Exploring Decision-Making Processes: The Impact of Intense Exercise

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Abstract: The present study aims at deciphering the impact of high-intensity interval exercise on cognitive processes related to perceptual decision-making through computational modelling. To that end, participants completed a perceptual decision task before, after, and while exercising at high-intensity (8 x 5min, 85 ± 8% HRmax). Cognitive processes were assessed by determining the best-fitting parameters of a drift diffusion model (DDM) based on behavioral data (accuracy and reaction times). Behavioral data indicated faster reaction time while cycling and a trend toward enhanced cognitive performance following exercise. Immediately post-exercise, the results revealed significant changes in the main parameters of the drift-diffusion model compared to before exercise, suggesting an improvement of perceptual discrimination, more efficient non-decisional processes (perceptual encoding and motor execution), associated with a more cautious decision strategy. The exercise-induced impact during exercise completion presented a different picture. When the cognitive task was performed while exercising, no modulation of perceptual discrimination was observed. Additionally, there was a modulation of the decision strategy, with progressively less cautious decisions during exercise, and a intricate dynamic in the evolution of non-decisional processes.

Running head: Enhanced decision-Making During and After Intense Exercise

Key words: acute exercise, exercise-cognition interaction, perceptual decision-making, exercise-induced effect, Drift Diffusion Model

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Introduction

April 15, 2019. Notre-Dame is ablaze. After a strenuous climb, a firefighter finally reaches the top of the tower. Now, she must decide which side of the raging fire to attack first. Is her decision influenced by her intense physical effort? And if so, which specific underlying cognitive processes are altered?

Recent meta-analyses reveal that engagement in physical activity enhances cognitive performance in various cognitive tasks, including memory, vigilance, and conflict resolution (Pontifex et al., 2019; Sudo, Costello, McMorris & Ando, 2022). However, these studies have predominantly focused on moderate-intensity exercises. This emphasis on moderate-intensity exercise, primarily driven by methodological considerations, has left a gap in our comprehension of the interaction between physical demand and cognitive performance, especially when physiological demands is substantial. The impact of high-intensity exercise, defined as physical demand exceeding 80% maximal oxygen uptake (McMorris, 2016), or equivalent [e.g., exceeding 80% maximal heart rate (HR)], deserves deeper investigation. This is particularly crucial because it is associated with far more pronounced cellular and molecular changes than conventional exercises (Herold, Müller, Gronwald & Müller, 2019). Consequently, its influence on cognitive processes, likely mediated by specific peripheral biomarkers associated with high-intensity exercise, such as circulating lactate (Hashimoto et al., 2021), blood glucose, circulating cortisol levels, or neurotrophic factors (Singh & Staines, 2015), may differ from the commonly reported findings in the existing literature. These induced systemic physiological adaptations have implications for the entire organism, particularly on cognitive functioning, by potentially enhancing motor

cortex sensitivity to upstream influences, increasing sensory sensitivity (promoting stimulus encoding), raising arousal levels (accelerating processing speed), and modulating corticospinal excitability (promoting the execution of the response).

Quantifying the influence of physical exercise on cognitive processes poses a challenge because these processes cannot be directly observed. The cognitive computational approach provides a way to tackle this issue. It offers theoretically grounded models, whose parameters represent latent cognitive processes and can be inferred from behavioral data. In this study, we relied on the Drift Diffusion Model (DDM, Ratcliff, 1978) to decipher the impact of high-intensity interval exercise on cognitive processes involved in a perceptual decision-making task. This model has proven to be particularly fruitful (Ratcliff et al., 2016). It belongs to the wide class of Evidence Accumulation Models (EAM, Bogacz et al., 2006), that postulate that decisions result from the continuous accumulation of a stochastic evidence until a given amount of evidence is attained. The basic DDM contains four parameters, each related to a different cognitive process: the starting point of the accumulation process (z), which represents the bias of the decision; the drift rate of the accumulation process (v), which depends on the difficulty of the task or on the subject's perceptual ability; the distance between the bounds corresponding to each response (a), which represent the subject's cautiousness (the larger a, the more accurate and slower the responses); and a non-decision time (Ter), that encompass the encoding of relevant information and the decision execution processes.

