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The cognitive load of physical activity in individuals with high and low tolerance to effort: An ecological paradigm to contrast stepping on the spot and stepping through space

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ABSTRACT

Performing a physical activity means dealing with the challenges and difficulties occurring during the task. The more a person possesses the cognitive ability to deal with the complexity of the task, the more that person will be able to face the difficulties in activity regulation. However, no studies have been designed to investigate the cognitive dimension of physical activity. In the present study, we present an original in-task methodology that offers the means to assess the cognitive and physical load of a physical activity. Through the application of a dual task paradigm, we report in-task changes in cognitive abilities and physiological experiences in low and high tolerant individuals during the practice of one of two whole-body stepping tasks. The findings confirmed that stepping through space is a physical activity that requires more cognitive resources and is perceived as more cognitively and physically challenging than stepping on the spot. We demonstrated also that the tolerance to effort, which is a psychological factor, plays a non-negligible role in the way the activity sessions were experienced. The affective states in low tolerant individuals were always more negative than those reported by high tolerant individuals. Our findings argue for the existence of a cognitive dimension to physical activity with tolerance to effort being a moderator of individuals' affective experience to exercise.

1. Introduction

Moving is costly. The action of setting one's body into motion requires decision, control and adjustment (Brick et al., 2015; Brick et al., 2016). Hence, even the simplest stepping action mobilizes cognitive and physical effort, which probably explains why it is easier to sit on a couch than to go out for a walk (Cheval et al., 2018). Nevertheless, regular physical activity is essential to live and prosper in good health (Oja & Borms, 2004). It has been suggested that the pleasure experienced during a physical session could create positive memories that in turn will influence physical engagement on the long term (Ladwig et al., 2018). In the present study, we address the issue of the cognitive cost of physical activity and the importance of considering an individual's tolerance to effort when designing fun physical activity routines for sustained engagement and benefit.

Affective states are an inclusive psychological construct referring to accessible evaluative feelings in which a person feels good or bad, likes or dislikes what he/she is experiencing (Gray & Watson, 2007). Affects are a neurophysiological state, not cognitive or reflective (Russell, 2003) always available to consciousness (Russell & Barrett, 1999). Affects have an adaptive role (Lewis & Cañamero, 2016) as they provide the primary means by which information about critical disruptions of homeostasis enters consciousness (Cabanac, 1979; Panksepp, 1998). During the production of behaviors, affective states offer a better understanding of the physical and physiological changes occurring within the body during task production. This may explain why affects are considered as the key factors that inform people about the (relative) state of danger in which he/she finds him/herself. Negative affective states would indicate a possible danger to the body's integrity whereas experiencing positive ones would indicate body safety (Hartman et al., 2018). If inner feelings were not accessible, humans would have no inclination to move toward or away from anything, jeopardizing the species' survival (Cisek & Kalaska, 2010; Lee et al., 2016). Thus, affective states are thought to play a fundamental role in the approach and avoidance behavior towards physical activity to be performed immediately (Carlier, & Delevoye-Turrell, 2017; Elsangedy et al., 2018; Ouvrard et al., 2018) or in an immediate future (Jekauc, 2015; Kanning et al., 2015; Kwan & Bryan, 2010; Mohiyeddini et al., 2009; Rhodes & Kates, 2015; Wienke &

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Jekauc, 2016; Zenko et al., 2016). But, not everyone is able to experience the same amount of positive affects during physical activity (Van Landuyt et al., 2000).

Performing a physical activity means dealing with the challenges and difficulties occurring during the task. Adaptive behavior requires constant re-adjustments of the required movement, the output intensity ("This is getting hard.") as well as the management of thoughts and doubts that may emerge to consciousness about body safety ("Is this too hard for me … should I stop?"). Hence, the more a person possesses the cognitive ability to deal with the complexity of the task, the more that person will be able to face the difficulties in motor regulation (Audiffren & André, 2015, 2019; Brick et al., 2015; Brick et al., 2016; Edwards et al., 2017; Loprinzi et al., 2020; Pesce & Ben-Soussan, 2016; Schmit & Brisswalter, 2018). The corollary discharge theory offers a theoretical framework to the complex interaction of the perceptual, cognitive, and affective processes occurring during motor performances (Abbiss et al., 2015; Brick et al., 2015; Brick et al., 2016; Schmit & Brisswalter, 2018). Before performing a physical activity, a person is required to plan and anticipate all possible actions according to his/her objectives and the environment in which the action is to be performed. Then, when actually moving, the motor predictions will be compared to what the body is actually producing and experiencing. In the case of a match, motor output corresponds to what is expected, and the motor activity can pursue its outflow without modulation. In addition, as the motor planning and the sensorial feedbacks correspond, the system is reinforced by a positive valence in affective states, which may play the role of a reinforcement signal that is in fact required for sustained motor performance (Carver, 1998; Carver et al., 2015). Within the action tendency theory, the case of match could even code for higher intense positive affective states if the motor production is performed better than predicted, e.g., with the need of less effort than anticipated (Frijda, 1988; Ridderinkhof, 2017). Conversely, the case of motor mismatch codes for a discrepancy that emerges between the sensorimotor predictions and the actual sensorimotor feedback. In such case, a negative affective state can emerge, and the size of the error relates to the perceived degree of danger set upon the system (Carver & Scheier, 2001).

Predicting the sensorimotor outcome of a simple movement (lifting a finger) is easier than computing the sensorimotor predictions of a motor action that requires the coordination of multiple motor elements (shifting the weight and placing arms to maintain body balance when lifting a foot off the grown). In the complex case, the cognitive resources are furthermore important as the prediction error can lead to a fall – the extreme case of a motor mismatch during whole-body movement. Neuroimaging studies have consistently shown an increase in activation in many areas of the cortex, such as sensorimotor cortex, as a function of motor complexity (Rao et al., 1996; Shibasaki et al., 1993; Verstynen et al., 2005). Such increase in brain activity may be related to the augmented need in cognitive resources as a function of motor complexity when performing laboratory-type motor tasks (Gálvez-García et al., 2018; Greenhouse et al., 2015; Wexler et al., 1997). If extrapolated to physical activities, we suggest that some individuals may experience physical activities as more difficult than others because of a cognitive limitation (Delevoye-Turrell et al., 2019). In healthy adults, differences in cognitive abilities may predict differences in the pleasure experienced during body movement, as affective states depend not only on the physical requirements but also of the quantity of cognitive resources needed for motor adjustments (Benzing et al., 2018, 2016; Benzing & Schmidt, 2017; Pesce & Ben-Soussan, 2016; Tomporowski & Pesce, 2019). When a mismatch occurs between the resources people can provide and the demands of the task, the session may be perceived as too difficult leading to early arrest (Macmahon et al., 2019) as the task at hand is experienced as too effortful compared to that anticipated and possibly sustainable (Chatain et al., 2019; Filipas et al., 2019; Pageaux & Lepers, 2018; Penna et al., 2018; Slimani et al., 2018; VAN Cutsem et al., 2017). But to date, no quantitative data has provided the means to demonstrate a direct relation between cognitive cost and the motor complexity of a physical activity.

