complexity of the response criterion in each trial. In the simple criterion (low load) version, the participant is just asked to respond to one letter and not to respond to the other. In the double criterion (high load) version, each of the two letters can appear within a square or without any other stimulus present. Instructions demand a response to one of the letters when it appears alone, but not if that same letter appears within the square; similarly, the participant is instructed not to respond to the other letter alone, but to respond if that letter appears within a square. Thus, the discrimination between the go and the no-go stimuli cannot be made on the basis of one feature alone (the identity of the letter or the presence of the square), but only on the basis of the combination of both.

In the present experiment, each participant did the whole task three times (one for each cognitive load condition, with a separation of, at least, 72 hours between two consecutive ones). In one of them, the effort test was carried out without any concomitant mental workload task (No load condition); in another one with the low load tasks (Low load condition); and, in the remaining one, with the high load tasks (High load condition). The order of conditions was counterbalanced. Load was the main independent variable.

In the two load conditions, the type of task (N-back, Go/No-go) alternated between blocks. The duration of each cognitive load task block coincided with the duration of each incremental effort block (2'). During recovery (8'), blocks were separated only by perceived exertion assessments, and the cognitive tasks kept on alternating every two minutes.

Recording of perceived exertion. Approximately four seconds were required to reprogram the cycloergometer between effort levels. While one experimenter did this, a second one questioned the participant about his/her level of perceived exertion (this one also checked that the pedalling pace remained at 70 rpm). The RPE 6-20 scale[2] (Borg, 1998) was used to collect local, central, and total scores of perceived exertion. Before each session, each participant was familiarised with the scale. Standardised instructions were provided on how to report feelings of exertion during exercise in the three different subscales, following the procedure described by Swank, Steinel, and Moore (2003).

Perceived exertion ratings were collected after every two minutes (after every cognitive task block, and so exactly before the effort level was increased), at exhaustion, and after every two minutes during recovery. The number of measuring points during exercise varied from one participant to another, as the number of effort levels performed before exhaustion depended on their fitness level.

Recording of oxygen consumption and heart rate. Oxygen consumption was recorded for all participants during the effort and recovery stages. A K4 b² ® gas composition analyzer was used. The gas analyzer was submitted to the manufacturer's offices for technical revision before the experiment began (technical revisions are recommended for this model every 6 months), and was individually calibrated for each session, following the manufacturer's instruction manual. The instrument generates an observation point for each inhaling/exhaling cycle in ml/min·kg, computed from the difference between concentrations of oxygen in inhaled and exhaled air.

Heart rate was monitored by using a Polar ® wrist device. BPM measures as recorded by this device, and oxygen consumption measures near exhaustion, were used for condition comparability checks only. Online recordings for complete sessions, before and after exhaustion can be provided by the corresponding author on demand.

Results

Condition comparability checks

Effort level escalated until the participant reported being unable to exercise any longer at the same level. As noted above, only the participants who reached 18 points or more in the RPE-Total subscale were considered for further analyses.

Mean RPE at the exhaustion point did not vary across conditions, which ensures that, at this point, the three conditions were equated in subjectively perceived exertion. A 3 (Load: high load, low load, no load) x 3 (RPE subscale: local, central, total) within-subject ANOVA did not yield any significant effect. Mean (SE) RPE scores for the high-load, the low-load, and the no-load conditions were 19.48 (.30), 19.56 (.25), and 19.54 (.27) [$F<1$]. The Subscale x Load interaction was not significant either [$F(4, 60)=2.03$; $MSE=.17$, $p=.10$]. However, the effect of the subscale was rather close to significance. Mean (SE) scores for the local, central, and total scales were 19.60 (.15), 19.42 (.19), and 19.56 (.13) [$F(2, 30)=3.02$; $MSE=.15$; $p=.064$].

On the other hand, heart rate was monitored during effort and recovery. At exhaustion, mean (SE) percentages over the individually estimated maximum heart rate (computed as 220 minus age) for the three conditions were 92.44% (1.54), 95.11% (1.00), and 93.90% (1.74) [$F(2, 30)=2.29$, $MSE=12.50$; $p=.12$]. This ensures, first, that participants were actually close to exhaustion when they reported being exhausted, and, second, that the three conditions were equated in that moment. As will be discussed later, any difference found from that point beyond could be attributed to the mental load manipulation.

For each participant and each condition, we averaged VO2 measures for consecutive 30 s. intervals, corresponding to approximately 10 minutes (the last 30 second interval is incomplete for some participants who exhausted during that interval; averaging was used to stabilize the measure). Oxygen consumption gradually increased during exercise, almost linearly with respect to the physical effort exerted during the task. Only the effect of interval was significant, $F(19, 285)=316.78$, $MSE=9.00$, $p<.001$. Neither the effect of Load nor the Block x Load interaction was close to significance ($F<1$ in both cases)[3].

And finally, we also collected oxygen consumption, averaged for the last 30 seconds prior to exhaustion. Mean (SE) VO_2 values, measured in ml/kg·min were 43.15 (2.85), 44.97 (2.65), and 44.83 (2.98), for the high-load, the low-load, and the no load conditions, respectively. These values did not differ significantly among them ($F<1$). Three recordings from two participants seemed clearly anomalous ($VO_2<25$), so we also carried out the same analysis discarding those participants. Mean (SE) VO_2 values, were then 44.51 (2.76), 47.12 (2.50), and 48.38 (2.00). The effect of Cognitive load remained non-significant [$F(2, 26)=1.08$, $MSE=50.58$, $p=.36$].