Specifically, participants performed a random dot motion task, a task for which the DDM consistently offers excellent explanations for behavioral data, both before, during, and after engaging in high-intensity exercise sessions (eight 5-minutes blocks, at 86 ± 7% HRmax). Cognitive processes were assessed by determining the best-fitting parameters of a model based on behavioral data (accuracy and reaction times).

Method

Participants. Nineteen young adults (age range: 18–34; mean age: 25 years) voluntarily participated in the experiment. All participants were healthy and practised regular physical activities (peak oxygen uptake: 55 ± 8 mL kg−1 min−1; maximal heart rate: 184 ± 9 bpm). This sample size was determined based on prior studies reporting significant effects on cognitive performance using comparable physiological intensity (range 16 – 19 subjects; (Ando et al., 2022; Ramdani et al., 2021). All participants were fully informed about the study and signed a written informed consent before inclusion. The study was approved by the Ethics Committee for Research in Science and Technology of Physical Sports Activities (IRB00012476-2022-21-01-148).

Apparatus. We used a perceptual decision-making task, the random dot motion task (RDK), for which the DDM has consistently provided excellent accounts of behavioral data. The experiment was programmed in Python, using components of the PsychoPy toolbox (Peirce et al., 2019), and was run on a PC computer natively running Windows 10. Responses were communicated to the computer by means of two buttons (one for each hand).

Random dot motion task (RDK)
The task requires participants to determine the global direction of a random dot kinematogram featuring a proportion of dots moving coherently in the left or right signal direction. Each trial started with the presentation of the random dot motion stimulus, which remained on the screen until the participant responded. A response time deadline was set to 5 s. The interval between the response to the stimulus and the next trial was 1.5 s. The coherence parameter (proportion of dots moving in the same direction) was set for each participant at the beginning of the experiment according to a 2 up and 1 down staircase method lasting 30 trials. White dots were presented within a virtual 12.6° circular aperture centred on a 24.8° 3 13.9° black field. Each dot was a 4 x 4 pixel (0.05° square), moving at a speed of 8°/s. Dot density was fixed at 16.7 dots/deg2/s. Random dot motion was controlled by a white noise algorithm (Pilly & Seitz, 2009).

Procedure. Participants made three separate visits to the laboratory, each spaced at least 48 hours apart: a characterization session, a familiarization session, and the experimental session. Participants were positioned on an upright cycle ergometer (Lode Excalibur Sport, Groningen, The Netherlands), equipped with

two thumb response buttons on the right and left handle grips. A computer screen was positioned at eye level, approximately 1 meter in front of the participant.

The preliminary session was conducted to individually adjust the difficulty of the cognitive task, assess the VO2max, and determinate the power associated to the ventilatory thresholds (Wasserman, 2012) (see Table 1 for details).
Participants were seated on the cycle ergometer, fitted with a facemask to measure gas exchange data (Innocor CO, Cosmed, Italia) and a heart rate monitor. The incremental cycling exercise to exhaustion test started at an initial power level defined according to the participant's level (100 watts for non-cyclists and 150 watts for cyclists) and increased by 30 watts every 2 minutes until exhaustion. The end of the test was determined by volitional cessation of exercise or failure to maintain pedal cadence above 60 rpm despite strong verbal encouragement. During the first step of this maximal test, 30 trials of the RDK task was performed to set up the consistency parameter according to a staircase procedure.

	Mean ± standard deviation
Variables	**All**
Sample size	19
Age (years)	25±5
Height (cm)	177±7
Weight (kg)	67±9
Fat mass (%)	15±4
$\dot{V}O_2$max (ml.kg^{-1}.min^{-1})	55±8
Heart rate max (bpm)	184±9
Maximal aerobic power (W)	295±58
P_{SV1} (W)	208±55
P_{SV2} (W)	254±52
Heart rate HIE (% max)	86±6
Central temperature HIE (°C)	38,2±0,4

Table 1. Anthropometric and physiological characteristics of participants. PSV: Power corresponding to the ventilatory threshold, HIE: high-intensity exercise, VO2max: maximal oxygen consumption.