The dual-task paradigm is a common tool that offers a scientific-based assessment of how people manage the cognitive demands of a task (Kahneman, 1973). In the context of physical activity, the dual-task paradigm has been used mostly to assess how physical activities modulate individuals' cognitive efficiency (e.g., Davranche et al., 2018). Dual-task paradigms have also been used to reveal that conducting a cognitive task in addition to performing a motor task influences motor performance (Burcal et al., 2019; Cruz-Montecinos et al., 2018; Cyril et al., 2019). In gait research, for example, the dual-task paradigm was used to demonstrate that walking is not automatic and that it demands cognitive resources especially in older adults (Woollacott & Shumway-Cook, 2002; Yogev-Seligmann et al., 2008). However, to date no research has applied dual-tasking to physical activities to reveal specifically the quantity of cognitive resources needed for in-task motor performance. Furthermore, little research has questioned the impact of psychological individual differences (Drollette et al., 2014; Forte et al., 2019; Godde & Voelcker-Rehage, 2017) such as tolerance to effort as predictors of differences in the way one experiences the cognitive load of physical activity.

Tolerance to effort influences one's ability to continue exercising at an imposed intensity even if the activity becomes uncomfortable or unpleasant (Ekkekakis et al., 2005). It has been reported that the tolerance level of an individual is related to one's perception of the physical effort of exercising (Hall et al., 2014), to one's self-regulation strategies applied while cycling (Carlier, & Delevoye-Turrell, 2017) and/or to the affective responses experienced while moving (Hutchinson et al., 2020). Thus, dual tasking should reveal that the more cognitive resources allocated to perform a physical activity the more low tolerance individuals should experience the activity session as unpleasant.

The objective in the present study was to report qualitative and quantitative data confirming that both the complexity of a physical activity and the tolerance to effort of a participant will impact in-task affective experiences. Furthermore, regression analyses will be used to assess whether the key cognitive, affective and/or physical factors contribute significantly to the desire of a person to re-engage in a similar physical activity session. To do so, we designed two naturalistic activities that provided in-task measurements while being similar in nature to exercises commonly used in rehabilitation sessions: stepping on the spot (standing lifting-knee repetitions) and stepping through space (front-back and left-right dancing steps). Through the use of a procedure developed in a previous work (Carlier & Delevoye-Turrell, 2017), we report in-task changes in cognitive abilities and physiological experiences in both low and high tolerance individuals. We hypothesized that moving through space (referred in the following as the space-stepping task) is a motor action that is more cognitively challenging than stepping on the spot (H1). This later task will be referred to as spot-stepping. Because of a lower threshold to effort, low tolerance individuals will run out more rapidly of cognitive resources than high tolerance individuals and thus, scores in the dual-task paradigm will be weaker in low than in high tolerance individuals (H2). Because more effort is required, the low tolerance individuals will experience the space-stepping sessions as less pleasurable than the high tolerance individuals (H3). As stepping on the spot requires little cognitive resources, the differences between low and high tolerance groups will be smaller in the spot-stepping than in the space-stepping task, both when considering the levels of pleasure and the dual-tasking scores (H4).

2. Method

2.1. Participants

A total of 40 subjects volunteered to take part in the study, 10 men and 30 women ($M_{age} = 22.13 \pm 3.77$ years, $M_{BMI} = 24.73 \pm 9.20$ kg.m-2). All participants obtained a medical certificate from their medical physicians before being included in the study. At arrival, they read an information letter and completed a written consent form. The study was approved by the Ethics Committee for studies in Human Behavior of the University of Lille. Participants were asked not to do any physical training 48 h before their inclusion. Results reported here are part of a larger study that has been published as a thesis publication (https://www.theses.fr/2017LIL30039).

Participants were allocated to two different physical activity groups as a function of their tolerance to effort, which was determined with the tolerance items of the PRETIE-Q questionnaire. The eight-item tolerance scale (see S1) contains four items that target high physical activity tolerance (e.g., ''I always push through muscle soreness and fatigue when working out'') and four that target low physical activity tolerance (e.g., ''During exercise, if my muscles begin to burn excessively or if I find myself breathing very hard, it is time for me to ease off''). Each item is composed of a 5-point response scale (1 = ''I totally disagree''; 2 = ''I disagree''; 3 = ''Neither agree or disagree''; 4 = ''I agree''; 5 = ''I strongly agree''). A high score of tolerance to physical activity corresponds to a high capacity to pursue the physical activity although it becomes uncomfortable or unpleasant (Ekkekakis et al., 2005). To obtain two contrasting groups, a median tolerance score was calculated across all groups. Participants with scores lower than the median (18) were considered as Low Tolerant; individuals with scores greater than the median were classified as High Tolerant. Within each tolerance group, participants were assigned randomly to either one of the two physical activity types – spot-stepping or space-stepping – with a similar repartition of 10/10 and 9/11 for Low and High Tolerant individuals, respectively.

2.2. Materials and procedure

After reading and completing the consent form, a heart rate monitor (Polar Team 2 - Polar Electro Oy, Kempele, Finlande) was fitted to the participant's chest to monitor heart rate. Each participant was then asked to complete a series of questionnaires to obtain socio-demographic data. A testing diagram is presented in Figure 1 to illustrate the experimental design.

2.3. Assessment of self-reported fitness level

The IPAQ (International Physical Activity Questionnaire) was used to assess the amount of daily physical activity practiced by a participant (Craig et al., 2003; Sember et al., 2020). The quantity of physical activity practiced by each participant was calculated by considering the intensity of the self-reported physical activity sessions (expressed in METs – Metabolic Equivalent of Task – for 3 different categories: low vs. moderate vs. vigorous) as a function of duration (time in minutes) and of the number of days declared of physical activity per week (METs-minute/-week). The main feature of this questionnaire was to consider the overall self-reported physical activity level (i.e., including daily exercises) and not only the physical activity practiced during leisure sports. Four different measures were obtained: (1) the Total Physical Activity score, which contains the total amount of physical activity practiced (e.g., METs-minute/week$_{\text{_Low}}$, METs-minute/week$_{\text{_Moderate}}$ and METs-minute/week$_{\text{_Vigorous}}$), (2) the Total Low Physical Activity score, (3) the Total Moderate Physical Activity score and (4) the Total Vigorous Physical Activity score.

2.4. Assessing the load of performing a physical activity

The cognitive and physical load of performing a physical activity was assessed through a series of objective and subjective measures. During the session, objective measures were collected to avoid intervening during the activity. First, physiological responses were collected as a marker of physical load. The heart rate monitor that was fitted to each participant's chest gave the opportunity to record heart rate both at baseline and throughout the session. Data were sampled at 100 Hz.

Dual-task responses were collected as a marker of cognitive load. While moving, the participant performed the 7-backward counting exercise as the secondary cognitive task. As all participants had French as their mother tongue, the cognitive task was done in French. A baseline measure was obtained before starting the physical activity. Then, during 1-min intervals, the participant was required to count backwards 7 by 7 at a rate of one response every 3 s, starting from a number pre-selected by the experimenter (i.e., the starting numbers were the same for all individuals). A total of eight measures were obtained during the physical activity session after 1′, 5′, 9′, 13′, 17′, 21′, 25' and 29 min of activity. During the warm-up and the recovery periods, the participant was asked to perform the physical activity without performing the dual-task. The percentage of correct counts per minute was the dependent variable (CC in %).

