Perception of effort and the allocation of physical resources: a generalization to upper-limb motor tasks

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Abstract

Purpose: The perception of effort (PE) is widely used to prescribe and monitor exercise during locomotor and resistance tasks. The present study examines the validity of PE to prescribe and monitor exercise during upper-limb motor tasks under various loads and speed requirements.

Methods: Forty participants volunteered in two experiments. In experiment 1, we used four PE intensities to prescribe exercise on a modified version of the box and block test (BBT) and a pointing task. We investigated the possibility of monitoring the exercise intensity by tracking changes in PE rating in response to three different tempos or additional weights. Experiment 2 replicated the possibility of prescribing the exercise with the PE intensity during the BBT and explored the impact of additional weights on performance and PE during the standardized version of the BBT. Muscle activation, heart rate and respiratory frequencies were recorded.

Results: In experiment 1, increasing the PE intensity to prescribe exercise induced an increased performance between each intensity. Increasing task difficulty with faster movement tempo and adding weight on the forearm increased the rating of PE. Experiment 2 replicated the possibility to use PE intensity for exercise prescription during the BBT. When completing the BBT with an additional weight on the forearm, participants maintained performance at the cost of a higher PE. In both experiments, changes in PE are associated with changes in muscle activation.

Conclusion: Our results suggest that PE is a valid tool to prescribe and monitor exercise during upper-limb motor tasks.

246 words

Keywords: perceived exertion, upper-limb task, CR100 scale, motor control, psychophysiology, Box and Block Test, Pointing Task. (Min.5-Max. 8)

Introduction

The perception of effort, also known as perceived exertion or sense of effort (Marcora, 2010; Pageaux, 2016), can be described as “*the particular feeling of that energy being exerted*”, and “*is accompanied by a sensation of strain and labour, a feeling that intensifies the harder a person tries*” (Preston & Wegner, 2009). Effort is experienced during physical (e.g., running to catch the bus) or cognitive tasks (e.g., completing Sudoku) and in the context of self-restraint behaviour (e.g. smoking cessation ; Preston, 2009). It is thought to influence how we move, i.e., how the nervous system selects a given movement amongst a myriad of possibilities (Gaveau et al., 2021; Izawa et al., 2008). Due to its omnipresence in our daily life, the interest in understanding perception of effort is growing amongst researchers. This perception is linked to the task intensity and the amount of resources invested (Inzlicht et al., 2018); strongly influences the self-regulation of human behaviour (Inzlicht et al., 2018; Marcora, 2015); is one of the main features of fatigue in various contexts (Enoka & Stuart, 1992; Pageaux & Lepers, 2016); and is exacerbated in various pathologies such as chronic fatigue syndrome (Barhorst et al., 2020; Cook et al., 2007), stroke (Kuppuswamy et al., 2015), chronic kidney disease (Macdonald et al., 2012) or cancer (Fernandez et al., 2020). Perception of effort is a fundamental experience that directly influences our everyday decisions to engage or disengage in various actions, by monitoring the cognitive and motor resources necessary to perform any task (Pageaux, 2016; Preston, 2009). The perception of the amount of effort invested in a task is also closely linked to the regulation of motor performance (Marcora, 2019; Pageaux, 2014, 2016). According to the motivation intensity theory (Brehm & Self, 1989; Richter et al., 2016), one maintains performance by increasing effort when task difficulty increases, and one lets performance decrease when no longer able or willing to invest additional effort.

Perception of effort is widely investigated during global locomotor tasks, such as walking or cycling, in both healthy and symptomatic populations (Au et al., 2017; Décombe et al., 2020; Flairty & Schedler, 2020; Horstman et al., 1979; Zinoubi et al., 2018) to prescribe and monitor exercise (Azevedo et al., 2016; Eston & Parfitt, 2018; Impellizzeri et al., 2004). Perception of effort is also investigated during isolated motor tasks involving the upper or lower limb, in strength training program (Miller et al., 2009; Zourdos et al., 2016), in studies aiming at better understanding the regulation of endurance performance (Maikala & Bhambhani, 2006; Pageaux et al., 2013) or the mechanisms associated with the development of muscle fatigue during repetitive tasks (de Morree et al., 2012; Jacquet et al., 2021; Otto et al., 2019; Yang et al., 2019). To the best of our knowledge, most of the

studies investigating perception of effort are performed during locomotor exercises or isolated exercises performed with the lower limbs (de Morree et al., 2014; Faelli et al., 2019; Luu et al., 2016; Meir et al., 2015). Although perception of effort is of interest to understand how the nervous system controls our everyday movements, motor control studies have mostly indirectly investigated it by measuring the force output, the decision made by the participants, or motor strategies (Cos, 2017; Gaveau et al., 2021; Izawa & Shadmehr, 2008; Morel et al., 2017; Shadmehr et al., 2016; Wang et al., 2021). While these methods present several advantages in the context of decision-making tasks, not considering the rating of perception of effort as a dependant variable limits the exploration of the subjective experience of the participant during task completion (Pageaux, 2016; Wang et al., 2021). As the perception of effort has been recently proposed to finely regulate motor control (Cos, 2017) and thus, to affect decision-making and performance in a task involving movement regulation (Shadmehr et al., 2016; Wang et al., 2021), there is an urgent need for studies exploring the perception of effort during upper limb tasks. Such studies could provide opportunities to better understand the interaction between perception of effort and motor control.

In this context, the present study aimed to validate the use of the perception of effort to prescribe and monitor exercise in healthy young adults performing upper limb motor tasks. To do so, two experiments manipulated the physical demand to alter the task difficulty. In the first experiment, by using a modified version of the classical box and block test (Mathiowetz, 1985) and a pointing task, we tested the possibility i) to prescribe exercise at different intensities with the perception of effort and ii) to monitor changes in perception of effort when task difficulty was altered with manipulation of the physical demand. As effort and its perception vary in relation to performance (Brehm & Self, 1989; Richter et al., 2016), we monitored perception of effort while controlling for performance. We hypothesized that i) it is possible to prescribe different exercise intensities with the perception of effort, as attested by an increased task performance when the prescribed intensity of perceived effort increases; and ii) that increasing task difficulty, with faster tempos or additional weights, will be reflected in higher perceptions of effort. In the second experiment, by using the classical box and block test with its validated instructions, we tested the effect of increasing physical demand on subsequent performance and rating of perception of effort. We hypothesized that performance could be maintained at the cost of a higher resource mobilization as reflected by the increases in the perception of effort.

Materials and methods

1. 1. Participants

Twenty participants volunteered to participate in experiment 1 and twenty participants volunteered to participate in experiment 2. The description of the participants is available in Table 1. None of the participants reported any pain-related, neurological, psychological disorders, or somatic illnesses. Written informed consent was obtained from each participant. Experiment 1 took place at the Centre de recherche de l'Institut universitaire de gériatrie de Montréal. Experiment 2 took place at the Espace d'Etude du Mouvement—Etienne Jules MAREY de l'Université de Bourgogne. All participants gave written informed consent and all procedures were approved by the local ethics committee of each institution. As caffeine and sleep deprivation are known to alter the perception of effort (Morree et al., 2014), participants in both experiments were asked to refrain from ingesting caffeine at least 3 h before their visits and to get at least 7 h of sleep the night before (Temesi et al., 2013).

Table 1. Description of participants

	Experiment 1		Experiment 2	
	Women (n = 18)	Men (n = 2)	Women (n = 7)	Men (n = 13)
Age (yrs)	24 ± 2	24 ± 2	26 ± 2	25 ± 2
Weight (kg)	62 ± 11	72 ± 14	59 ± 7	76 ± 10
Height (cm)	164 ± 10	187 ± 5	163 ± 6	178 ± 5.4
Physical activity (/30)	19.06 ± 5.4	23 ± 0	21.5 ± 6.3	23.6 ± 3.5
Right-handed	17	2	7	11
Left-handed	1	-	-	2

Yrs = years, kg = kilogram, cm = centimeter. The physical activity score was measured with the Dijon Physical activity questionnaire (Robert et al., 2004). Data are presented as mean ± SD.