Cognitive involvement check

In both the N-back and the Go/No-go tasks, target stimuli are those for which a response is right, and distrac-

[2] The RPE 6-20 scale (Noble & Robertson, 1996) has been customarily used in the last decades to assess perceived exertion. Although some recent evidence has shown a certain superiority of CR10 scales (Borg, & Kaijser, 2006) over the RPE 6-20 scale, such a potential superiority has more to do with the functions relating peripheral physiological indexes to perceived exertion, than with sensitivity of the tool to its construct variable.

[3] Our cycloergometer does not provide an independent estimate of power output. However, given the close intra-individual relationship between power output and oxygen consumption, comparable curves of oxygen consumption across conditions ensure that the absence of differences among conditions in RPE during mounting effort is not due to differences in objective physical effort.

tors are those not meeting the criterion for responding. If the participant succeeds to some degree in the cognitive task, the rate of responding must be higher for targets than for distractors. The *hit rate* (*h*) is customarily defined as the rate of responding to targets, whereas the *false alarm rate* (*f*) is the rate of responding to distractors. There are a number of discriminabilty measures based on the difference between hit and false alarm rates; here, we will use a customarily accepted non-parametric score (see Perales, Catena, Shanks, & González, 2005): the *difference of arcsines* [DA=acos(f)-acos(h)].

We computed discriminability (DA) for 30-second intervals across the whole task. Given that all participants in all conditions completed at least 5 effort levels, we have 20 discriminability scores for all of them, plus another 16 for the 8-minute recovery stage. For the sake of simplicity, and in order to stabilize measurement, we averaged discriminability scores for the four 30-second intervals within each 2-minute effort level. In addition, we analyzed Go/No-go and N-back together. The same discriminability analysis can be applied to the two tasks, so the type of task must be considered a counterbalanced factor. Figure 2 displays averaged discriminability levels for each 2-minute level during effort (top panel) and recovery (bottom panel), for the two Load conditions (high-load and low-load; obviously there was no cognitive task to check in the no-load condition). During incremental effort, the Cognitive load (high, low) x Level (1-5) ANOVA yielded a significant effect of Load [$F(1, 30)=102.09$, $MSE=.20$, $p<.01$]. Neither the effect of Level nor the Load x Level interaction were significant [$F(4, 120)=1.70$, $MSE=.08$, $p=.15$, and $F(4, 120)=1.62$, $MSE=.08$, $p=.17$, respectively].

During recovery, there was again a main effect of Cognitive Load [$F(1, 30)=67.33$, $MSE=.21$, $p<.01$], with the expected better performance in the low-load condition. Additionally, performance moderately improved with progressive recovery [$F(3, 90)=3.08$, $MSE=.09$, $p=.03$]. The Cognitive load x Recovery level interaction did not reach significance [$F(3, 90)=1.58$, $MSE=.09$, $p=.20$].

In summary, discriminability in the two levels was well above zero for all measurement points, which is interpretable as a significant involvement of participants with the task during exercise. Additionally, as expected, performance was significantly better for the low-load task. In neither of the two load conditions did performance worsen with incremental exertion although in both of them, it moderately improved during recovery.

Time to exhaustion

Mean time to exhaustion did not differ across Cognitive load conditions. Participants exercised during 774 (23.02), 752 (28.45), and 765 (36.44) seconds, in the high-, low-, and no-load conditions, respectively [$F<1$]. In other words, cognitive workload did not accelerate exhaustion.

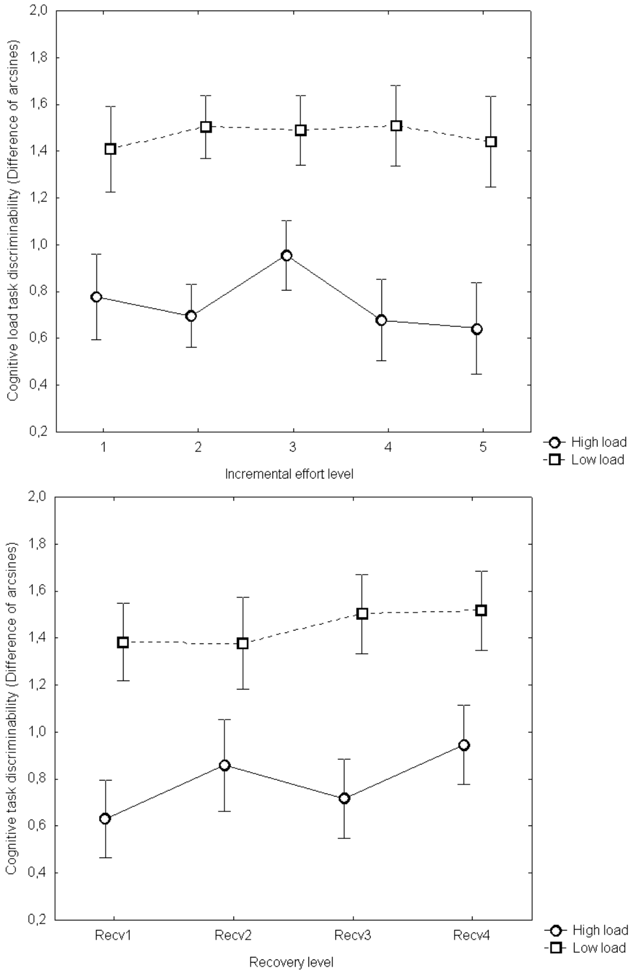

Figure 2. Averaged discriminability levels for each 2-minute level during effort (top panel) and recovery (bottom panel), for the two Load conditions (high-load and low-load).