After the completion of the physical activity session, the participant was invited to respond to the NASA_tlx questionnaire to gain insight on the subjective perception of the physical and cognitive loads of moving. The French version of the NASA Task Load Index was used (NASA_tlx; Cegarra & Morgado, 2009) to help each participant report "how physically demanding was the task" and "how mentally demanding was the task". Answers were given on a scale ranging from 1 "very low" to 20 "very high".

2.5. Assessing affective states throughout physical activity

The Feeling Scale (Hardy & Rejeski, 1989) was used to assess the changes in the valence of the affective states (pleasure/displeasure). This scale consists of a 11-point, single-item, bipolar scale, used to assess the valence component of affective responses during physical activity. The scales range from −5 to +5. Anchors are provided at zero, and at all odd integers (+5 = very good; +3 = good; +1 = fairly good; 0 = neutral; −1 = fairly bad; −3 = bad; −5 = very bad). The FS was administered before warm up, after warm-up, between each 5-min interval during the physical activity phase, and after recovery. Nine periods were identified: one before warm-up (0′), one after warm-up (5′), six during the test (10′, 15′, 20′, 25′, 30′, 35′), one just after the recovery phase (40′) and two after stopping the task (45′, 50'). For all participants, debriefing was

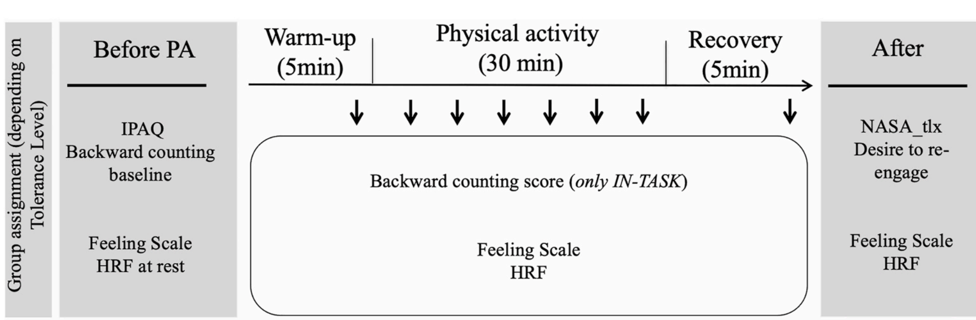

Fig. 1. Testing diagram to detail the experimental design that was used. The different measures taken before, during and after are specified.

systematically conducted after the session to explain the aims and the construct of the study.

2.6. Assessing the desire to re-engage the physical activity

The desire of the participant to re-engage in a physical activity was quantified through the use of a 9-point bipolar scale. This scale was created to capture a feel of how much each participant wanted to re-engage in the same type of physical activity 10 min after finishing it. The scale ranged from −4 to +4. Anchors were provided at zero and at all even integers (−4 = not at all; −2 = not really; 0 = neutral; +2 = a lot; +4 = to a large degree).

2.7. Physical activity type

The physical activities were performed in a calm and large room with indirect sun light to optimize the pleasurable experience of the session (Shaulov & Lufi, 2009). Nevertheless, the shades were closed to avoid external distractions and to offer good viewing of the images that were projected on a white screen (image dimension: 195 cm × 280 cm). When ready to start, the participant was asked to stand 250 cm in front of the screen. In the spot-stepping activity, a picture of a path leading through a forest was projected on the screen. This image was static and remained throughout the entire session. In the space-stepping, the Domyos Interactive System by Decathlon S.A. was used. The participant was to step left, right, forwards or back in synchrony with the sequence of flashed dots projected on the white screen. The pacing of the sequence was moderate (1 step per second) in order to allow all participants to succeed in the task. The stepping sequence were identical for a given session. Hence, individuals could predict the steps that were to come.

The session was organized in three distinct periods following the ACSM recommendations (American College of Sports Medicine et al., 2010): warm-up (5 min), in-task (30 min), and recovery (5 min). During warm-up, each participant was asked to step at low intensity, i.e., at a tempo that would allow them simply to warm-up and to become familiar with the material. During the physical activity period, the participant was required to perform the task in order to experiment the session as "somewhat difficult" on the Borg RPE scale (RPE 13 on the 6–20 Borg Scale; Borg, 1998). As different definitions can be considered when asking individuals to select the score of perceived effort (Abbiss et al., 2015), the effort was defined in the present study as “the amount of mental or physical energy being given to [the] task”. The heart rate frequency (HRF) was measured every minute. Results are here reported at a frequency of one measure every 5 min to correspond to the sampling frequency of the questionnaires.

2.8. Statistical analyses

A series of t-Student analyses were conducted on the demographic data to reveal possible differences between groups for the Physical Activity Types (*spot-stepping* vs. *space-stepping*) and Tolerance Levels (*low* vs. *high*). Cohen’s d (d) was calculated to report the effect sizes. Khi^2 analyses were used to test for possible sex frequency differences.

In a first series of analyses, mixed Model ANCOVAs were run to determine effects of Activity Type {2}, Tolerance Level {2} and Assessment Time {10} on the Feeling Scale (FS) and on the Heart Rate Frequency (HRF) while controlling for sex. For the percentage of Correct Counts (CC), the between-group baseline values were different. Hence, the mixed Model ANCOVAs were run to determine effects of Activity Type {2}, Tolerance Level {2} and Assessment Time {10} on CC, including baseline values and sex within the statistical model as covariates. Throughout these analyses, partial eta squares (η^2_p) were calculated to report effect sizes. Bonferroni-adjusted pairwise comparisons were used when required in the post-hoc analyses. The alpha level was set at 0.05. These analyses were conducted to test H1, H2, H3 and H4.

In a second series of analyses, regression analyses were conducted to explain the graded desire to re-engage in a physical activity as a function of the collected dependent measures. Before conducting the regression analysis, correlational analyses were run between factors using Pearson’s correlation coefficients to guide the selection of the best fit regression factors. The procedure of minimizing at best factor-overlap was applied. Then, the regression analysis was conducted from a descendant perspective by removing those factors playing a non-significant role, i.e., not increasing the predictive value of the regression model.

3. Results

3.1. Group demographics

The Activity Type did not differ in age [$F(1,38) = 0.08, p = .773, d = -0.092$], in sex frequency ($X^2 = 0.00, p = 1.00$), in body mass index [$F(1,38) = 0.78, p = .380, d = -0.279$], in the number of low and high tolerant individuals ($X^2 = 0.10, p = .752$), in the overall tolerance scores [$F(1,38) = 0.99, p = .658, d = 0.150$], and in educational level ($X^2 = 3.38, p = .497$). No differences were revealed in the scores for total physical activity [$F(1,38) = 0.01, p = .937, d = 0.025$], total low [$F(1,38) = 0.68, p = .416, d =$ - 0.260], total moderate [$F(1,38) = 0.31, p = .582, d = 0.178$] and total vigorous physical activity [$F(1,38) = 0.30, p = .589, d = 0.173$]. Detailed results are presented in Table S2.