2. Upper limb motor tasks

In this study, the upper limb motor tasks were the Box and Block Test (BBT) and a Pointing Task (PT). A full description of these tests is available below. We chose these two tests for their relevance in the context of clinical settings as well as research.

a. Box and Block test

The BBT (Mathiowetz, 1985), illustrated in Figure 1A, is used to assess manual dexterity, defined as “the ability to make coordinated hand and finger movements to grasp and manipulate objects” (Makofske, 2011). This test has been validated in several populations such as older adults (Desrosiers et al., 1994), fibromyalgia patients (Canny et al., 2009) and stroke rehabilitation (Lin et al., 2010). The test consists of a wooden box (53.7 cm x 25.4 cm x 8.5 cm) separated into two containers of 25.4 cm each. It includes 150 wooden cubes (2.5 cm). Participants have to grasp one block at a time with the dominant hand, transport the block over the partition, and release it into the opposite compartment. Standardized instructions require participants to move as many blocks as possible in 60 s, and performance is monitored as the number of blocks moved. In experiment 1, we used a 30 s modified version of the BBT where participants had to move the blocks at a prescribed effort intensity or by following a pre-determined tempo signaled by an auditory cue to control for the number of blocks moved (performance). In experiment 2, we used the standardized instructions in the absence and presence of additional weight on the dominant forearm. In both experiments, the compartment containing the block was placed in front of the participants’ dominant hand. Errors were visually counted by an experimenter when the fingertips did not go beyond the partition, and the associated block was not counted in the final score.

b. Pointing task

Pointing tasks (PT) are widely used in research to study motor control (e.g., Domkin et al., 2002; Missenard et al., 2009). A PT (illustrated in figure 1B) was performed in experiment 1. Participants had to go back and forth between targets (squares of 1 cm²) as quickly as possible in a given time. Participants started from target 1 (reference target) and had to follow a pre-determined order, depending on their dominant hand. Right-handed participants had to reach target 2 and come back to target 1, then reach target 3 and come back to target 1, then reach target 4 and come back to target 1, then reach target 5 and come back to target 1. This sequence was repeated for 30 s, either with the

instructions of reaching the targets at a prescribed effort intensity or by following a pre-determined tempo to control for the number of targets reached (i.e., performance). For left-handed participants, the order of the sequence was reversed. They had to first reach target 5. Participants performed the test with a pencil in their hand and had to point where they reached, thus allowing an experimenter to visually control for the exact number of targets correctly reached.

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Figure 1. Panel A: Illustration of the Box and Block Test (Mathiowetz, 1985) used in experiments 1 and 2. Briefly, participants had to grasp one block at a time with the dominant hand, transport the block over the partition, and release it into the opposite compartment.

Panel B: Illustration of the Pointing Task used in experiment 1. Starting from target 1, participants had to go back and forth between each target. Right-handed participants started by reaching target 2 for their first-round trip, while left-handed participants started by reaching target 5 for their first-round trip. Measures are being taken from the center of all squares (1×1 cm). The distance between each upper square is 5.1 cm. Distance between targets 1-2 and 1-5 is 22.3 cm, respectively. Distance between targets 1-3 and 1-4 is 21 cm, respectively.

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3. Overview of the two experiments

a. Experiment 1

This experiment aimed to test, with a modified version of the BBT and a PT, the possibility i) to use the perception of effort to prescribe exercise (Exp. 1A), and ii) to monitor changes in the rating of perception of effort when performance is controlled and task difficulty manipulated (Exp. 1B). i) To test the possibility of prescribing exercise with a target level of perceived effort, we monitored performance associated with four intensities of perception of effort (presented in fig. 2A) ii) To test the possibility of monitoring changes in the perception of effort, we manipulated task difficulty by increasing physical demand. Task difficulty was increased by increasing the speed of movement (*tempo session*) or by adding a weight on the forearm (*weight session*). The weight session was performed at a controlled paced such that the effect of task demand on PE was assessed at a controlled performance level (i.e. constant speed). The *tempo session* and *weight session* were performed in two different laboratory visits, in a randomized order. An overview of the sessions is presented in figure 2B. All tests were performed in a seated position. At the onset of the first laboratory visit, participants completed several questionnaires allowing the characterization of the population studied (anthropometry, physical activity score; Robert et al., 2004), Edinburgh Handedness Inventory (Oldfield, 1971). Then, each session was performed as described below, with all BBT trials performed in one block and all PT trials related performed in another block. The order of each block (BBT performed first vs PT performed first) was randomized between participants and kept constant for each participant between the two laboratory visits (*tempo session* vs *weight session*).

Tempo session. Participants were equipped with the apparatus allowing measurement of EMG, heart rate and/or respiratory frequency. We subsequently provided standardized instructions on how to use the psychophysical rating scale to monitor the perception of effort and how to perform the BBT and the PT. Participants had 1 min to familiarize themselves with each test and could ask any questions. Following this familiarization, participants were asked to perform a block of trials for the BBT or PT. The first block consisted of trials using a target level of PE intensity to prescribe the exercise, and the second block consisted of trials where performance was controlled by different tempos and where perception of effort was reported by the participant. Trials related to the use of PE to prescribe the exercise intensity consisted of performing one test of 30 s per target PE intensity level (light effort, moderate effort, strong effort and very strong effort), with each test interspaced by 30 s of recovery. The experimenter recorded performance for each prescribed intensity. Then, participants performed

two tests of 30 s per difficulty level (low, moderate, high), with each test interspaced by 90 s of recovery. Once a block (BBT vs PT trials) was completed, a 120 s rest was given, and participants completed the other block following the same structure. Following pilot experiments, three tempos specific to each task were chosen to produce three levels of difficulties. For the PT, the following tempos were used: 1 Hz (slow tempo), 1.5 Hz (moderate tempo) and 2 Hz (fast tempo). For the BBT, the following tempos were used: 0.5 Hz (slow tempo), 0.75 Hz (moderate tempo) and 1 Hz (fast tempo). The order of level of difficulties was randomized. The rating of perceived effort was measured immediately at the end of each repetition. Following the two repetitions of each difficulty level, participants reported their perceived workload using the NASA TLX scale as described below.

Weight session. The procedures in the *weight sessions* are identical to the procedures in the *tempo session*, except that task difficulty was manipulated by adding weights (4-lb pair, Enhance Fitness) on the dominant forearm of the participant while performing the BBT and PT at a fixed tempo (BBT: 0.75 Hz; PT: 1.5 Hz). The low difficulty level was performed with no additional weight (0 kg, light weight) on the forearm. The moderate and high difficulty levels were performed with additional weights, 0.5 kg (moderate weight) and 1 kg (heavy weight) respectively, on the forearm.

b. Experiment 2

The second experiment aimed (Exp. 2A) to replicate the results of the PE prescription condition of experiment 1A and to test the effect of increasing physical demand to manipulate BBT difficulty on subsequent performance and ratings of perception of effort (Exp. 2B). Participants visited the laboratory once. At their arrival, participants were equipped with the apparatus allowing measurement of EMG and heart rate. We subsequently provided standardized instructions on how to use the psychophysical scale to monitor the perception of effort and how to perform the BBT. Participants had 1 min to familiarize themselves with each test and could ask any questions. Following this familiarization, participants were asked to perform two blocks of trials. The first block consisted of trials related to using the perception of effort intensity to prescribe the exercise, as performed in experiment 1. In the second block of trials, participants completed the BBT according to the standardized duration of 60 s, in the absence (0 kg, low difficulty level) and the presence (0.5 kg, high difficulty level) of an additional weight on the dominant forearm, interspaced by a 2.5 min recovery between difficulties. The order of difficulty levels (0 kg, low difficulty level vs 0.5 kg, high difficulty level) was randomized between participants and repeated after a 15 min break. In total, each participant repeated each level of difficulty twice.

Pilot experiments revealed that the duration of 60 s with an additional weight of 1 kg induced an important level of fatigue to the participants. Consequently, to limit the induction of fatigue, the high level of difficulty was performed with a weight of 0.5 kg and a between level of difficulty recovery period of 2.5 min. The rating of perceived effort and performance (*i.e.*, number of blocks moved) was monitored immediately at the end of each repetition (3 repetitions per level of difficulty, with the order of difficulty randomized). Following each level of difficulty, participants reported their perceived workload using the NASA TLX scale as described below. An overview of the session is presented in figure 2C.

A. Experiment 1A and 2A : Prescribing exercise with perception of effort

B. Experiment 1B : weight or tempo session

C. Experiment 2B : weight manipulation during the Box and Block Test with its official instructions

Figure 2. Panel A: Experiments 1A and 2A overview : the procedures used to test the possibility to prescribe exercise using the perception of effort.

The exercise was prescribed at four intensities of perceived effort via the CR100 scale: light (13/100), moderate (23/100), strong (50/100), very strong (70/100). While both the pointing task (PT) and the

Box and Block Test (BBT) were performed in experiment 1A, only the BBT was performed in experiment 2A.

Panel B: Experiment 1B overview. Set up consisted of the placement of the respiratory frequency belt, heart rate monitor and the EMG surface electrodes. Then participants completed the indicated questionnaire or Visual Analog Scale (VAS). Participants performed two repetitions per level of difficulty with 30 s of recovery in between. Rating of Perceived Effort (RPE) and subjective workload using NASA TLX scale were assessed in-between each level of difficulty.

Panel C: Experiment 2B overview. Participants performed the Box and Block test for 60'' with the absence (0kg) or presence (0.5kg) of an additional weight. Set up consisted of the placement of the heart rate monitor and the EMG surface electrodes. Then, participants completed the indicated questionnaire or scale.

4. Psychological measurements

Perception of effort, defined as the conscious sensation of “how hard, heavy and strenuous a physical task is” (Marcora, 2010; Pageaux, 2016), was measured and used to prescribe the exercise with the CR100 scale (Borg & Kaijser, 2006). This scale ranges from 0 (“nothing at all”) to 100 (“maximal”) and includes verbal anchors, such as light (weak), moderate, strong (heavy) for intermediate values (Borg & Kaijser, 2006). Standardized instructions on how to use the CR100 scale to evaluate the perception of effort were provided at the onset of each session and participants were asked to exclude the perception of pain from their rating (Pageaux et al., 2020; Pageaux et al., 2016). To prescribe exercise, participants were asked to perform the tasks at four different effort intensities associated with the following verbal anchors and numbers on the CR100 scale: light (13), moderate (23), strong (50) and very strong (70). To report their perception of effort, participants were asked to first refer to the verbal anchors and then to report a number that best represents the intensity of their perception. The CR100 scale was printed on a legal format (8.5 × 14 in) and fixed on a wall ~1 m in front of the participants.