RPE during incremental effort

As noted above, all participants in all conditions completed at least five effort levels. Consequently, we have five RPE measurement points during effort (plus the initial measurement taken between the end of the warming up stage and the incremental effort stage). An Effort level (0-5) x Cognitive load (high-load, low-load, no-load) x RPE subscale (Local, Central, Total) within-subject ANOVA was carried out on the four first RPE measurements for all participants.

Figure 3 shows how RPE escalates with effort for the three cognitive load conditions and the three subscales. The effect of Effort level was obviously strongly significant, with RPE gradually increasing with physical effort, $F(5, 75)=212.72$, $MSE=9.1$, $p<.01$. Cognitive load, however, did not have any direct or interactive effect on RPE [$F<1$; $F(4, 60)=1.04$; $MSE=.70$; $p=.39$; $F(10, 150)=1.53$; $MSE=2.60$; $p=.13$; and $F(20, 300)=1.51$, $MSE=.20$; $p=.08$, for the marginal Load effect, the Load x Level interaction, the Load x Subscale interaction, and the 3-way interaction, respectively].

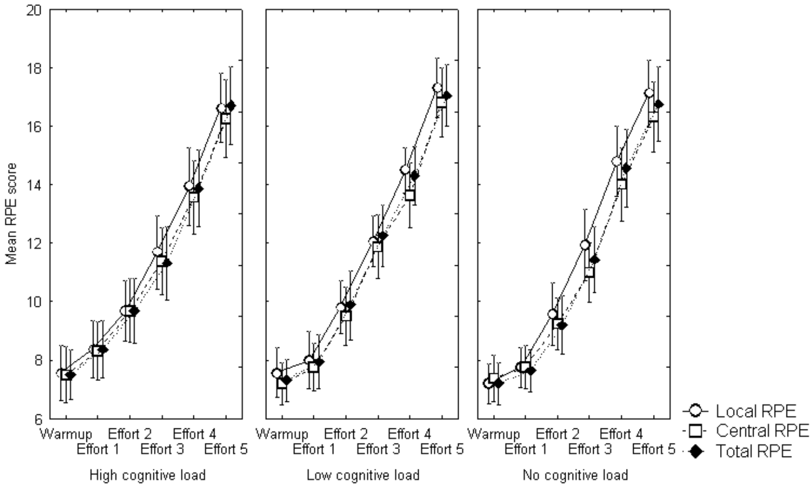

Figure 3. RPE for the three cognitive load conditions and the three subscales.

RPE scores differed between subscales [$F(2, 30)=5.95$, $MSE=1.50$, $p=.01$], with local and total subscales yielding higher scores than the central one. Mean (SE) scores for the local, central, and total subscales were 11.41 (1.29), 11.06 (1.43), and 11.27 (1.47), respectively. Planned comparisons yielded a significant difference between the local and the central score ($p=.02$), as well as between the central and the total score ($p<.01$), but not between the local and the total score ($p=.16$). In addition, Subscale interacted with Effort level [$F(10, 150)=3.00$; $MSE=.30$; $p<.01$]. As can be seen in Figure 3, perceived exertion accumulated faster locally than centrally, and total effort seems to be based more directly on local effort than in cardio-respiratory distress.

RPE during recovery

A 3 (Load) x 5 (Level: exhaustion, recovery 1, recovery 2, recovery 3, recovery 4) x 3 (Subscale) within-subject ANOVA on RPE scores yielded a significant effect of Load, $F(2, 30)=3.25$, $MSE=19.6$, $p=.05$. Planned comparisons showed a significant difference between high and no-load (p=.03). As can be seen in Figure 4 (top panel), low load mean RPE was between the high- and the low-load conditions, and was not significantly different from any of the two. Mean (SE) RPE values were 12.49 (2.31), 12.07 (1.90), and 11.47 (1.65) for the high-load, low-load, and no-load conditions respectively. Trend analyses showed that the effect of Load on RPE was exclusively linear ($p=.03$; $F<1$ for the other components).

Obviously, the effect of Effort level was strongly significant, $F(4, 60)=222.73$; $MSE=13.2$; $p<.01$. More interesting are the effects of Subscale, $F(2, 30)=12.31$; $MSE=2.60$; $p<.01$, and the Level x Subscale interaction, $F(8, 120)=2.70$, $MSE=1.00$; $p<.01$. Mean (SE) RPEs were 12.40 (1.87), 11.68 (1.74), and 11.94 (1.77) for the local, central, and total subscales, respectively. Planned comparisons yielded significant differences between the local and the central subscales ($p<.01$), and between the central and the total subscale ($p<.01$), but also between the local and the total subscale ($p<.01$). As it can be seen in Figure 4 (bottom panel), the local and total subscales were the ones most affected by effort; however the interaction is due to the fact that local RPE remained higher than central RPE, from exhaustion to the end of recovery, whereas the total RPE decreased more rapidly and matched central RPE by the end of recovery (for the sake of brevity, we do not analyze this interaction in detail).