The participants in the two Tolerance groups did not differ in age [$F(1,38) = 1.08, p = .305, d =$ - 0.329], in body mass index [$F(1,38) = 2.10, p = .156, d =$ - 0.459], in educational level ($X^2 = 2.26, p = .689$), in total physical activity [$F(1,38) = 1.66, p = .206, d =$ - 0.408], in total low [$F(1,38) = 0.75, p = .391, d =$ - 0.275], in total moderate [$F(1,38) = 0.11, p = .917, d = 0.033$] and in total vigorous physical activity [$F(1,38) = 2.82, p = .101, d =$ - 0.532]. An effect of Tolerance was observed on sex frequency ($X^2 = 4.04, p = .044$) with women having lower tolerance levels ($M_{women} = 18.0, SD = 5.0$) compared to men ($M_{men} = 21.6, SD = 4.7$). Detailed results are presented in Table S3.

3.2. The perceived load of stepping

In this section, we report the results obtained with the NASA questionnaire.

Perceived physical load. A main effect of Activity Type was revealed [$F(1,35) = 6.30, p = .017, \eta^2 = 0.15$ – Fig 2-*left*]. The space-stepping activity was perceived as more physically demanding ($M_{Space\text{-}Stepping} = 11.4, SD = 4.2$) than spot-stepping ($M_{Spot\text{-}Stepping} = 8.0, SD = 4.5$). No main effect of Tolerance Level was observed [F(1,35) = 0.97, $p = .331, \eta^2 = 0.03$]. The interaction Activity Type*Tolerance Level did not reach significance [$F(1,35) = 1.59, p = .215, \eta^2 = 0.04$].

Perceived cognitive load. A main effect of Activity Type was revealed [$F(1,35) = 9.35, p = .004, \eta^2 = 0.21$ – Fig 2-*right*]. The space-stepping activity was perceived as more cognitively demanding ($M_{Space\text{-}Stepping} = 15.9, SD = 2.5$) than spot-stepping ($M_{Spot\text{-}Stepping} = 12.5, SD = 4.3$). The main effect of Tolerance Level was not significant [$F(1,35) = 0.97, p = .331, \eta^2 = 0.03$]. The interaction Activity Type*-Tolerance Level did not reach significance [$F(1,35) = 1.59, p = .215, \eta^2 = 0.01$].

3.3. The physical load of stepping

In this section, we report the results obtained with mean heart rate frequencies (HRF).

Baseline measures. Neither the main effect of Activity Type [$F(1,29) = 1.20, p = .660, \eta^2 = 0.01$] nor the main effect of Tolerance Level were revealed [$F(1,29) = 0.01, p = .939, \eta^2 = 0.01$]. The interaction Activity Type*Tolerance Level did not reach significance [$F(1,29) = 0.80, p = .379, \eta^2 = 0.03$]. Thus, before starting the experimental session, the HRF in low and high tolerant individuals were similar across physical activity types.

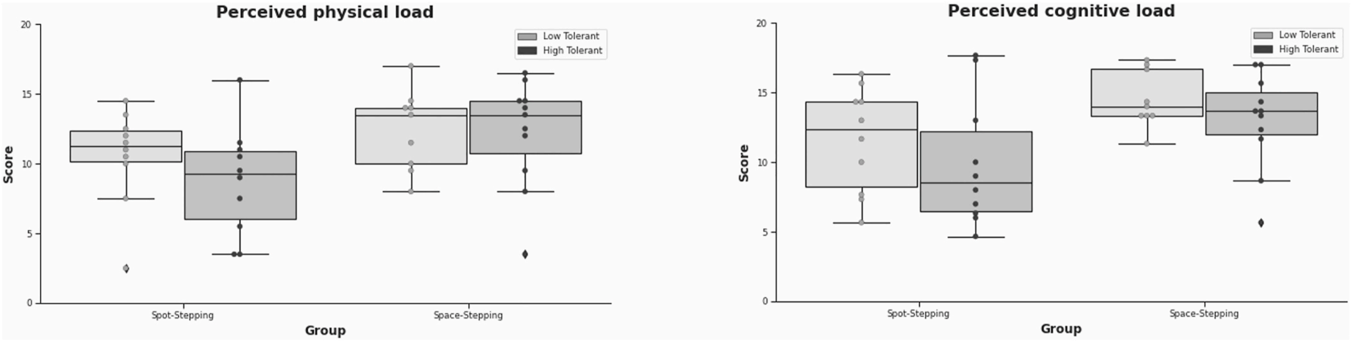

Fig. 2. Scores obtained for the perceived physical load (*left*) and perceived cognitive load (*right*) as a function of the Physical Activity Type: Spot-Stepping and Space-Stepping in Low Tolerant individuals (*grey*) and High Tolerant individuals (*black*). Error bars illustrate the confidence intervals 95% around the median (*p < .05).

Warm-up measures. Neither the main effect of Activity Type nor the main effect of Tolerance Level were revealed. The interaction Activity Type*Tolerance Level was not significant (Table 1). Thus, after the warm-up period, the HRF was similar in both low and high tolerant groups across physical activity types.

Practice measures. Neither the main effect of Activity Type nor the main effect of Tolerance Level were observed (Table 1). The interaction Activity Type*Tolerance Level did not reach significance (Table 1). The main effect of Assessment Time was significant. The interaction Assessment Time*Activity Type was also significant [$F(5,140) = 2.51$, $p = .033$, $\eta^2 = 0.09$], revealing a difference in response dynamics. More specifically, in the spot-stepping activity, mean HRF increased linearly right from the start of the session whereas in the space-stepping activity, mean HRF increased and stabilized as a plateau 10 min into the session (Fig 3-*left*). The interaction Assessment Time*Tolerance Level also reached significance (Table 1). Detailed results are presented in Fig 3-*left*. Overall, the high tolerant group maintained lower HRF in the space-stepping task than the low tolerant group. In the spot-stepping, both tolerant groups finished the activity with similar levels of HRF.

Recovery measures. A main effect of Activity Type was observed [$F(1,29) = 0.23$, $p = .633$, $\eta^2 = 0.01$). More specifically, the overall mean HRF was smaller in the space-stepping recovery ($M_{Space\text{-}Stepping} = 119.9$, $SD = 27.5$) than in the spot-stepping recovery activity ($M_{Spot\text{-}Stepping} = 141.9$, $SD = 23.4$; $p = .041$). No other main effects or interactions were significant.

Table 1
Reports the statistical results for the main effects and the interactions on Feeling Scale, Heart Rate Frequency and Correct Backward counts as a function of Physical Activity Type, Tolerance Level and Assessment time.