Perceived workload was measured with the Nasa Task Load Index (NASA TLX; Hart & Staveland, 1988). In line with the aims of our study, only the three following subscales were considered: Physical Demand, Temporal Demand and Effort. Participants had to score each of the items on a scale divided into 20 equal intervals anchored by a bipolar descriptor (e.g., High/Low). This score was multiplied by 5, resulting in a final score between 0 and 100 for each of the six subscales.

Fatigue. The presence of fatigue is known to increase the perception of effort (Enoka & Stuart, 1992a; Pageaux & Lepers, 2016a). We consequently monitored feelings of fatigue at the beginning and the end of each visit with a visual analog scale (Le Mansec et al., 2017). Participants had to place a mark on a 100 mm line with bipolar end anchors (0 = not fatigued at all; 100 = extremely fatigued). The fatigue score was determined by measuring the distance (in mm) from the left-hand end of the line to the mark made by the participant.

5. Physiological measurements

Electromyography (EMG) of the biceps brachii and triceps long head was measured in both experiments with adhesive, pre-gelled surface electrodes (Covidien, CA). Before placing the electrodes, the skin was shaved, cleaned with alcohol, and dried. Electrodes were placed using SENIAM recommendations (Hermens et al., 2000). The electrode reference was attached to the extremity of the elbow of the dominant arm. In experiment 1, EMG was recorded using a PowerLab system (26T, ADInstruments) with an acquisition rate of 1KHz and filtered with bandpass ranging from 20 to 400 Hz (auto adjust) and a notch filter with a center frequency of 60 Hz (auto adjust). Data were analyzed using the LabChart software (AD Instruments). In experiment 2, EMG was recorded using a Biopac system (MP150, Biopac Systems, Inc.) with an acquisition rate of 1 KHz and filtered with bandpass ranging from 20 to 400 Hz (auto adjust) and a notch filter with a center frequency of 60 Hz (auto adjust). Data were analyzed using Acknowledge software (Biopac Systems, Inc.). The root mean square (RMS) was automatically calculated with each software. Data were averaged for the last 5 s of each 30 s (experiment 1) or 60 s (experiment 2) trials. The EMG is reported as the sum of the triceps and biceps RMS values.

Heart rate frequency was measured in both experiments. In experiment 1, we used a finger pulse transducer (TN1012/ST, AD Instruments) placed on the non-dominant index finger. To limit movement artifacts, the non-dominant hand was placed on homemade support to rest on the table and stay as steady as possible. The signal was recorded with an acquisition rate of 1KHz and filtered with a digital filter of 7 Hz (low pass). Data analysis was automatically performed by the LabChart software. Heart rate frequency was averaged for the last 5 s of each 30 s trials. Due to numerous movement artifacts in experiment 1, monitoring heart rate was measured using a chest strap via the paired Polar watch (Polar RS400; Polar Electro Oy, Kempele, Finland) and measured as the average of the 60 s trial. The experimenter pressed the start/stop button of the watch at the beginning and end of each trial, and then recorded the average heart rate frequency calculated by the watch.

Respiratory frequency was measured in experiment 1 only via a respiratory belt transducer (TN11132/ST, AD Instruments). The respiratory belt was fixed on the participant's chest, the signal was recorded with an acquisition rate of 1KHz and filtered with a digital filter of 7 Hz (low pass). Data analysis was automatically performed by the LabChart software. Respiratory frequency was averaged from the last 5 s of each 30 s trials.

6. Statistical Analysis

All data are presented as mean $\pm$ standard deviation in the text. Assumptions of statistical tests such as normal distribution and sphericity of data were checked as appropriate. Greenhouse-Geisser correction to the degrees of freedom was applied when violation to sphericity was present.

Experiment 1A : All analyses subsequently described were performed for the modified BBT and PT. A 2×4 repeated-measures ANOVA was used to assess the effects of visit (1 and 2) and effort intensity (light, moderate, strong, very strong) on performance, heart rate frequency, respiratory frequency and EMG RMS. As these analyses were performed to test the possibility to use the perception of effort to prescribe the exercise, a significant main effect of effort intensity only was followed with the following pairwise comparisons adjusted with the Bonferroni correction: light effort vs moderate effort, moderate effort vs strong effort, strong effort vs very strong effort.

Experiment 1B : To test the possibility to monitor changes in perception of effort when task difficulty is altered with manipulation of the physical demand in both *tempo* and *weight sessions*, a repeated-measures ANOVA was used to assess the effects of difficulty (easy, medium, hard) on heart rate and respiratory frequencies. Significant effect of difficulty was followed-up with pairwise comparisons adjusted with the Bonferroni correction. A Friedman ANOVA was used to assess the effects of difficulty on performance, rating of perceived effort, EMG RMS, as well as the physical demand, temporal demand and effort subscales of the NASA TLX scale. Significant effect of difficulty was followed up with Wilcoxon signed-ranked tests adjusted with the Bonferroni correction.

Experiment 2A : A repeated-measures ANOVA was used to assess the effects of effort intensity (light, moderate, strong, very strong) on performance, heart rate frequency and EMG RMS. As these analyses were performed to test the possibility to use the perception of effort to prescribe the exercise, a significant effect of effort intensity only was followed with the following pairwise comparisons adjusted with the Bonferroni correction: light effort vs moderate effort, moderate effort vs strong effort, strong effort vs very strong effort.

A 2×2 repeated-measures ANOVA was used to assess the effects of repetition (1 and 2) and difficulty (easy and hard) on performance, heart rate frequency, EMG RMS, as well as the physical demand and effort subscales of the NASA TLX scale.

Experiment 2B : As the experiment 2B did not constrain the temporal demand of the task by imposing a tempo, we did not analyze the temporal demand subscale of the NASA TLX scale. If a repetition $\times$ difficulty interaction reached significance, the following follow-up tests were performed and adjusted with the Bonferroni correction: repetition 1/0 kg vs repetition 2/0kg, repetition 1/0.5 kg vs repetition 2/0.5 kg, repetition 1/0 kg vs repetition 1/0.5 kg, repetition 2/0 kg vs repetition 2/0.5 kg.

For both experiments, all statistical analyses were performed using the Statistical Package for the Social Sciences software, version 27 for Mac OS X (SPSS, Chicago, IL). Effect sizes for the repeated measures ANOVA are reported as the partial eta squared (η_p^2) provided by SPSS. Effects sizes for the pairwise comparisons are reported with r and calculated with Microsoft Excel according to the equations described below for parametric (i) and non-parametric (Myers et al.) tests (Field, 2005). Parameters t , df and Z were provided by SPSS, and N corresponds to the total number of observations (Field, 2005).

$$(i) \quad r = \sqrt{\frac{t^2}{t^2 + df}} \quad (\text{Myers et al.}) \quad r = \frac{Z}{\sqrt{N}}$$

Significance was set at 0.05 (2-tailed). Thresholds for small, moderate and large effects were set at 0.1, 0.3 and 0.5 for r (Cohen, 1988).

Results

7. Experiment 1

In this experiment, we used a modified version of the BBT and PT. We prescribed 30 s of exercise performed at four intensities of effort (light, moderate, strong and very strong) in two different visits. Performance, EMG RMS, heart rate and respiratory frequencies were monitored for each prescribed effort intensity. We also manipulated task difficulty levels (low, moderate, high) by manipulating physical demand and imposing three tempos or adding three different weights on the participant's dominant forearm while performing the task at a fixed tempo. Performance, heart rate frequency, respiratory frequency, EMG RMS and the subjective workload were measured for each difficulty.

a. Experiment 1A: Using the perception of effort to prescribe the exercise

Results of the main effects of effort intensity for the BBT and PT are presented in figures 3 and 4, respectively.

Performance: For the BBT (figure 3A), the main effect of visit did not reach significance [$F(1,19) = 2.105, p = .163, \eta_p^2 = .099$]. Increasing the prescribed effort intensity resulted in an increased performance during the BBT [$F(1.6, 31.2) = 172.335, p < .001, \eta_p^2 = .901$]. Follow-up test revealed an increase in performance between the light and moderate intensities [$t(19) = 10.509, p < .001, r = .924$], between the moderate and strong intensities [$t(19) = 10.474, p < .001, r = .923$], as well as between the strong and very strong intensities [$t(19) = 7.191, p < .001, r = .855$]. The visit $\times$ effort intensity interaction did not reach significance [$F(3,57) = .401, p = .752, \eta_p^2 = .021$]. For the PT (figure 4A), the main effect of visit did not reach significance [$F(1,19) = .749, p = .397, \eta_p^2 = .038$]. The main effect of effort intensity reached significance [$F(1.6, 31.1) = 112.050, p < .001, \eta_p^2 = .855$]. Follow-up test revealed an increase in performance between the light and moderate intensities [$t(19) = 8.162, p < .001, r = .882$], between the moderate and strong intensities [$t(19) = 10.681, p < .001, r = .926$], as well as between the strong and very strong intensities [$t(19) = 6.291, p < .001, r = .822$]. The visit $\times$ effort intensity interaction did not reach significance [$F(1.4,26.8) = 1.342, p = .270, \eta_p^2 = .065$].