Experiment 2

Experiment 1 showed a limited but relevant effect of cognitive workload on perceived exertion. This effect did not reach significance during incremental effort, but did reach it during recovery. Visually, the high-load condition seemed to boost perceived exertion at the beginning of the task, but that difference vanished as exercise continued. Importantly, it clearly reappeared (and reached significance) during recovery. On the other hand, mental workload did not interact with the type of subscale. In other words, although the three subscales showed slightly different dynamics, these remained unaffected by the cognitive workload manipulation.

Nevertheless, the effect of cognitive workload can be explained in an alternative way. Highly loading cognitive tasks are not only more cognitively demanding, but they also elicit more errors, which make them even more arousing and, potentially, hedonically negative. In Experiment 2 we tried to replicate the pattern of effects found in Experiment 1, but artificially manipulated the balance between positive and negative feedback for responses in the cognitive task, without actually manipulating the difficulty of the task. Additionally, the emotional state of the participant during the whole task was monitored.

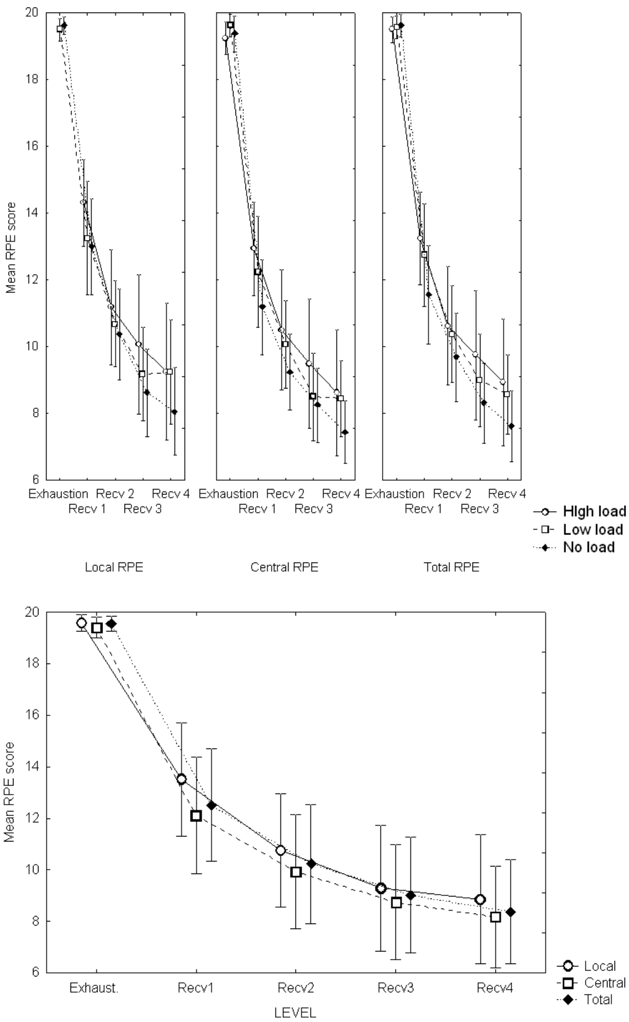

Figure 4. Mean RPE scores during exercise and recovery.

Method

Participants, apparatus and tasks

18 participants (9 women and 9 men; average age 21.72 years; age range 18-26 years) took part in the experiment. Participant recruiting and apparatus were identical to the ones in Experiment 1.

The cognitive task was a false sequence-tracking test. Participants were presented with a series of digits, one per trial (with duration and inter-stimuli intervals identical to the ones in Experiment 1). They were told that digit generation followed a hidden pattern, and their task was to discover that pattern. They were also told that not all the digits, but only a high proportion of them followed the pattern, so for each trial, they were asked to indicate whether the current digit followed the pattern or not ("press if yes, withhold your response if no"). In fact, there was no pattern to discover, and the feedback was programmed depending on the experimental condition. In the Load/Negative feedback condition, participants were given false positive feedback (a distinctive sound) in one fourth of the trials, and negative feedback in the other three fourths. In the Load/Positive feedback condition, on the other hand, they were given positive feedback in three fourths of the trials, and negative feedback in the other fourth. During the task, none of the participants reported having discovered that feedback was actually unrelated to the task. In the control no-load condition, no cognitive task was presented concomitantly to the physical task.

Apart from the variables described in Experiment 1 (RPE subscales, time to exhaustion, heart rate, and oxygen consumption), we also collected scores of emotional state. The *Self-assessment manikin* (SAM-Spanish version, Moltó et al., 1999) is a self-report scale in which participants are asked to assess their own emotional state, elicited by some environmental event, in three dimensions: Valence, Arousal, and Dominance. Only the valence and arousal scales were used in this experiment. The response is given by choosing one of 5 icons displayed horizontally on a sheet (or the intermediate point between two of them). The icons represent progressive emotional states (from low to high arousal, and from negative to positive valence). The response is coded as a value between 1 and 9. Participants were asked to report their emotional state in the two dimensions after each two-minute effort level.

Condition comparability checks

As described for Experiment 1, only those participants who reported total perceived exertion scores close to the maximum (RPE-Total >= 18) were taken into account, which left 12 participants for all further analyses.