	Warm up Period				Physical activity at RPE 13				Recovery Period			
	F	*df*	*p*	η^2_p	*F*	*df*	*p*	η^2_p	*F*	*df*	*p*	η^2_p
Main effects												
Feeling Scale												
Activity Type effect	1.314	1,35	0.259	0.04	0.018	1,35	0.895	0.00	0.880	1,35	0.355	0.03
Tolerance effect	0.693	1,35	0.411	0.02	5.199	1,35	**0.029**	0.13	4.041	1,35	**0.052**	0.11
Assessment Time	–	–	–	–	0.650	5175	0.692	0.02		–	–	–
Heart Rate Frequency												
Activity Type effect	0.232	1,29	0.633	0.01	3.407	1,28	0.077	0.11	8.289	1,28	**0.008**	0.23
Tolerance effect	0.450	1,29	0.983	0.00	3.213	1,28	0.084	0.10	0.251	1,28	0.620	0.00
Assessment Time	–	–	–	–	6.383	5140	**< 0.001**	0.19	–	–	–	–
Backward counts												
Activity Type effect	–	–	–	–	5.600	1,34	**0.024**	0.14	–	–	–	–
Tolerance effect	–	–	–	–	9800	1,34	**0.005**	0.21	–	–	–	–
Assessment Time	–	–	–	–	0.582	7238	0.770	0.02	–	–	–	–
Interactions effects												
Feeling Scale												
Activity Type *Tolerance	0.844	1,35	0.364	0.02	0.034	1,35	0.895	0.00	0.757	1,35	0.390	0.02
Assessment Time*Activity Type	–	–	–	–	0.843	5175	0.487	0.03	–	–	–	–
Assessment Time*Tolerance	–	–	–	–	1.899	5175	0.097	0.51	–	–	–	–
Assessment Time*Activity Type*Tolerance	–	–	–	–	2.709	5175	**0.022**	0.08	–	–	–	–
Heart Rate Frequency												
Activity Type*Tolerance	1.498	1,29	0.231	0.05	0.069	1,28	0.795	0.00	0.072	1,28	0.790	0.00
Assessment Time*Activity Type	–	–	–	–	2.510	5140	**0.033**	0.09				
Assessment Time*Tolerance	–	–	–	–	2.328	5140	**0.046**	0.08	–	–	–	–
Assessment Time*Activity Type *Tolerance	–	–	–	–	1.542	5140	0.181	0.05	–	–	–	–
Backward counts												
Activity Type*Tolerance	–	–	–	–	12.890	1,34	**0.001**	0.28	–	–	–	–
Assessment Time*Activity Type	–	–	–	–	1.294	7238	0.254	0.04	–	–	–	–
Assessment Time*Tolerance	–	–	–	–	2.015	7238	**0.054**	0.06	–	–	–	–
Assessment Time*Activity Type *Tolerance	–	–	–	–	0.973	7238	0.451	0.03	–	–	–	–

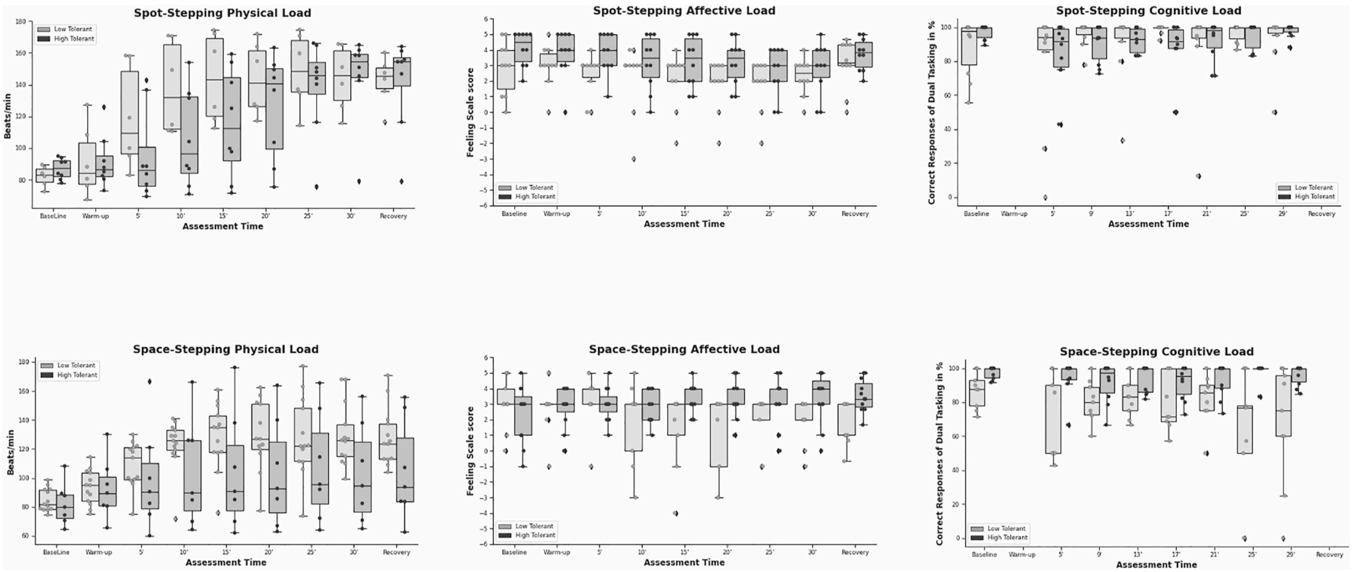

Fig. 3. Variations in Heart Rate Frequency, Affective States and Correct Backward counts as a function of the Physical Activity Type: Spot-Stepping (*top*) and Space-Stepping (*bottom)* in Low Tolerant individuals (*grey*) and High Tolerant individuals (*black*). Error bars illustrate the confidence intervals 95% around the median (**$p < .01$).

3.4. *The cognitive load of stepping*

In this section, we report the results obtained for the performance in backwards counting.

Baseline performances. No main effects of Activity Type [$F(1,36) = 0.69$, $p = .506$] were revealed. The main effect of Tolerance Level was observed [$F(1,36) = 4.66$, $p = .037$, $\eta^2 = 0.11$]. High tolerant individuals were able to count backwards more efficiently ($M_{High} = 96.3$, $SD = 6.1$) than low tolerant individuals ($M_{Low} = 89.1$, $SD = 13.7$). The interaction Activity Type*Tolerance Level was not significant [$F(1,36) = 0.22$, $p = .640$]. Hence, before performing the experimental session, low and high tolerant individuals possessed different abilities in backwards counting and thus, baseline values were used as covariates in the remaining statistical analyses.

Practice measures. The main effect of Activity Type on backwards counting was observed [$F(1,34) = 5.60$, $p = .024$, $\eta^2 = 0.14$] with individuals who performed the spot-stepping activity having higher scores ($M_{Spot\text{-}Stepping} = 91.4$, $SD = 7.8$) than individuals who performed the space-stepping activity ($M_{Space\text{-}Stepping} = 85.3$, $SD = 13.7$). The main effect of Tolerance was observed (Table 1) with low tolerant individuals obtaining lower scores in the backwards counting task than the high tolerant individuals. The interaction Activity Type*Tolerance Level was significant [$F(1,34) = 12.89$, $p = .001$, $\eta^2 = 0.28$]. More specifically, while in the spot-stepping activity the counting performances were similar in the low and high tolerant groups ($M_{Low} = 91.34$, $SD = 9.2$; $M_{High} = 91.4$, $SD = 6.5$), the groups obtained different performances in the space-stepping activity ($M_{Low} = 75.7$, $SD = 13.7$; $M_{High} = 92.3$, $SD = 8.8$). Neither the main effect of Assessment Time [$F(7,238) = 0.58$, $p = .077$, $\eta^2 = 0.02$] nor the interaction Assessment Time*Activity Type were significant (Table 1). However, the interaction Assessment Time*Tolerance Level was close to significancy [$F(7,238) = 2.01$, $p = .054$, $\eta^2 = 0.06$), indicating that the low tolerant groups had better scores at the beginning than at the end of the session, whereas this was not the case in the high tolerant groups (Fig 3-*right*).