EMG RMS: For the BBT (figure 3B), the main effect of visit did not reach significance [$F(1,18) = 2.377, p = .140, \eta_p^2 = .116$]. The main effect of effort intensity reached significance [$F(1.4,24.7) = 37.667, p < .001, \eta_p^2 = .676$]. Follow-up test revealed an increase in EMG RMS between light and moderate intensities [$t(18) = 5.904, p < .001, r = .812$], between the moderate and strong intensities [$t(18) = 5.229, p < .001, r = .777$], as well as between the strong and very strong intensities [$t(18) = 4.110, p = .002, r = .696$]. The visit $\times$ effort intensity interaction did not reach significance [$F(3,54) = .668, p = .575, \eta_p^2 = .036$]. For the PT (figure 4B), the main effect of visit did not reach significance [$F(1,18) = .247, p = .625, \eta_p^2 = .013$]. The main effect of effort reached significance [$F(1.2,22.7) = 44.335, p < .001, \eta_p^2 = .711$]. Follow-up test revealed an increase in EMG RMS between light and moderate intensities [$t(18) = 6.049, p < .001, r = .819$], between the moderate and strong intensities [$t(18) = 5.566, p < .001, r = .795$], as well as between the strong and very strong intensities [$t(18) = 5.202, p < .001, r = .775$]. The visit $\times$ effort intensity interaction did not reach significance [$F(1.7,30.8) = .873, p = .412, \eta_p^2 = .046$].

Heart rate frequency: For the BBT (figure 3C), the main effect of visit did not reach significance [$F(1,8) = .851, p = .383, \eta_p^2 = .096$]. The main effect of effort intensity reached significance [$F(3,24) = 8.166, p = .001, \eta_p^2 = .505$]. Follow-up test revealed an increase in heart rate frequency between the moderate and strong intensities [$t(17) = 3.176, p = .017, r = .610$]. Neither the increase in heart rate frequency between the light and moderate intensities [$t(17) = 1.490, p = .464, r = .340$], nor the one between the strong and very strong intensities did reach significance [$t(17) = 0.334, p = 1.000, r = .081$]. The visit $\times$ effort intensity interaction did not reach significance [$F(3,24) = .896, p = .458, \eta_p^2 = .101$]. For the PT (figure 4C), the main effect of visit did not reach significance [$F(1,14) = .218, p = .647, \eta_p^2 = .015$]. The main effect of effort reached significance [$F(3,42) = 14.804, p < .001, \eta_p^2 = .513$]. Follow-up test revealed an increase in heart rate frequency between the moderate and strong intensities [$t(19) = 3.285, p = .012, r = .602$], but not between the light and moderate intensities [$t(19) = 2.182, p = .126, r = .448$] not between the strong and very strong intensities [$t(19) = 1.941, p = .202, r = .407$]. The visit $\times$ effort intensity interaction did not reach significance [$F(3,42) = .406, p = .748, \eta_p^2 = .028$].

Respiratory frequency: For the BBT (figure 3D), the main effect of visit did not reach significance [$F(1,13) = .008, p = .930, \eta_p^2 = .001$]. The main effect of effort intensity reached significance [$F(3,39) = 6.463, p = .001, \eta_p^2 = .332$]. However, neither the increase in respiratory frequency between the light and moderate intensities [$t(19) = 2.450, p = .072, r = .490$], nor between the moderate and strong intensities [$t(19) = 2.131, p = .139, r = .439$] or between the strong and very strong intensities did reach significance [$t(19) = 1.663, p = .338, r = .357$]. The visit $\times$ effort intensity interaction did not reach significance [$F(3,39) = .084, p = .970, \eta_p^2 = .006$]. For the PT (figure 4D), the main effect of visit did not reach significance [$F(1,15) = .142, p = .711, \eta_p^2 = .009$]. The main effect of effort intensity reached significance [$F(3,45) = 10.893, p < .001, \eta_p^2 = .421$]. However, again, neither the increase in respiratory frequency between the light and moderate intensities [$t(19) = 1.648, p = .347, r = .354$], nor between the moderate and strong intensities [$t(19) = 2.451, p = .072, r = .490$] or between the strong and very strong intensities did reach significance [$t(19) = 1.052, p = .917, r = .235$]. The visit $\times$ effort intensity interaction did not reach significance [$F(3,45) = .195, p = .899, \eta_p^2 = .012$].

Figure 3. Experiment 1A: using the perception of effort to prescribe the exercise during the Box and Block test.

Effect of increasing the prescribed effort intensity on performance (panel A, $n = 20$), EMG root mean square of the sum of the biceps and triceps brachial muscles (panel B, $n = 19$), heart rate frequency (panel C, $n = 18$) and respiratory frequency (panel D, $n = 20$) during the Box and Block Test. The exercise was prescribed at four intensities of perceived effort via the CR100 scale: light (13/100), moderate (23/100), strong (50/100), very strong (70/100). Data are presented as the main effect of effort intensity. The n indicates the number of participants with all the data in each four effort intensities. Changes in the n reflects data loss due to the issue with equipment or movement artefact. Individual data are presented in grey circles and means in black triangles. * difference between two intensities of effort. One symbol for $p < 0.05$, two symbols for $p < 0.01$ and three symbols for $p < 0.001$.

Figure 4. Experiment 1A: using the perception of effort to prescribe the exercise during the Pointing task.

Effect of increasing the prescribed effort intensity on performance (panel A, $n = 20$), EMG root mean square of the sum of the biceps and triceps brachial muscles (panel B, $n = 20$), heart rate frequency (panel C, $n = 20$) and respiratory frequency (panel D, $n = 20$) during the Pointing Task. The exercise was prescribed at four intensities of perceived effort via the CR100 scale: light (13/100), moderate (23/100), strong (50/100), very strong (70/100). Data are presented as the main effect of effort intensity. Individual data are presented in grey circles and means in black triangles. * difference between two

intensities of effort. One symbol for $p < 0.05$, two symbols for $p < 0.01$ and three symbols for $p < 0.001$.

b. Experiment 1B : Manipulating the tempo to alter task difficulty.

Results for the BBT and PT during the tempo sessions are presented in figures 5 and 6, respectively.

Performance: For the BBT (figure 5A), manipulation of the tempo increased performance [$\chi^2(2) = 40, p < .001$]. Performance increased between the low and moderate difficulties ($Z = 3.990, p < .001, r = .631$), between the low and high difficulties ($Z = 3.935, p < .001, r = .622$), as well as between the moderate and high difficulties ($Z = 3.941, p < .001, r = .623$). One participant did not show an increase in performance between the moderate and high difficulties, as shown in the figure. For the PT (figure 6A), manipulation of the tempo increased performance too [$\chi^2(2) = 40, p < .001$]. Performance increased between the low and moderate difficulties ($Z = 3.965, p < .001, r = .627$), between the low and high difficulties ($Z = 3.941, p < .001, r = .623$), as well as between the moderate and high difficulties ($Z = 3.932, p < .001, r = .622$).

Perception of effort: For the BBT (figure 5B), manipulation of the tempo increased the rating of perceived effort [$\chi^2(2) = 30.152, p < .001$]. Rating of perceived effort increased between the low and moderate difficulties ($Z = 3.747, p = .001, r = .592$), between the low and high difficulties ($Z = 3.790, p < .001, r = .599$), as well as between the moderate and high difficulties ($Z = 3.460, p = .002, r = .547$). For the PT (figure 6B), manipulation of the tempo increased the rating of perceived effort too [$\chi^2(2) = 36.1, p < .001$]. Rating of perceived effort increased between the low and moderate difficulties ($Z = 3.865, p < .001, r = .611$), between the low and high difficulties ($Z = 3.921, p < .001, r = .620$), as well as between the moderate and high difficulties ($Z = 3.883, p < .001, r = .614$).

EMG RMS: For the BBT (figure 5C), manipulation of the tempo increased the EMG RMS [$\chi^2(2) = 27.9, p < .001$]. EMG RMS increased between the low and moderate difficulties ($Z = 3.285, p = .003, r = .519$), between the low and high difficulties ($Z = 3.360, p = .002, r = .531$), as well as between the moderate and high difficulties ($Z = 3.024, p = .007, r = .478$). For the PT (figure 6C), manipulation of the tempo increased the EMG RMS too [$\chi^2(2) = 40, p < .001$]. EMG RMS increased between the low and moderate difficulties ($Z = 3.920, p < .001, r = .620$), between the low and high difficulties ($Z = 3.920, p < .001, r = .620$), as well as between the moderate and high difficulties ($Z = 3.920, p < .001, r = .620$).