Again, we checked for possible differences between Load conditions at the exhaustion point. Mean (SE) RPE values were 19.61 (.27), 18.97 (.55), and 19.41 (.26) for the High Load, the Low Load, and the No Load conditions, respectively. As happened in Experiment 1, these values were close to the maximum (20) and did not differ between them $F(2, 22)=2.73$, $MSE=1.41$, $p=.09$. RPEs for the three subscales differed between them at this point, $F(2, 22)=3.67$, $MSE=.19$, $p<.05$. Planned comparisons showed a significant difference between the Local and the Total scale, ($p=.04$), but not between the Local and the Central scale, ($p=.24$). The one between the Central and the Total scale was very close to significance ($p=.053$). Mean (SD) RPE values for the three scales were 19.19 (.37), 19.33 (.26), and 19.47 (.21) for the local, the central, and the total scales, respectively. In this case, unlike what was observed in Experiment 1, it was the total RPE subscale, but not the local RPE subscale, the one that most strongly reflected perceived exertion.

At exhaustion, mean (SE) percentages over the individually estimated maximum heart rate (computed as 220 minus age) for the three conditions were 92.21% (1.63), 93.45% (1.60), and 93.72% (1.09). The effect of Feedback/load was far from significance ($F<1$). Again, this ensures that participants were close to exhaustion by the end of the incremental effort stages, but also that the three conditions were equated at this point.

As expected, oxygen consumption increased during exertion, $F(18, 198)=290.11$, $MSE=6.40$, $p<.001$. At difference with Experiment 1, oxygen consumption increased at different rates for different Load conditions, $F(36, 396)=2.31$, $MSE=2.80$, $p<.001$[4].

Mean (SE) VO_2 values, measured in ml/kg·min and averaged for the 30 seconds prior to exhaustion were 50.49 (1.69), 46.48 (3.56), and 48.39 (2.38), for the high-load, the low-load, and the no load conditions, respectively. These values did not significantly differ among them ($F<1$). One recording from one participant seemed clearly anomalous ($VO_2<25$), so we also carried out the same analysis disregarding that participant. Mean (SE) VO_2 values, were then 50.75 (1.83), 48.44 (3.25), and 47.51 (2.42). The effect of Cognitive load remained non-significant ($F<1$).

Time to exhaustion

Time to exhaustion yielded differences among the three conditions, but not in the direction expected. Mean (SD) times to exhaustion for the Load/negative feedback, the Load/Positive feedback, and the No Load conditions were 885.5 (38.26), 787.5 (33.97), and 752.5 (30.68) seconds, respectively. In other words, people in the Load/negative feedback condition cycled for longer than in the other two conditions [F(2, 22)=22.06; MSE=2586, p<.01] (note, however, that this difference is not reflected by oxygen consumption rates, and does not affect RPE ratings at the exhaustion point; see Footnote 4).

RPE during incremental effort

Figure 5 shows mean RPE scores for the three RPE subscales during incremental effort. All participants completed at least four effort levels in the three conditions. A 3 (Load/Feedback: Load-Negative feedback, Load-Positive feedback, No load) x 5 (Level: Warming up plus four levels) x 3 (Subscale: L, C, T) within-subject ANOVA only yielded a significance effect of effort level, with RPE almost linearly increasing with level. Mean (SE) RPE values for the three conditions were 12.00 (1.33), 12.66 (1.66), and 12.72 (1.13), for the Load/negative feedback, the Load/positive feedback, and the No-load conditions, respectively [$F(2, 22)=1.99$; $MSE=14.26$, $p=.16$]. Unlike Experiment 1, RPEs for the three subscales did not differ between them [$F(2, 22)=1.77$; $MSE=2.47$, $p=.19$], nor interacted with Load/Feedback ($F<1$).

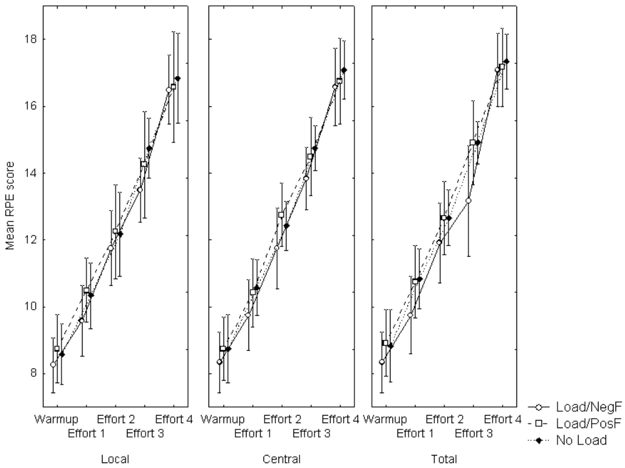

Figure 5. Mean RPE scores for the three RPE subscales during incremental effort.

SAM-valence and SAM-arousal during incremental effort

Changes in emotional state valence and arousal, as measured by the SAM scale are displayed in Figure 6. Reported valence decreased almost linearly with effort, reflecting the intuition that incremental effort is felt as hedonically negative, $F(4, 44)=39.74$, $MSE=1.46$, $p<.01$. Mean (SE) valence values were 7.94 (.48), 7.46 (.48), 6.61 (.38), 5.72 (.38), and 4.83 (.52), for the warming-up, and the four effort levels, respectively. Effort level did not interact with Load/Feedback (F<1)