3.5. *The affective load of stepping*

In this section, we report the results obtained in the Feeling Scale questionnaire.

Resting state. Neither the main effect of Activity Type [$F(1,36) = 2.54$, $p = .120$) nor the main effect of Tolerance Level were significant [$F(1,36) = 0.31$, $p = .586$]. The interaction Activity Type*Tolerance Level did not reach significance [$F(1,36) = 3.20$, $p = .082$]. Thus, before starting the physical activity the affective states were similar across activity types in both low and high tolerant individuals.

Warm-up measures. Neither the main effect of the Activity Type nor the main effect of Tolerance Level were observed. The interaction Activity Type*Tolerance Level did not reach significance (Table 1). Thus, after warming-up the affective states were similar across activity types in both low and high tolerant individuals.

Practice measures. No main effect of Activity Type was observed. The main effect of Tolerance Level was revealed [$F(1,35) = 5.20$, $p = .029$, $\eta^2 = 0.13$] with low tolerant individuals having lower scores on the Feeling Scale ($M_{Low} = 1.7$, $SD = 1.5$) than high tolerant individuals ($M_{High} = 3.1$, $SD = 1.2$). The interaction Activity Type*Tolerance Level was not significant (Table 1). Neither the main Assessment Time nor the interaction Assessment Time*Activity Type were significant. Additionally, the interaction Assessment Time*Tolerance Level did not reach significance (Table 1). However, the triple interaction Assessment Time*Activity Type*Tolerance Level was significant [$F(5,175) = 2.71$, $p = .022$, $\eta^2 = 0.08$ – Fig 3-middle), indicating that the low tolerant groups reported more negative affective states at the end than at the start of the session than the high tolerant groups; this phenomenon was stronger in the space-stepping than in the spot-stepping activity.

Recovery measures. No main effect of Activity Type was revealed (Table 1). The main effect of Tolerance Level was significant [$F(1,35) = 4.04$, $p = .052$, $\eta^2 = 0.11$], with more negative affective states in the low tolerant groups than in the high tolerant groups. The interaction Activity Type*Tolerance Level did not reach significance (Table 1).

After stopping the task. When considering the Feeling Scale scores after the recovery period (5 and 10 min within), a strong effect of Tolerance Level was observed [$F(1,35) = 12.16$, $p < .001$, $\eta^2 = 0.26$]. The Feeling Scale average score was higher in the high tolerant groups ($M_{High} = 3.5$, $SD = 1.2$) than in the low tolerant groups ($M_{Low} = 2.3$, $SD = 1.6$). A significant main effect of Activity Type was also revealed [$F(1,35) = 5.93$, $p = .020$, $\eta^2 = 0.15$], indicating that affectively recovering from the space-stepping activity was more complicated than recovering after the spot-stepping activity (Fig 4).

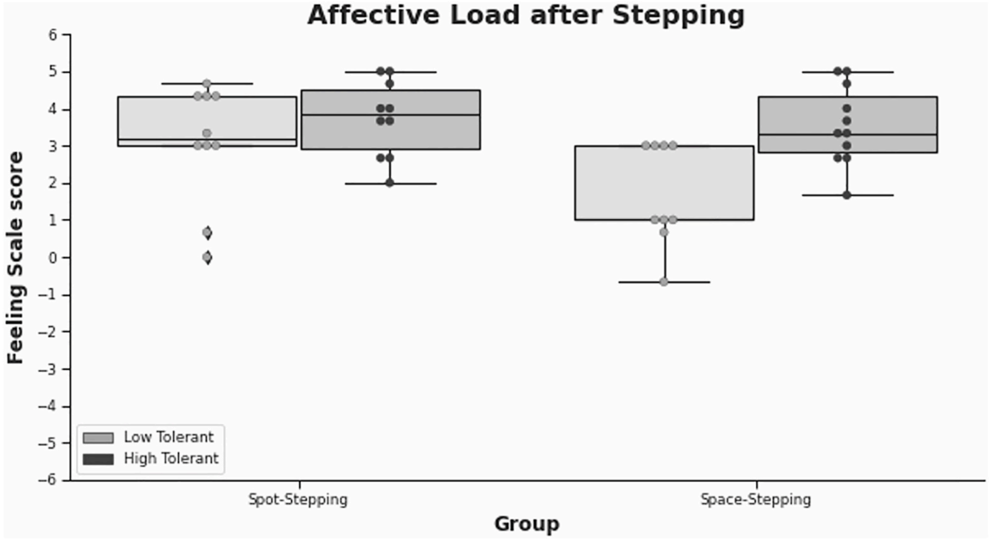

Fig. 4. Mean Affective States measured after the recovery period as a function of the Physical Activity Type: Spot-Stepping (*left*) and Space-Stepping (*right)* in Low Tolerant individuals (*grey*) and High Tolerant individuals (*black*). Error bars illustrate the confidence intervals 95% around the mdeian (*p < .05).

3.6. Predicting the desire to re-engage in a physical activity

Desire to re-engage in the physical activity: The correlational analysis was conducted between factors and results are presented in Table 2. The findings of the regression analysis argue in favor of a significant role of the affective states during practice (referred to as Pleasure in the final equation presented here after; $t = 2.40$, $p = .025$, $B = 0.328$), the Heart Rate Frequency during recovery (referred to as Physiological recovery; $t = 3.34$, $p = .003$, $B = 0.405$), participants Tolerance level (referred to as Cognitive ability level; $t = 2.33$, $p = .029$, $B = 0.355$) and the participants' perception of the physical load during practice (referred to as Perceived difficulty; $t = 2.67$, $p = .014$, $B = 0.401$ – adjusted $r2 = 0.458$, $F(5,22) = 6.70$, $p < .001$). These results can be modelled using the following equation:

desire to re-engage in a physical activity = 0.328*Pleasure +0.458*Perceived-Difficulty + 0.405*Physiological-Recovery + 0.355 *Cognitive-Ability.

4. Discussion

Humans are emotional. When they decide to do something, their decision is not based only on their senses but also on what they are actually feeling (Gendolla, 2017). If their action is experienced as pleasurable, they engage. Otherwise, they quit (Mees & Schmitt, 2008). Experiencing positive affects during a physical activity session is thus essential to transform an essay into a long-term commitment. In the present study, we developed a method using two classic fitness physical activities – related to spot-stepping and space-stepping activity type – to confirm that physical activity requires cognitive resources and to suggest that the reported scientific-based findings are generalizable to natural exercising situations.