Heart rate frequency: Despite controlling for movement artifacts data was lost in two participants during the BBT and two participants during the PT, both during the completion of the high difficulty. For the BBT (figure 5D), manipulation of the tempo increased the heart rate frequency [$F(2,34) = 9.826, p < .001, \eta_p^2 = .366$]. Heart rate frequency increased between the low and moderate difficulties [$t(19) = 2.517, p < .001, r = .500$], between the low and high difficulties [$t(17) = 3.861, p < .001, r = .684$], as well as between the moderate and high difficulties [$t(17) = 2.297, p < .001, r = .487$]. For the PT (figure 6D), manipulation of the tempo increased the heart rate frequency too [$F(2,34) = 15.707, p < .001, \eta_p^2 = .480$]. Heart rate frequency increased between the low and moderate difficulties [$t(19) = 2.707, p = .042, r = .528$], between the low and high difficulties [$t(17) = 4.911, p < .001, r = .766$], as well as between the moderate and high difficulties [$t(17) = 3.604, p = .007, r = .658$].

Respiratory frequency: For the BBT (figure 5E), manipulation of the tempo increased the respiratory frequency [$F(2,38) = 10.5, p < .001, \eta_p^2 = .355$]. The increase in respiratory frequency between the low and moderate difficulties did not reach significance [$t(19) = 2.373, p = .085, r = .478$]. Respiratory frequency increased between the low and high difficulties [$t(19) = 3.797, p = .004, r = .657$] as well as between the moderate and high difficulties [$t(19) = 2.8, p = .036, r = .537$]. For the PT (figure 6E), manipulation of the tempo increased the respiratory frequency too [$F(2,38) = 5.3, p = .009, \eta_p^2 = .219$]. Respiratory frequency increased between the moderate and high difficulties [$t(19) = 3.380, p = .009, r = .613$]. The increase in respiratory frequency neither reached significance between the low and high difficulties [$t(19) = 2.391, p = .082, r = .481$], nor between the low and moderate difficulties [$t(19) = .184, p = 1.000, r = .042$].

NASA TLX scale, physical demand: For the BBT (figure 5F), manipulation of the tempo increased the physical demand score [$\chi^2(2) = 17.815, p < .001$]. The increase in physical demand score between the easy and medium difficulties did not reach significance ($Z = 2.213, p = .081, r = .350$). Physical demand score increased between the low and high difficulties ($Z = 3.307, p = .003, r = .523$) as well as between the moderate and high difficulties ($Z = 3.051, p = .007, r = .482$). For the PT (figure 6F), manipulation of the tempo increased the physical demand score too [$\chi^2(2) = 14.464, p = .001$]. Physical demand score did not increase between the low and moderate difficulties ($Z = 1.690, p = .273, r = .267$). Physical demand score increased between the low and high difficulties ($Z = 3.354, p = .002, r = .530$) as well as between the moderate and high difficulties ($Z = 3.066, p = .007, r = .485$).

NASA TLX scale, temporal demand: For the BBT (figure 5G), manipulation of the tempo increased the temporal demand score [$\chi^2(2) = 7.28, p = .026$]. Temporal demand score neither increased between the low and moderate difficulties ($Z = .572, p = 1.000, r = .090$), nor between the low and high

difficulties ($Z = 2.194$, $p = .085$, $r = .347$). Temporal demand score significantly increased between the moderate and high difficulties ($Z = 2.686$, $p = .022$, $r = .425$). For the PT (figure 6G), manipulation of the tempo increased the temporal demand score too [$\chi^2(2) = 23.792$, $p < .001$]. The increase in temporal demand score between the low and moderate difficulties did not reach significance ($Z = 2.144$, $p = .096$, $r = .339$). Temporal demand score significantly increased between the low and high difficulties ($Z = 3.712$, $p = .001$, $r = .587$) as well as between the moderate and high difficulties ($Z = 3.736$, $p = .001$, $r = .591$).

NASA TLX scale, effort: For the BBT (figure 5H), manipulation of the tempo increased the effort score [$\chi^2(2) = 18.123$, $p < .001$]. Effort score did not increase between the low and moderate difficulties ($Z = .177$, $p = 1.000$, $r = .028$) but did so between the low and high difficulties ($Z = 3.184$, $p = .004$, $r = .503$), as well as between the moderate and high difficulties ($Z = 3.202$, $p = .004$, $r = .506$). For the PT (figure 6H), manipulation of the tempo increased the effort demand score too [$\chi^2(2) = 22.776$, $p < .001$]. Effort score did not increase between the low and moderate difficulties ($Z = 1.759$, $p = .236$, $r = .278$) but did so between the low and high difficulties ($Z = 3.637$, $p = .001$, $r = .575$), as well as between the moderate and high difficulties ($Z = 2.882$, $p = .012$, $r = .456$).

VAS fatigue: Feelings of fatigue did not increase during the tempo session (from 2.9 ± 2.2 to 3.2 ± 1.9 ; $Z = .952$, $p = .340$).

Figure 5. Experiment 1B: Manipulating the tempo to alter task difficulty during the Box and block test.

Effect of manipulating the tempo during the Box and Block Test on performance (panel A, $n = 20$), Rating of perceived effort (panel B, $n = 20$), EMG root mean square of the sum of the biceps and triceps brachial muscles (panel C, $n = 20$), heart rate frequency (panel D, $n = 18$), respiratory frequency (panel E, $n = 20$) and NASA TLX scores for physical demand (panel F, $n = 20$), temporal demand (panel G, $n = 20$) and subjective effort (panel H, $n = 20$). For the low difficulty, a 0.5 Hz tempo was imposed. For the moderate difficulty, a 0.75 Hz tempo was imposed. For the high difficulty, a 1 Hz tempo was imposed. Data are presented as the main effect of difficulty. The n indicates the number of participants with all the data in each three level of difficulties. Changes in the n reflects data loss due to the issue with equipment or movement artefact. Individual data are presented in grey circles and means in black triangles. * difference between two difficulty level. One symbol for $p < 0.05$, two symbols for $p < 0.01$ and three symbols for $p < 0.001$.

Figure 6. Experiment 1B: Manipulating the tempo to alter task difficulty during the Pointing task.

Effect of manipulating the tempo during the Pointing Task on performance (panel A, $n = 20$), Rating of perceived effort (panel B, $n = 20$), EMG root mean square of the sum of the biceps and triceps brachial muscles (panel C, $n = 20$), heart rate frequency (panel D, $n = 18$), respiratory frequency (panel E, $n = 20$) and NASA TLX scores for physical demand (panel F, $n = 20$), temporal demand (panel G, $n = 20$) and subjective effort (panel H, $n = 20$). For the low difficulty, a 1 Hz tempo was imposed. For the moderate difficulty, a 1.5 Hz tempo was imposed. For the high difficulty, a 2 Hz tempo was imposed. Data are presented as the main effect of difficulty. The n indicates the number of participants with all the data in each three level of difficulties. Changes in the n reflects data loss due to the issue

with equipment or movement artefact. Individual data are presented in grey circles and means in black triangles. * difference between two difficulty level. One symbol for $p < 0.05$, two symbols for $p < 0.01$ and three symbols for $p < 0.001$.

c. Experiment 1B : Adding weight on the forearm to alter task difficulty

Results for the BBT and PT during the weight sessions are presented in figures 7 and 8, respectively.

Performance: For the BBT (figure 7A) and PT (figure 8A), manipulation of the weight did not alter performance [BBT, ($\chi^2(2) = 4.899$, $p = .086$; PT $\chi^2(2) = 2.032$, $p = .362$].

Perception of effort: For the BBT (figure 7B), manipulation of the weight increased the rating of perceived effort [$\chi^2(2) = 36.026$, $p < .001$]. Rating of perceived effort increased between the low and moderate difficulties ($Z = 3.341$, $p = .003$, $r = .528$), between the low and high difficulties ($Z = 3.921$, $p < .001$, $r = .620$), as well as between the moderate and high difficulties ($Z = 3.624$, $p = .001$, $r = .573$). For the PT (figure 8B), manipulation of the weight increased the rating of perceived effort too [$\chi^2(2) = 32.076$, $p < .001$]. Rating of perceived effort increased between the low and moderate difficulties ($Z = 3.324$, $p = .003$, $r = .526$), between the low and high difficulties ($Z = 3.920$, $p < .001$, $r = .620$), as well as between the moderate and high difficulties ($Z = 3.502$, $p = .001$, $r = .554$).

Heart rate frequency: Despite controlling for movement artifacts data was lost during the BBT in four participants during the completion of the moderate difficulty and in one participant during the completion of the high difficulty. During the PT, data was lost in two participants during the completion of the low difficulty, in one participant during the completion of the moderate difficulty and in one participant during the completion of the high difficulty. For the BBT (figure 7C), manipulation of the weight increased the heart rate frequency [$F(2,30) = 13.758$, $p < .001$, $\eta_p^2 = .478$]. Heart rate frequency did not increase between the low and moderate difficulties [$t(15) = .748$, $p = 1.000$, $r = .190$] but did so between the low and high difficulties [$t(15) = 4.213$, $p = .002$, $r = .736$], as well as between the moderate and high difficulties [$t(15) = 5.115$, $p < .001$, $r = .797$]. For the PT (figure 8C), manipulation of the weight significantly increased the heart rate frequency too [$F(2,32) = 11.257$, $p < .001$, $\eta_p^2 = .413$]. The increase in heart rate frequency between the low and moderate difficulties [$t(16) = 2.636$, $p = .054$, $r = .550$] as well as between the moderate and high difficulties [$t(16) = 2.541$, $p = .065$, $r = .536$] did not reach significance. Heart rate frequency significantly increased between the low and high difficulties [$t(16) = 4.190$, $p = .002$, $r = .723$].