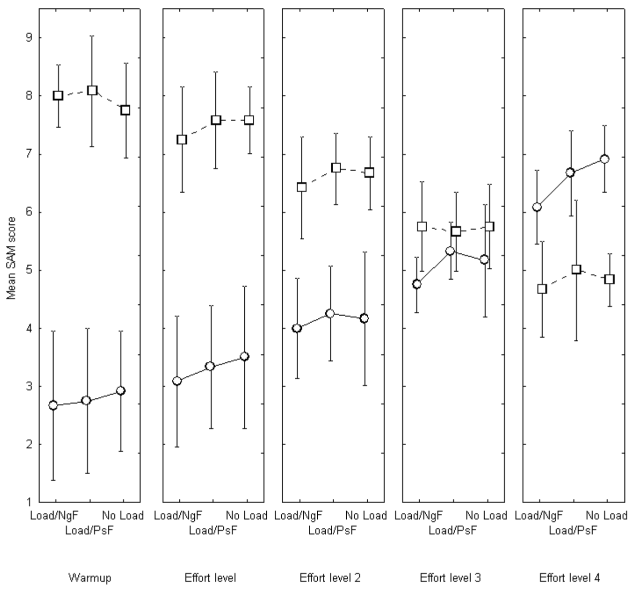

Figure 6. Changes in emotional valence (dotted line) and arousal (non-dotted line), during exercise, as measured by the SAM scale

[4] However, oxygen consumption did not match Load. Actually, the condition with no load was the one in which the increase of oxygen consumption was (visually) most marked. According to LSD post-hoc comparisons, only the Load/positive feedback condition significantly deviated from the No-load condition (oxygen consumption for this condition was slightly lower in measurement intervals 18 and 19). Following the logic described above, this difference might have masked a potential RPE difference between the No-load and the Load/negative feedback conditions during mounting effort. At the exhaustion point, however, all differences disappear, so that all effects after this point are fully reliable.

Arousal neatly increased with Effort level. Mean (SE) arousal values across levels were 2.78 (.73), 3.31 (.78), 4.14 (.59), 5.08 (.45), and 6.56 (.37) for the warming up, and the 4 effort levels, respectively [F(4, 44)=63.39, MSE=1.28, p<.01]. The effect of Load and the Load x Level interaction were very far from significance (both F<=1).

RPE during recovery

Figure 7 displays mean RPE measures from exhaustion point to the end of recovery. Apart from the obvious effect of Level (Exhaustion, Recovery 1-4) [F(4, 44)=319.59, MSE=7.20, p<.01], with RPE scores gradually declining during recovery, there was a strongly significant Load/Feedback x Level interaction [F(8, 88)=7.38, MSE=2.68, p<.01]. The interaction was due to the different rates of recovery in the different Feedback/Load conditions. More specifically, if the analysis is restricted to the exhaustion point and the first recovery stage, there is a significant effect of Load [F(2, 22)=4.51, MSE=5.04, p=.02]. Mean (SE) RPE scores restricted to this segment were 16.32 (.89), 15.32 (.64), and 15.35 (.37), for the Load/Negative feedback, the Load/positive feedback, and the No-load conditions, respectively. RPE scores are larger for the Load/negative feedback condition than for the other two [F(1, 11)=5.48, MSE=8.28, p=.04], and thus this effect contains a significant quadratic component [F(1, 11)=5.06, MSE=2.64; p=.046].

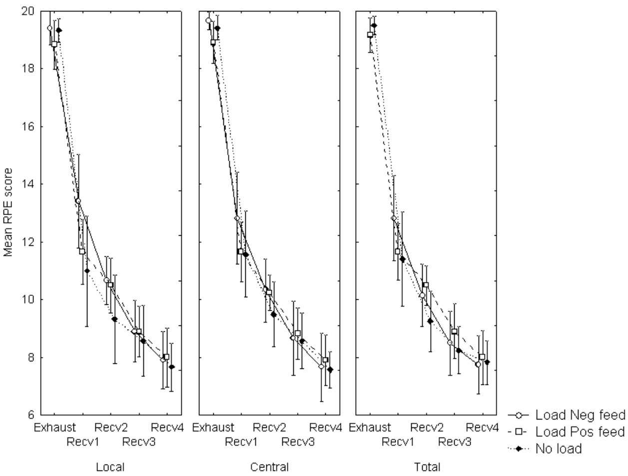

Figure 7. Mean RPE scores from exhaustion point to the end of recovery.

If the analysis is extended to the second recovery stage, mean (SE) RPE scores (restricted to this segment) are 14.34 (1.01), 13.69 (.73), and 13.37 (1.21), for the Load/Negative feedback, the Load/Positive Feedback, and the No load conditions, respectively. The main effect of Load remained significant [F(2, 22)=3.44; MSE=7.73; p=.05], but the quadratic component vanished (F<1).

In other words, there is a significant effect of Load/Feedback, mostly attributable to the first stages of recovery. In contrast with what happened in Experiment 1, this effect tended to vanish as recovery progressed.

Unlike Experiment 1, however, there was no effect of the subscale type [F<1 for the marginal effect of subscale; mean (SE) values were 11.61 (1.23), 11.56 (.97), and 11.57 (.96) for the local, central, and total subscales, respectively]. The subscale was very far from interacting with any of the other factors [F(4, 44)=1.80, MSE=.48, p=.15; MSE(8, 88)=1.66, MSE=.26, p=.12; and F(16, 176)=1.16; MSE=.24, p=.30, for the Feedback/Load x Subscale, Level x Subscale, and the three-way interactions, respectively].

SAM valence and arousal during recovery

Figure 8 displays valence and arousal values for the three Load/feedback conditions, from exhaustion point to the end of the recovery interval (Exhaustion, Recovery 1-4).