The results reported here confirmed that space-stepping is a motor task that is perceived as more cognitively and physically challenging than spot-stepping, confirming H1. Furthermore, the scores in the dual-task paradigm were weaker in the low than the high tolerant individuals,

Table 2
Reports the statistical results for the correlation analysis conducted between Physical Activity Type, Tolerance Level, Total Physical Activity, NASA-tlx sub-scales (Mental demand, Physical demand), Desire to re-perform the physical activity, FS during practice, FS during recovery, HRF during practice, HRF during recovery and the Correct Backward count performances (*p < .05).

	Physical Activity Type	Tolerance Level	Total Physical Activity	Mental demand	Physical demand	Desire to re-perform	FS during practice	FS during recovery	FS after recovery	HRF during practice	HRF during recovery
Tolerance Level	−0.08	–	–	–	–	–	–	–	–	–	–
Total Physical Activity	−0.01	0.36	–	–	–	–	–	–	–	–	–
Mental demand	0.45**	−0.18	−0.03	–	–	–	–	–	–	–	–
Physical demand	0.37*	−0.35*	−0.27	0.23	–	–	–	–	–	–	–
Desire to re-perform	−0.11	0.36*	−0.12	−0.16	0.42*	–	–	–	–	–	–
FS during practice	0.00	0.58***	0.13	0.03	0.21	0.41**	–	–	–	–	–
FS after recovery	−0.24	0.70***	0.15	−0.06	0.25	0.21	0.64***	–	–	–	–
FS after recovery	−0.29	0.74***	0.12	−0.09	0.22	0.25	0.58***	0.97***	–	–	–
HRF during practice	−0.32	−0.05	−0.43*	−0.19	−0.00	0.22	−0.01	0.22	0.18	–	–
HRF during recovery	−0.42*	−0.06	−0.39*	−0.49*	−0.00	0.43*	−0.08	0.13	0.11	0.72***	–
Counting performances	−0.27	0.28	0.20	−0.33	0.08	−0.11	0.06	0.11	0.20	−0.07	−0.04

confirming H2. However, the affective states in low tolerant were always more negative than that observed in high tolerant individuals. Thus, both activity types were experienced as less pleasurable in the low than in the high tolerant individuals, confirming only partially H3 and H4. More specifically, the decline in affective states experienced by the low tolerant individuals was not only due to the fact that space-stepping was more cognitively demanding; the negative affective states experienced by the low tolerant individuals was also due to the overall perception that moving is difficult. Hence, the findings of this study argue for the existence of a cognitive dimension to physical activity. For all individuals, certain physical activities (space-stepping, acting as a proxy for dancing) require more cognitive resources than others (spot-stepping, acting as a proxy for knee-lifts). Nevertheless, the affective states experienced by an individual is a combination of both the type of physical activity and that person's perception of the effort to invest. Future research needs to model the in-task changes in affective states as the evolution of the inner sensorial states may be what predicts both the difficulty of a fitness session and the probability of participants engaging in regular practice.

The performance of a "somewhat difficult" physical activity requires both cognitive and physical energy to be performed. The way one self-regulates the distribution of energy expenditure throughout a physical activity is extremely important as it pre-determines the ability to maintain the intensity of a physical activity across a given period of time (Abbiss et al., 2015). Executive functions are as the most elaborated cognitive processes for adjusting, regulating and adapting human behavior (André et al., 2019a; Audiffren & André, 2019; Koziol et al., 2011; Schmit & Brisswalter, 2018). These cognitive functions enable the integration of information emerging from different cortical or subcortical regions (Cisek & Kalaska, 2010; Koziol et al., 2011) in order to maintain a coordinated and adapted goal-oriented behavior to a given situation (Blair & Ursache, 2011; Otero & Barker, 2014). In our study, the cognitive load of physical activity was assessed with a dual task paradigm requiring updating abilities (Miyake et al., 2000) Indeed, participants were invited to perform a 7-backward counting exercise without visual or auditory aids, at a imposed pace of an answer every second. They could only rely on working memory capacities. Indeed, the updating ability is an executive function, which refers to the monitoring and the coding of incoming information for relevance to the task by replacing old, no longer relevant information with newer, more relevant information (Miyake et al., 2000). The results reported in the present study indicate that the participants who stepped on the spot had more resources to perform the dual task than the participant who stepped through space. In fact, the participants who spot-stepped were able to reach 91% of their updating best performances while moving; those who space-stepped rarely reached 85% of their updating best performances.

The in-task use of a physiologically measure (heart rate frequency – HRF) offered the means to confirm these findings. Indeed, while baseline HRF were similar across condition and participants, the HRF during activity differed significantly between the two stepping exercises. In the spot-stepping task, mean HRF increased slowly but consistently from the start to the end of the session. In the space-stepping task, mean HRF increased significantly right from the start but then, stabilized as a plateau, 10 min into the physical activity session. In the literature, HRF has been reported as the tell-tale of both the physical and the cognitive load of a task with greater heart rate being associated to higher perceived fatigue (Ekblom & Goldbarg, 1971; Eston & Williams, 1988; Robertson et al., 1986). Hence, we may here sustain the hypothesis that the mechanism of effort during physical activity differs as a function of the complexity of the task performed. In addition, as argued by André and collaborators (2019), the way one sustains that effort is associated with both physical and mental exertion. Hence, while the performance in each physical activity type (i.e., spot-stepping and space-stepping) may relate to the ratio between cognitive and physical loads, more studies are now needed to confirm the possibility that similar control cognitive mechanism code for perceived effort in intense and non-intense physical activities. Furthermore, in present study, we used an updating task during dual tasking. Hence, to determine the exact nature of the cognitive resources required for physical activity (Audiffren & André, 2019; Schmit & Brisswalter, 2018), more studies must be conducted to pinpoint the relative role of updating, switching, inhibition or even sustained attention for optimized motor performance and affective experiences.

Tolerance to effort and its related Comfort Zone. In sport psychology, the dual mode theory suggests that the way one experiences a physical activity emanates from (1) the physiological changes occurring during the motor task, (2) the psychological characteristics of an individual and (3) the interplay between the two (Ekkekakis, 2003). In our study, we used tolerance to effort to distinguish individuals by their ability to continue exercising at an imposed level of intensity even if the activity becomes uncomfortable or unpleasant (Ekkekakis et al., 2005). The results obtained revealed that low tolerant individuals experience less positively both spot-stepping and space-stepping activities. In spot-stepping, there were no differences in cognitive abilities during dual tasking. Hence, the affective differences emerged from differences in the way low and high tolerant individuals self-regulated physical effort. In space-stepping, affective differences emerged from differences in the way individuals self-regulated both physical and cognitive effort. Hence, when asking people to perform a "somewhat difficult" physical activity, the mental image or representation that one makes of task difficulty may be divergent between low and high tolerant individuals, even if the task itself is identical. A similar phenomenon has been proposed when working with stroke patients (Lacroix et al., 2014). To compensate and keep their body and mind safe while performing a "somewhat difficult" physical activity, low tolerant individuals may decide to perform a physiologically less intense physical activity than high tolerant individuals (Fig. 5). Conversely, because they can manage higher intense physiological discomfort, in addition to the physical and cognitive challenges occurring during the session, high tolerant individuals may decide to perform a physiologically more intense physical activity. This theoretical hypothesis now needs to be confirmed and tested experimentally. Such knowledge would be powerful in explaining why, for a same physical activity session, some people are able to positively experience the session while others are not (Ekkekakis et al., 2005).