599 *EMG RMS*: For the BBT (figure 7D), manipulation of the weight increased the EMG RMS [$\chi^2(2)$.
 600 = 31.3, $p < .001$]. EMG RMS increased between the low and moderate difficulties ($Z = 2.987$, $p = .008$,
 601 $r = .472$), between the low and high difficulties ($Z = 3.323$, $p = .003$, $r = .525$), as well as between the
 602 moderate and high difficulties ($Z = 3.920$, $p < .001$, $r = .620$). For the PT (figure 8D), manipulation of
 603 the weight increased the EMG RMS too [$\chi^2(2)$. = 14.8, $p = .001$]. EMG RMS did not increase between
 604 the low and moderate difficulties ($Z = .000$, $p = 1.000$, $r = 0$) but did so between the low and high
 605 difficulties ($Z = 2.061$, $p = .007$, $r = .326$), as well as between the moderate and high difficulties ($Z =$
 606 3.285, $p = .003$, $r = .519$).

607 *Respiratory frequency*: During the BBT, data was lost in one participant during the completion of
 608 both the low and high difficulties. During the PT, data was lost in one participant for the three
 609 difficulties and in one participant during the high difficulty. For the BBT (figure 7E) and PT (figure
 610 8E), manipulation of the weight did not alter respiratory frequency [BBT, $F(2,36) = 1.931$, $p = .159$,
 611 $\eta_p^2 = .097$; PT, $F(2,34) = 1.477$, $p = .243$, $\eta_p^2 = .080$].

612 *NASA TLX scale, physical demand*: For the BBT (figure 7F), manipulation of the weight increased
 613 the physical demand score [$\chi^2(2)$. = 18.2, $p < .001$]. Physical demand score increased between the low
 614 and moderate difficulties ($Z = 3.373$, $p = .002$, $r = .533$), between the moderate and high difficulties (Z
 615 = 2.630, $p = .026$, $r = .416$), as well as between the low and high difficulties ($Z = 3.497$, $p = .001$, $r =$
 616 .553). For the PT (figure 8F), manipulation of the weight significantly increased the physical demand
 617 score too [$\chi^2(2)$. = 35.351, $p < .001$]. Physical demand score increased between the low and moderate
 618 difficulties ($Z = 3.218$, $p = .004$, $r = .509$), between the moderate and high difficulties ($Z = 3.734$ $p =$
 619 .001, $r = .590$), as well as between the low and high difficulties ($Z = 3.930$, $p < .001$, $r = .621$).

620 *NASA TLX scale, temporal demand*: For the BBT (figure 7G), manipulation of the weight increased
 621 the temporal demand score [$\chi^2(2)$. = 7, $p = .031$]. Temporal demand score did not increase between the
 622 low and moderate difficulties ($Z = .361$, $p = 1.000$, $r = .057$), as well as between the low and high
 623 difficulty ($Z = 1.934$, $p = .159$, $r = .306$), but did between the moderate and high difficulty ($Z = 2.423$,
 624 $p = .046$, $r = .383$). For the PT (figure 8G), manipulation of the weight increased the temporal demand
 625 score too [$\chi^2(2)$. = 8.222, $p = .016$]. Temporal demand score did not increase between the low and
 626 moderate difficulties ($Z = 2.042$, $p = .123$, $r = .323$), as well as between the moderate and high
 627 difficulties ($Z = 2.110$, $p = .105$, $r = .334$), but did between the low and high difficulties ($Z = 3.086$, p
 628 = .006, $r = .488$).

NASA TLX scale, effort: For the BBT (figure 7H), manipulation of the tempo increased the effort score [$\chi^2(2) = 28.353$, $p < .001$]. Effort score increased between the low and moderate difficulties ($Z = 3.309$, $p = .003$, $r = .523$), between the moderate and high difficulties ($Z = 3.225$, $p = .004$, $r = .510$), as well as between the low and high difficulties ($Z = 3.798$, $p < .001$, $r = .601$). For the PT (figure 8H), manipulation of the tempo increased the effort score too [$\chi^2(2) = 25.507$, $p < .001$]. Effort score did not increase between the low and moderate difficulties ($Z = 1.720$, $p = .256$, $r = .272$), but did so between the moderate and high difficulties ($Z = 3.362$, $p = .002$, $r = .532$), as well as between the low and high difficulties ($Z = 3.604$, $p = .001$, $r = .570$).

VAS fatigue: Feelings of fatigue increased during the tempo session (from 3.1 ± 2.3 to 3.9 ± 1.9 ; $Z = 2.315$, $p = .021$).

Figure 7. Experiment 1B: Adding weight on the forearm to alter task difficulty during the Box and Block test.

Effect of manipulating the weight during the Box and Block Test on performance (panel A, $n = 20$), Rating of perceived effort (panel B, $n = 20$), EMG root mean square of the sum of the biceps and triceps brachial muscles (panel C, $n = 20$), heart rate frequency (panel D, $n = 16$), respiratory frequency (panel E, $n = 20$) and NASA TLX scores for the physical demand (panel F, $n = 20$), the temporal demand (panel G, $n = 20$) and the subjective effort (panel H, $n = 20$). Movements were performed at a fixed tempo of 0.75 Hz. For the low difficulty, no additional weight on the forearm was added. For the

moderate difficulty, a weight of 0.5 kg was added. For the high difficulty, a weight of 1kg was added. Data are presented as the main effect of difficulty. The n indicates the number of participants with all the data in each three level of difficulties. Changes in the n reflects data loss due to the issue with equipment or movement artefact. Individual data are presented in grey circles and means in black triangles. * difference between two difficulty level. One symbol for $p < 0.05$, two symbols for $p < 0.01$ and three symbols for $p < 0.001$.

Figure 8. Experiment 1B: Adding weight on the forearm to alter task difficulty during the Pointing Task.

Effect of manipulating the weight during the Pointing Task on performance (panel A, $n = 20$), Rating of perceived effort (panel B, $n = 20$), EMG root mean square of the sum of the biceps and triceps brachial muscles (panel C, $n = 20$), heart rate frequency (panel D, $n = 17$), respiratory frequency (panel E, $n = 20$) and NASA TLX scores for the physical demand (panel F, $n = 20$), the temporal demand (panel G, $n = 20$) and the subjective effort (panel H, $n = 20$). Movements were performed at a fixed tempo of 1.5 Hz. For the low difficulty, no additional weight on the forearm was added. For the moderate difficulty, a weight of 0.5 kg was added. For the high difficulty, a weight of 1kg was added. Data are presented as the main effect of difficulty. The n indicates the number of participants with all the data in each three level of difficulties. Changes in the n reflects data loss due to the equipment. Individual data are presented in grey circles and means in black triangles. * difference between two difficulty level. One symbol for $p < 0.05$, two symbols for $p < 0.01$ and three symbols for $p < 0.001$.

8. Experiment 2

In this experiment, participants visited the laboratory once. In Experiment 2A, we prescribed 30 s of exercise with the BBT performed at four intensities of effort (light, moderate, strong and very

strong). Performance, EMG RMS and heart rate frequency were monitored for each prescribed effort intensity. Then, in Experiment 2B, we manipulated task difficulty (low, high) by adding two different weights on the participant's dominant forearm while performing the standardized 60 s BBT. Each level of difficulty was repeated twice. Performance, EMG, heart rate frequency and the subjective workload were measured for each repetition of each level of difficulty.

a. Experiment 2A : Using the perception of effort to prescribe the exercise

Results are presented in figure 9.

Performance: Increasing the prescribed effort intensity resulted in an increased performance [$F(1.7, 31.6) = 168.560, p < .001, \eta_p^2 = .899$; figure 9A]. Performance increased between the light and moderate effort intensities [$t(19) = 11.393, p < .001, r = .934$], between moderate and strong effort intensities [$t(19) = 12.564, p < .001, r = .945$], as well as between strong and very strong effort intensities [$t(19) = 4.258, p = .001, r = .699$].

Heart rate frequency: Increasing the prescribed effort intensity resulted in an increased heart rate [$F(3,57) = 29.074, p < .001, \eta_p^2 = .605$; figure 9B]. The increase in heart rate frequency between the light and moderate effort intensities did not reach significance [$t(19) = 2.316, p = .096, r = .469$]. Heart rate frequency significantly increased between the moderate and strong difficulty [$t(19) = 4.027, p = .002, r = .679$], as well as between strong and very strong effort intensities [$t(19) = 2.925, p = .026, r = .557$].

EMG RMS: Increasing the prescribed effort intensity resulted in an increased EMG RMS [$F(1.4, 26.8) = 36.901, p < .001, \eta_p^2 = .660$; figure 9C]. EMG RMS increased between the light and moderate intensities [$t(19) = 4.476, p = .001, r = .716$], between moderate and strong effort intensities [$t(19) = 5.233, p < .001, r = .768$], as well as between strong and very strong effort intensities [$t(19) = 4.310, p = .001, r = .703$].