As expected, valence became gradually more positive during recovery [F(4, 44)=45.03, MSE=3.49, p<.01]. More interestingly, there was a strong main effect of Load/Feedback [F(2, 22)=7.54, MSE=2.15, p<.01]. Mean (SD) valence values were 5.50 (.55), 6.12 (.47), and 6.53 (.37) for the Load/negative feedback, the Load/positive feedback, and the No-load conditions, respectively. Trend analyses showed only the linear component to be significant. In other words, the Load/Negative feedback condition elicited a less positive valence than the No-load condition, with the positive feedback condition located between them [F(1, 11)=18.98, MSE=1.69, p<.01].

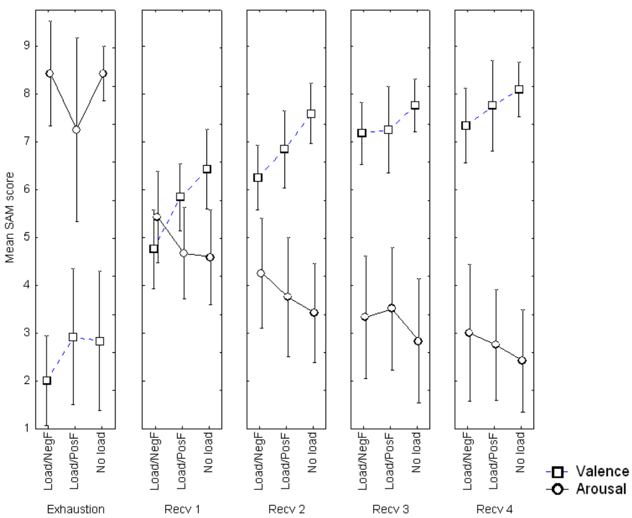

Figure 8. Valence and arousal values for the three Load/feedback conditions, from exhaustion point to the end of the recovery interval.

Arousal, on the other hand, gradually decreased during recovery [F(4, 44)=31.12, MSE=5.17, p<.01]. Load/feedback, however, did not exert any significant effect on arousal [F(2, 22)=2.36, MSE=2.35, p=.11], nor interacted with recovery level [F(8, 88)=.13, MSE=1.54, p=.35]. On other words, our procedure was effective at influencing the hedonic state of the participants (at least during recovery), without significantly influencing their level of arousal.

Correlations between emotional dimensions and perceived exertion

The effect of Load/feedback was more evident on valence than on arousal. However, we were interested in checking which of the two emotional dimensions was more predictive of RPE values.

On an individual basis, the correlation between valence and RPE (averaged across subscales for the whole recovery stage) was r=-.85, whereas the one between arousal and RPE was r=.77. The difference between these two correlations (for 180 observations, related samples, and reversing the sign of the negative r) was well above the significance level [t(3)=-22.63, p<.01]. In other words, RPE is much more closely related to hedonic valence than to arousal. Given that valence was a better predictor of RPE than arousal (despite the fact that arousal and RPE are *directly* correlated, and valence and RPE are *inversely* correlated), it rules out the possibility that the effect of Load/Feedback on RPE is exclusively due to contamination from valence, or vice versa. If that were the case, contamination would have reached *all* scales (including arousal).

Summary of results

In Experiment 1, we experimentally generated cognitive workload during exercise by asking participants to solve two alternative executive function tasks while they cycled in a cycloergometer up to the exhaustion point, and later on, during active recovery. A condition of high cognitive load was compared against a condition of lower cognitive load, and a control condition without any cognitive task concomitant to exercise. Perceived exertion, measured by means of the Borg RPE scale, was monitored during the whole process.

Results from Experiment 1 partially confirmed the hypothesis that cognitive workload contributes to the feeling of exertion, but only during active recovery. The three conditions behaved very similarly during incremental effort. Perceived exertion did not reflect cognitive load, and participants in the three conditions did not differ in the time they took to reach the exhaustion threshold. During recovery, however, a significant effect of cognitive workload on RPE was found, with cognitive workload linearly boosting perceived exertion. In other words, people solving difficult executive function tasks reported recovering more slowly than those experiencing lower cognitive demands.

Participants in this experiment were actively involved with the task during the two stages. For both cognitive load conditions, discriminability scores (measuring cognitive performance) were clearly above chance. In addition, performance was worse for the high-load condition, which indirectly demonstrates that the high-load condition is actually more difficult than the low-load one.

A poorer performance implies a lower level of success, and thus a larger amount of negative feedback. The influence of cognitive workload on perceived exertion during recovery can thus be due, either to cognitive workload per se, or to the emotional effects generated by negative feedback. In Experiment 2, the two load conditions did not differ in terms of task difficulty, but only in the proportion of positive/negative feedback to performance in the cognitive task. Feedback sign was in fact enough to reproduce the cognitive load effect. The effect of feedback type was slightly less intense and more transient than the effect of cognitive workload, which implies that feedback sign, if not the only factor contributing to the effect of cognitive workload on perceived exertion is, at least, a significant contributor to it.

As important as the effect of cognitive load on perceived exertion is the description of the affect dynamics that accompany exertion, and how these are also affected by mental load. During incremental exertion, arousal gradually increased, and hedonic valence decreased with cumulative effort. Maximal exertion interruption was immediately followed by a steep increase in valence (visually larger than the one in RPE), probably partially revealing sudden relief. Most importantly, valence inversely followed RPE scores across conditions, thus reflecting the effect of the Load/feedback manipulation during active recovery.