In a final step, we proposed a complementary analysis to investigate potential mediators for long-term engagement. Our findings suggest that perceived difficulty and one's tolerance to effort are the major two factors influencing the desire to re-engage in a physical session. This result is coherent with the findings reported by Ladwig and collaborators (2018) that indicated that the pleasure experienced during a physical session is what creates positive memories and is what will influence physical engagement on the long term. If I experience the session as too difficult (or too easy) for my representation of an activity, then I will encode that experience as less positive than a session that gave me a sweat without hurting. And it is that memory trace of my affective trajectory that will trigger my desire to reengage (or not). Our results indicate nevertheless that the affective memory trace will also be modulated by my fitness level. Indeed, physical health influences directly physiological recovery after an activity. Hence, cognitive and physical fatigue will add a negative layer to my experience, and negatively impact my desire to re-engage. Ultimately, to create a pleasurable session adapted to all and geared to encourage physical engagement, one must consider not only the intensity and nature of the activity but also the pleasurable aspect of exercising as it counts for one third of the equation for projected motivation. Future projects should consider for example the potential of augmented sensorial environments like odors and sounds to trigger pleasure experiences for long term engagement (e.g., see https://www.echosciences-hauts-de-france.fr/communautes/doctorants-des-hauts-de-france/articles/playful-city).

Limitations. This study offers new insights in the question of

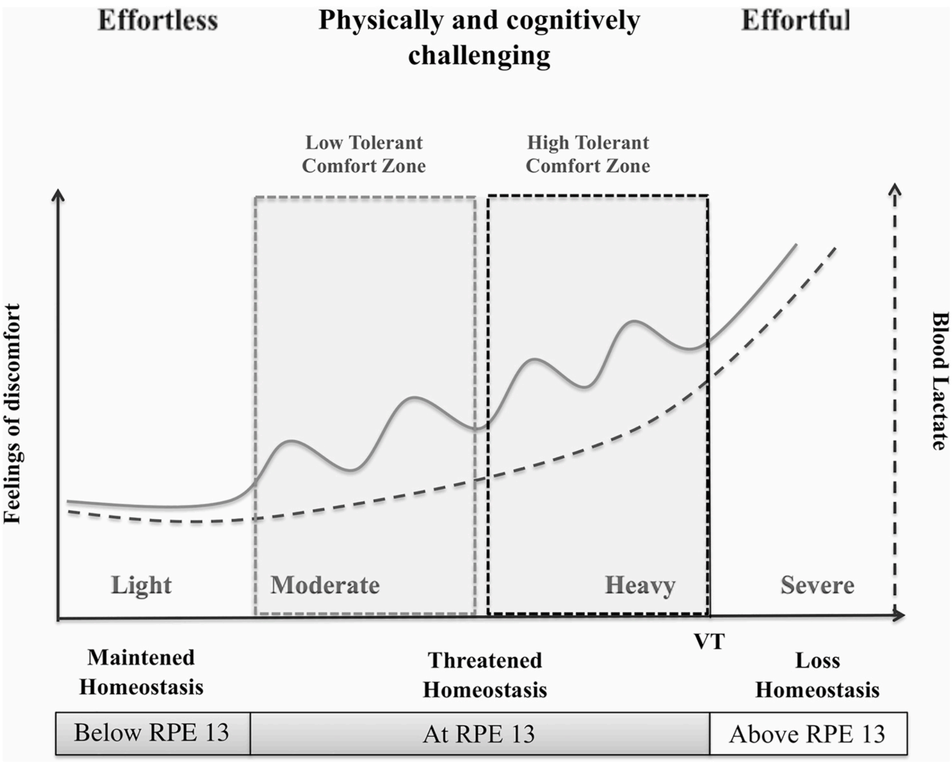

Fig. 5. A psycho-physiological framework of the dynamic between physical activity characteristics, tolerance level and affective states. This conceptual framework illustrates the possible functional association between biological (lactate concentration—not measured here), and psychological factors (Feelings of discomfort; Tolerance to effort). Setting the physical activity intensity to “moderately difficult” (RPE13), feelings of discomfort will augment with increasing concentrations of lactate in the blood. As a function of one’s tolerance to inner states of sensorial distress, individuals will target different pre-defined levels of acceptable discomfort, which may be used to detect the upcoming loss of homeostasis. Understanding the psychological factors that modulate one’s ability to set and predict correctly one’s tolerable level of sensorial discomfort may help us gain a better understanding of why some like it slow and easy, and others like it vigorous.

pleasurable physical effort but reveals nevertheless several limitations. First, our work does not reflect the psychological heterogeneity known within human society. Indeed, our participants were all Caucasian adults having received higher education. Future studies should include other population groups especially those at a greater risk of physical inactivity (Kanters et al., 2013). Second, we estimated the fitness level of our participants with self-reported questionnaires only whereas the use of actimeters could have provided a more complete picture of the physical activity profiles of our participants (Colley et al., 2018). Finally, the affective effects of space-stepping could be associated with the presence of light signals in comparison to that experienced in the spot-stepping condition. If this had been true, we would have expected a lighter cognitive load in the space-than in the spot-stepping, with the visual-vestibular stimulation facilitating postural control (Furman et al., 2012). This was not the case. Nevertheless, a future study could be carried out to confirm the results reported in the present paper by presenting light rhythmic signals in both space- and spot-stepping conditions.

Conclusion. Physical inactivity increases the risks in developing metabolic syndromes, psychological diseases and is related to higher mortality rates throughout the world (WHO, 2020). Hence, finding keys to get people to engage in regular physical activity is essential if we want to decrease public health expenses and improve global health and genuine fulfillment. In the present study, we described an original in-task methodology that offers the means to determine the objective and perceived cognitive and physical effort of a physical activity session. We demonstrated that the tolerance to effort, which is a psychological factor, plays a non-negligible role in the way physical activity sessions are experienced. The affective responses to physical activity predict the desire to re-engage and thus, must be taken into account when designing fun physical activity routines for sustained engagement and benefit. Scientific-based studies using in-task measures will offer the possibility to create individualized well-adapted and more pleasurable physical activity sessions.

Credit author statement

Mauraine Carlier: Conceptualization, Methodology, Investigation, Writing-Original draft preparation.
Yvonne N. Delevoye-Turrell: Conceptualization, Data curation, Writing and Editing.

Ethics

The scientific study meets all ethical publication standards and follows the latest guidelines of the APA manual, edition VI. The authors declare that the submission fully follows these ethical guidelines, and where appropriate, has received the approval of an ethics committee. Authors declare that their work is original, it has not been published previously, and that is not under consideration for publication elsewhere. This declaration covers the submission itself or the data used or samples (or relevant parts of them).

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.psychsport.2021.102076.

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