Figure 9. Experiment 2A: using the perception of effort to prescribe the exercise during the Box and Block test.

Effect of increasing the prescribed intensity of effort on performance (panel A, $n = 20$), EMG root mean square of the sum of the biceps and triceps brachial muscles (panel B, $n = 20$), heart rate frequency (panel C, $n = 20$) during the Box and Block Test. The exercise was prescribed at four intensities of perceived effort via the CR100 scale: light (13/100), moderate (23/100), strong (50/100), very strong (70/100). Data are presented as the main effect of effort intensity. Individual data are presented in grey circles and means in black triangles. * difference between two intensities of effort. One symbol for $p < 0.05$, two symbols for $p < 0.01$ and three symbols for $p < 0.001$.

b. Experiment 2B : Effects of adding weight on the forearm when completing the Box and Block test with the standardized instructions.

Results of the main effects of difficulty are presented in figure 10.

Performance: Main effect of repetition revealed a greater performance in the second repetition compared to the first repetition [$F(1, 19) = 34.836, p < .001, \eta_p^2 = .647$]. Main effect of difficulty did not reach significance [$F(1, 19) = 1.867, p = .188, \eta_p^2 = .090$; figure 10A]. The repetition $\times$ difficulty interaction reached significance [$F(1, 19) = 5.166, p = .035, \eta_p^2 = .214$]. Follow-up tests revealed an increased performance between the first and second repetitions for both the low (from 84.3 ± 6.6 to 89.7 ± 8.0 ; [$t(19) = 5.219, p < .001, r = .768$]) and high (from 84.0 ± 7.0 to 86.8 ± 6.9 ; [$t(19) = 3.667, p = .005, r = .644$]) difficulties. Performance did not differ for the first repetition between the low and high difficulties (84.3 ± 6.6 and 84.0 ± 7.0 ; [$t(19) = .188, p = 1.000, r = .043$]). During the second repetition, performance did not significantly decrease between the low and high difficulties (89.7 ± 8.0 and 86.8 ± 6.9 ; [$t(19) = 2.316, p = .096, r = .469$]).

Perception of effort: Main effect of repetition revealed a higher rating of perceived effort in the second repetition compared to the first repetition [$F(1, 19) = 14.350, p = .001, \eta_p^2 = .430$]. Main effect

of difficulty revealed an increase in rating of perceived effort with the increase in difficulty [$F(1, 19) = 6.779, p = .017, \eta_p^2 = .263$; figure 10B]. The repetition $\times$ difficulty interaction did not reach significance [$F(1, 19) = .005, p = .946, \eta_p^2 < .001$].

Heart rate frequency: Main effect of repetition [$F(1, 19) = 1.094, p = .309, \eta_p^2 = .054$], difficulty [$F(1, 19) = .664, p = .425, \eta_p^2 = .034$; figure 10C] and repetition $\times$ difficulty interaction [$F(1, 19) = .492, p = .492, \eta_p^2 = .025$] did not reach significance.

EMG RMS: Main effect of repetition revealed a higher EMG RMS in the second repetition compared to the first repetition [$F(1, 19) = 11.692, p = .003, \eta_p^2 = .381$]. Main effect of difficulty revealed an increase in EMG RMS with the increase in difficulty [$F(1, 19) = 14.280, p < .001, \eta_p^2 = .429$; figure 10D]. The repetition $\times$ difficulty interaction did not reach significance [$F(1, 19) = .002, p = .964, \eta_p^2 < .001$].

NASA TLX scale, physical demand: Main effect of repetition revealed a higher physical demand score in the second repetition compared to the first repetition [$F(1, 19) = 20.328, p < .001, \eta_p^2 = .517$]. Main effect of difficulty revealed an increase in physical demand score with the increase in difficulty [$F(1, 19) = 13.426, p = .002, \eta_p^2 = .414$; figure 10E]. The repetition $\times$ difficulty interaction did not reach significance [$F(1, 19) = 1.342, p = .261, \eta_p^2 = .066$].

NASA TLX scale, effort: Main effect of repetition did not reach significance [$F(1, 19) = 2.664, p = .119, \eta_p^2 = .123$]. Main effect of difficulty revealed an increase in effort score with the increase in difficulty [$F(1, 19) = 8.780, p = .008, \eta_p^2 = .316$; figure 10F]. The repetition $\times$ difficulty interaction did not reach significance [$F(1, 19) = .039, p = .846, \eta_p^2 = .002$].

Figure 10. Experiment 2B: Adding weight on the forearm to alter task difficulty during the Box and Block test with its validated instructions.

Effect of weight manipulation on performance (panel A, $n = 20$), rating of perceived effort (panel B, $n = 20$), EMG root mean square of the sum of the biceps and triceps brachial muscles (panel C, $n = 20$), heart rate frequency (panel D, $n = 20$), and NASA TLX scores for physical demand (panel E, $n = 20$) and effort (panel F, $n = 20$) during the Box and Block Test with its official instructions. Data are presented as the main effect of difficulty. Individual data are presented in grey circles and means in black triangles. * difference between two difficulty levels. One symbol for $p < 0.05$, two symbols for $p < 0.01$ and three symbols for $p < 0.001$.

Discussion

In this study, we investigated the possibility to prescribe and monitor exercise with the perception of effort during two upper-limb motor tasks: the box and block test and a pointing task. Our results demonstrate that performance in both tasks increased when the perception of effort intensity used to prescribe the exercise increased. When the task difficulty was altered by manipulating the physical demand via different tempos or weight added on the forearm, our results demonstrate that perception of effort increased when task difficulty increased and that performance could be maintained at a cost of a higher perception of effort. This increased perception of effort was observed during both the modified version of the box and block test as well as the pointing task performed in experiment 1. Finally, when completing the standardized version of the box and block test in the absence and presence of additional weight on the forearm, in experiment 2, we observed a maintained performance at a cost of a higher perception of effort. Overall, results from both experiments demonstrate that perception of effort can be efficiently used in healthy young adults to prescribe and monitor physical resources allocation during upper-limb motor tasks.

Perception of effort can be used to prescribe the exercise intensity of upper-limb motor tasks.

Perception of effort is widely used in the field of exercise sciences to prescribe exercise (Borg, 1998; Eston & Parfitt, 2018). As an example, the intensity of perception of effort has been used to prescribe locomotor exercise such as running or cycling (e.g., Christian et al., 2014; Hobbins et al., 2019), and resistance exercise involving the upper and lower limb (e.g., Gearhart et al., 2009; Helms et al., 2017; Zourdos et al., 2016). However, to the best of our knowledge, the possibility to use the intensity of perception of effort for exercise prescription in the context of upper-limb motor tasks remains untested. As the intensity of effort engaged in a task is proposed to determine the performance in this task (Brehm & Self, 1989; Richter et al., 2016), performance should increase when the intensity of perceived effort increases. We tested this possibility in both experiments. In experiment 1, we observed during the box and block test and a pointing task a gradual increase in performance between each intensity of perceived effort used to prescribe the exercise. This observation was subsequently reproduced in experiment 2 with another sample of participants performing the regular box and block test. Therefore, as previously observed during locomotor exercise or resistance exercise, our results suggest that the intensity of perceived effort could be an efficient tool to prescribe the exercise during upper-limb motor tasks.

To further confirm the possibility to use the perception of effort to prescribe exercise, we also monitored several physiological responses to the task performed: muscle activation, heart rate and respiratory frequencies. These physiological responses are known to rise when the intensity of a task is increased during locomotor exercise as well as resistance exercise (de Morree & Marcora, 2010, 2012; Eston & Parfitt, 2018); we therefore hypothesized that the physiological responses would rise with the increased perceived effort intensity. As expected, all physiological parameters rose with the increased exercise intensity, confirming an increase in physical resources involved in the upper-limb motor tasks performed when the prescribed perceived effort intensity increased. However, it is crucial to note that solely the muscle activation gradually increased between each prescribed perceived effort intensity. In experiment 1, our planned follow-up tests on the main effect of effort intensity failed to reveal a significant increase in respiratory frequency between each intensity. These tests also revealed that heart rate frequency solely increased between the intensities moderate – strong, and not between the intensities light – moderate and strong – very strong. As upper-limb motor tasks involve a lower muscle mass than locomotor exercise or resistance exercise and increasing the muscle mass involved in a task is known to increase cardiorespiratory responses to the exercise (MacInnis et al., 2017; Sidhu et al., 2013), the lack of observed increase between intensities in heart rate frequency and respiratory frequency in our study may be due to the low muscle mass involved in the tasks performed. In experiment 2, we used a chest belt to better control for movement artifact and increasing the quality of our heart rate frequency measurement. Using the chest belt, compared to the finger pulse transducer, allowed us to avoid data loss and capture an increased heart rate frequency between the intensities moderate – strong and strong – very strong, but not between the intensities light – moderate. Consequently, by integrating the two experiments, our results suggest that when prescribing the exercise during upper-limb motor tasks with the intensity of perceived effort, researchers and clinicians should prioritize the use of EMG over heart rate and respiratory frequencies to monitor physiological changes in the physical resources engaged in the task. During upper-limb tasks, perception of effort would seem more sensitive than heart rate frequency or respiratory frequency.