Discussion

Our results are relevant on several fronts. The first relevant piece of evidence is the finding and replication of the effect of mental workload on perceived exertion during recovery. However, we did not find any significant effect of mental load on perceived exertion during incremental effort, and failed to find an acceleration of exhaustion generated by such a manipulation.

This result is in apparent contradiction with previous reports. For example, Marcora, Staiano & Manning (2009) found mentally fatigued participants reached the physical exhaustion point earlier than controls. However, in their study, the cognitive and the physical task did not temporally overlap, but the cognitive task was prior to exercise. Moreover, the authors' aim was not to generate mental workload, but mental fatigue (see Footnote 1), and check whether it impaired physical performance. A long and at least mildly difficult task is necessary to generate mental fatigue. Even considering that our high-load task was rather difficult, our participants worked on it only for a few minutes before and after exhaustion, which is surely insufficient to generate enough mental fatigue. In other words, our results do not contradict Marcora et al.'s, but add some new evidence: mental workload hampers subjective recovery from effort.

In the field of industrial ergonomics, DiDomenico & Nussbaum (2008) failed to show any effect of a mentally loading task on estimates of reported effort (measured by using the Borg CR10 scale; Borg, 1982) during physical exertion in a simulated work situation. However, the task used by these authors (lifting and placing weights) was far from being exhausting. In fact, the maximum physical load condition elicited a mean CR10 score about 5 (in a 0-10 range). Differences in our data started to be evident after exhaustion. Tentatively, apart from the many procedural differences, our data could imply that DiDomenico and Nussbaum's null result is not generalizable to more physically demanding situations. In the previously mentioned Marcora et al.'s study (2009), the effect of mental fatigue was evident even from the initial stages of the exercise test; this could indicate that the effects of mental fatigue and mental load could be different on this regard.

Also on the strengths' side, this is the first study – to our knowledge – to monitor the exerciser's emotional state during exertion. On average, exercisers' hedonic state started to be more negative than positive (SAM valence < 5) by the fourth effort level, and rapidly became more positive than negative as soon as maximal effort was interrupted after exhaustion. Most importantly, and in concordance with the idea that the feeling of effort is motivational in its essence, valence and RPE were tightly related, and so valence showed the same effect of load/feedback as RPE. This is at difference with what happened with arousal, which was also related to RPE, but significantly more loosely, and did not show any effect of the Load/feedback manipulation.

The fact that valence is more directly linked to exertion than arousal can be due to the different emotional features of effort and fatigue. In the cognitive field, it has been shown that fatigue makes arousal gradually decrease, whereas load is arousing (Di Stasi et al., 2010, 2011). However, both effort and fatigue are hedonically negative. It is likely that physical tasks have similar emotional effects, with physical load and physical fatigue producing opposite effects on subjectively perceived arousal, but similar effect on hedonic valence.

The weaknesses of the present study arise from the differences between the results of the two experiments. First, in Experiment 1, the feeling of effort was (as expected) stronger locally and globally than centrally. That effect was not replicated in Experiment 2, where effort was more strongly felt globally than locally or centrally. The procedures of the two experiments, with regard to the instructions provided to participants, were identical. The two samples were also recruited following the same random procedure. In consequence, the difference must be in the measurement methods. In Experiment 1, participants were asked only about perceived exertion (using the three subscales); in Experiment 2 participants were questioned about the 3 RPE scores, plus valence and arousal. The correlations among these measures show that, likely, exercisers did not discriminate across RPE scales, but did so across scales of perceived exertion and emotional state. As noted above, the correlation between RPE (averaged across subscales) and valence was r=.85, and correlation between RPE and arousal was r=.77. In the same experiment, correlations within RPE scores were much higher (r=.97 for the local-central correlation, r=.97 for the local-total correlation, and r=.99 for the central-total correlation). Within-RPE correlations clearly indicate that, practically, exercisers were using the three subscales as if they were one. That does not mean that people were not accurately assessing their level of perceived exertion, but the different RPE subscales definitely lose their differential meaning.

The second difference involves time to exhaustion. Cognitive load in the first experiment did not significantly altered time to exhaustion (nor any of the objective measures of effort). However, in Experiment 2, the Negative feedback/load condition elicited longer times to exhaustion than the other two. For such a reason, it was especially important to check that the three conditions were equated in all aspects (RPE, oxygen consumption, and heart rate) by the end of the mounting effort stage. This potential flaw does not affect the reliability of the effect of Feedback/load during recovery. Moreover, if negative feedback/load had interfered with cycling pace during recovery, that condition should have yielded lower RPE ratings, and lower oxygen consumption scores than the other two. If any, the only possible effect of such a potential interference would have been to mask to some degree the effect of Load/feedback on recovery measures.

The effect of mental workload and feedback on recovery feelings, and the parallel emotional dynamics open a promising line of future research. The first open question has to do with the relative weight of purely cognitive and emotional factors in this effect. Our data seem to show that the sign of feedback (as seen in Experiment 2) contributes to the effect, but this effect seems weaker and more transient than the one of executive load (including a simultaneous cognitive and emotional manipulation). And secondly, more research needs to be done on the origin of the emotional effect. Negative feedback generates negative feelings, and these feelings can directly boost the painfulness of exertion. On the other hand, negative feedback can motivate efforts to improve performance, and thus indirectly generate mental load. The fact that RPE scores are more closely linked to valence than to arousal seem to indicate that the first possibility is more viable. Still, direct manipulations of the affective state, not mediated by feedback, are required to answer this question.

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