Perception of effort changes with the manipulation of physical demand

Perception of effort is not only used to prescribe the exercise, but also to monitor the exercise (Borg, 1998; Eston & Parfitt, 2018). Indeed, the intensity of perception of effort during a motor task has been extensively shown to be responsive to changes in task difficulty imposed by various experimental manipulations. As an example, perception of effort is altered by the intensity of muscle

contraction (e.g., de Morree & Marcora, 2010, 2012), the presence of muscle or mental fatigue (e.g., Jacquet et al., 2021; Pageaux & Lepers, 2016; Pageaux & Lepers, 2018) or changes in environmental conditions (e.g., Borg et al., 2018; Girard & Racinais, 2014; Jeffries et al., 2019). In our study, to test the possibility to monitor the exercise intensity during upper-limb motor tasks, we altered task difficulty by manipulating the physical demand of the tasks performed via imposing various movement tempos or adding weight on the forearm. We expected the perception of effort to raise with task difficulty, regardless of the type of physical demand manipulation used.

In experiment 1, during the tempo session, we manipulated the task physical demand by imposing three different movement speeds to complete the box and block test and pointing task. The increased number of blocks moved during the box and block test and targets reached during the pointing task confirmed that we were successful in our experimental manipulation. We observed an increased perception of effort between each task difficulty, suggesting the possibility to track changes in task difficulty imposed by changes in movement speed during upper-limb motor tasks. This increased perception of effort was associated with consistent increased muscle activation and heart rate frequency during both tasks. During the weight session, we manipulated the task physical demand by adding weights on the forearm and imposing a single movement tempo to constrain performance across task difficulties. The lack of changes in performance in both tasks across difficulties confirms that we were successful in our experimental manipulation. In line with the motivational intensity theory (Brehm & Self, 1989; Richter et al., 2016), when task difficulty increases, performance could be maintained by increasing the effort invested in the task. This proposed mechanism to maintain performance is verified in our experiment via the increased perception of effort intensity between each task difficulty, suggesting the possibility to track changes in task difficulty imposed by manipulating the weight of the exercising forearm moved during upper-limb motor tasks. The increased muscle activation and heart rate frequency over task difficulties further support the mechanism proposed by the motivational intensity theory. However, it noticeable that muscle activation did not increase in the pointing task between the easy – medium difficulties, and solely between the medium – hard difficulties. This lack of changes when increasing the difficulty from no additional weight on the forearm (easy difficulty) to a light additional weight on the forearm (0.5k, medium difficulty) is most likely due to the recruitment of other muscle groups than the elbow flexor-extensors to compensate for this specific increase in difficulty.

In experiment 2, we performed the standardized version of the box and block test by adding a weight on the forearm to increase task difficulty. Neither performance nor movement speed was

controlled, the participants had to move as many blocks as possible in 60 s. In this specific experimental paradigm, the motivational intensity theory would predict two possible outcomes (Brehm & Self, 1989; Richter et al., 2016) : i) performance will drop if the increase in task difficulty is beyond the participants capacity, or ii) performance will be maintained if the increase in task difficulty is within the participants capacity, and this maintained performance will be possible at a cost of a higher effort invested in the task. As our participants were young and healthy, and the weight added on the forearm was chosen following pilot experiments aiming to limit the development of fatigue, we expected that our participants would be able to maintain performance by increasing the effort invested in the task. In line with our hypothesis performance did not differ between the easy and hard difficulty, and the maintained performance was associated with an increased rating of perceived effort reported by the participants. This increase in perception of effort was associated with increased muscle activation, as observed in experiment 1 to compensate for the heavier forearm to move during the box and block test.

Interestingly, not all the physiological variables monitored were responsive to changes in task difficulty in both experiments. In experiment 1, the respiratory frequency did not increase between the difficulties easy – medium in both tasks when the physical demand was manipulated with the tempo, and no main effect of task difficulty was observed on respiratory frequency when the physical demand was manipulated with the addition of weight on the forearm. Regarding heart rate frequency, changes in this variable between each difficulty were consistently observed only when the task difficulty was manipulated with the tempo. Furthermore, the increased perception of effort observed in experiment 2 to maintain performance during the box and block test performed with the standardized instructions did not occur in the presence of increased heart rate frequency. These results extend the previous observation of the lack of changes in heart rate frequency and respiratory frequency when the intensity of perceived effort is used to prescribe the exercise and confirm that neither heart rate nor respiratory frequency can be used as an efficient physiological correlate of perception of effort in the context of upper-limb motor tasks. Additionally, it is important to note that we systematically monitored the perceived workload of each task at each difficulty by using the NASA-TLX scale, a validated tool used to monitor perceived workload in various contexts (Hart, 2006; Hart & Staveland, 1988). While this scale captured most manipulations of the physical demand performed in both experiments, a lack of changes in the physical demand score, temporal demand score or effort score was observed in some experimental conditions. Therefore, our results suggest that monitoring of perception of effort with category ratio scales as we did in this study could be a complementary approach for researchers in

human factors interested in capturing fine changes in perceived workload when task difficulty is manipulated.

Integration with the neurophysiology of perception of effort

While our experiment did not aim to investigate the neurophysiology of perception of effort, the changes (or lack of changes) in the physiological variables monitored during both experiments allow us to reconcile our results with existing theories on the neurophysiology of perception of effort in the context of motor tasks (de Morree & Marcora, 2015; Pageaux, 2016). In brief, while there is an ongoing debate on the sensory signal(s) generating perception of effort (Amann & Light, 2014; Broxterman et al., 2018; Marcora, 2009; Pageaux, 2016; Smirmaul, 2014; Steele & Fisher, 2018), accumulating evidence suggest that when effort perception is investigated as a sensation dissociated from other exercise-related sensations (e.g., pain or discomfort), perception of effort is generated by the neuronal process of the corollary discharge associated with the central motor command and not by afferent feedback from the working muscles and organs (de Morree et al., 2012; de Morree & Marcora, 2015; Marcora, 2009; Pageaux & Gaveau, 2016). Our results are consistent with this corollary discharge model of perception of effort. Indeed, muscle activation measured with EMG is traditionally used as a marker of the central motor command (Carrier et al., 2011; Gaveau et al., 2021; Kozlowski et al., 2021; Thoroughman & Shadmehr, 1999), and among the three physiological variables measured, only muscle activation was able to track the changes in perception of effort across manipulations of task difficulties and prescription of exercise via the intensity of this perception. Furthermore, in line with the corollary discharge model of perception of effort and the traditional use of this perception as a marker of the central motor command (Jacquet et al., 2021; Kjær et al., 1999; Kozlowski et al., 2021; McCloskey et al., 1974; Mitchell et al., 1989; Seed et al., 2019), our results should motivate the monitoring of this perception in various population with impaired motor control such as older adults (Carment et al., 2018), stroke patients (Neva et al., 2019), Parkinson patients (Sacheli et al., 2019) or other populations with neurological disorders. Future studies should replicate our results with such populations and explore how this perception in the context of specific upper-limb motor tasks is impaired in comparison to healthy individuals. Such studies could provide interesting insights into this perception by further validating its use as a marker of the central motor command in various populations, and potentially open new possibilities in rehabilitation and testing of capacities.

910 *Limits, perspectives, and conclusions*

911 While our results provide strong support in favor of the use of perception of effort to prescribe
912 and monitor the exercise in the context of upper-limb motor tasks, we have to acknowledge some
913 limitations to be considered for futures studies. Despite our attempt to control for the induction of
914 fatigue, subjective feelings of fatigue slightly increased in the weight session of experiment 1 (+ 0.9
915 +/- 1.5 on a visual analog scale). However, as the completion of the box and block test and the pointing
916 task, as well as the difficulties, were randomized, we are confident that this slight increase in fatigue
917 did not impact the validity of our results. Nonetheless, future studies using physical demand
918 manipulations and controlling for the presence of fatigue should consider increasing the recovery
919 period between each task completion. In this study, we focused on the box and block test as well as a
920 pointing task, and our results should be extended to other upper-limb tasks routinely used in research
921 and clinical settings with a stronger focus on manual dexterity such as the Purdue pegboard test
922 (Backman et al., 1992; Shahrar et al., 1998) or the Minnesota manual dexterity test (Cederlund, 2009;
923 Lourenção et al., 2005). To conclude, the present study provides strong evidence in favor of the use of
924 the perception of effort to prescribe and monitor the exercise in the context of upper-limb motor tasks.
925 By integrating the results of the two experiments, measurement of muscle activation seems to be the
926 best physiological correlate of perception of effort during upper-limb motor tasks when the physical
927 demand of the task is manipulated. As effort is perceived not only in the physical domain but also in
928 the mental domain (Inzlicht et al., 2018; Pageaux, 2016; Preston, 2009), future studies should test the
929 possibility to extend our results in the context of the manipulation of the mental demand.

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Author contributions

AC, BP, JG, MPG and PR designed the study. AC, CFB and MPG conducted the experiments. AC, BP, JG and MPG contributed to the data analysis. MP and BP created the figures. MPG created the first draft of the manuscript. All authors edited and/or approved the final version.

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Conflict of interest and data availability

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. Individual data are presented within the manuscript figures.

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