A familiarization session (about 1,250 trials), identical in all respects to the experimental session, was conducted to ensure performance stability and eliminate any potential practice-related effects before the experimental session.
The experimental protocol involved a high-intensity intermittent exercise, lasting 48 minutes. Participants completed the cognitive task before exercise (PRE), during six of the eight 5-minutes exercise sequences, and after exercise (POST).Participants gradually increased their pedaling intensity to reach 90% of the first ventilatory threshold (SV1). At this intensity level, participants engaged in 8 x 5 minutes of cycling intersperse by 1 minute of recovery. Cardiorespiratory parameters were continuously monitored during the exercise, and capillary blood samples from the fingertip were collected before and immediately after each of the eight blocks for the measurement of lactate and glucose levels. The skin was prepared by cleaning with alcohol, allowed to dry, and then punctured with an automated lancet. Blood samples were analyzed using a Biosen blood analyzer (EKF Diagnostics, UK).

Data Analyses. The experimental protocol was designed to evaluate the exercise-induced effects on cognitive processes throughout the exercise duration and immediately following the physical stress. Due to the substantial increase in cognitive load induced by the dual-task condition, cognitive data recording at rest (before and after, 4916 trials), and in a dual-task situation (while cycling, 12402 trials) were analyzed separately.

During exercise, we anticipated that the effects on decision-making processes may vary according to exercise duration. To prevent the loss of detailed aspects of how exercise affects cognitive performance, we conduct

analyses on three time windows: the Beginning of the exercise, spanning from 1 to 12 minutes (B1-B2); the Middle of the exercise, covering minutes 19 to 30 (B4-B5); and the End of the exercise, encompassing minutes 37 to 48 (B7-B8). The cognitive performance recorded during the first 5 min-exercise block (B1) was used as a baseline, as the cognitive task is performed in a condition of dual-task situation (while cycling), and the exercise-induced effect is not fully established.

Anticipations (RTs $<$ 200 ms; 0.13 %) were discarded from all analyses. Five subjects did not perform the perceptual task appropriately (i.e., percentage of accuracy under 50% or undesirable response strategy). They were excluded from the initial sample of 24 participants. We conducted a mixed-effects generalized logistic regression analysis on accuracy, and performed a linear mixed-effects model analysis on correct reaction time, including 'block' as a fixed effect, with 'subject' and 'block' intercepts treated as random effects.
Regarding physiological measures, we analyzed glucose and lactate levels within linear mixed-effects models. These models included the 'sample' (PRE and B1 to B8) expressed in mmol/L as a fixed effect, with 'subject' as random effect.

The Drift Diffusion Model parameters were estimated using a hierarchical Bayesian procedure implemented with the DMC package (Heathcote et al., 2019) for the R software (R Core Team, 2016). Specifically, we considered the DDM with inter-trial variability in the drift rate (sv) and the starting point (sz), and let the drift (v), threshold (a), non-decision time (Ter) and drift rate variability vary across conditions. We used broad truncated normal distributions for the means and uniform distribution on [0,1] for the standard-deviations. In order to fit the model to the data, we used the two-steps procedure described by Heathcote et al. (2019). In a first step, we fitted each participant's data individually. The averaged resulting parameters were used in a second step as starting values for hierarchical sampling. The quality of the fit was evaluated by visually inspecting Markov chain Monte Carlo chains, comparing predicted data according to best fitting parameters to actual data, and computing Brooks and Gelman's (1998) R statistics (see Appendix). Finally, we tested the presence of an effect of the condition on the parameter values by computing Bayesian p values (Heathcote et al., 2019).

Results

Physiological measures. The intensity level set during the high-intensity interval exercise corresponds to 86% $\pm$ 7% of HRmax, ranging from 71% to 99% of HRmax. Linear mixed model demonstrated a significant effect of block ($F(7, 126) = 15.114$, $p < .001$). Heart rate was lower during the blocks B1 and B2 and then remained stable from the 3th block to the end of exercise (Figure 1). Specifically, block B1 differed from the blocks B3, B4, B5, B6, B7 and B8; and the block B2 differed from the blocks B5, B6, B7 and B8.

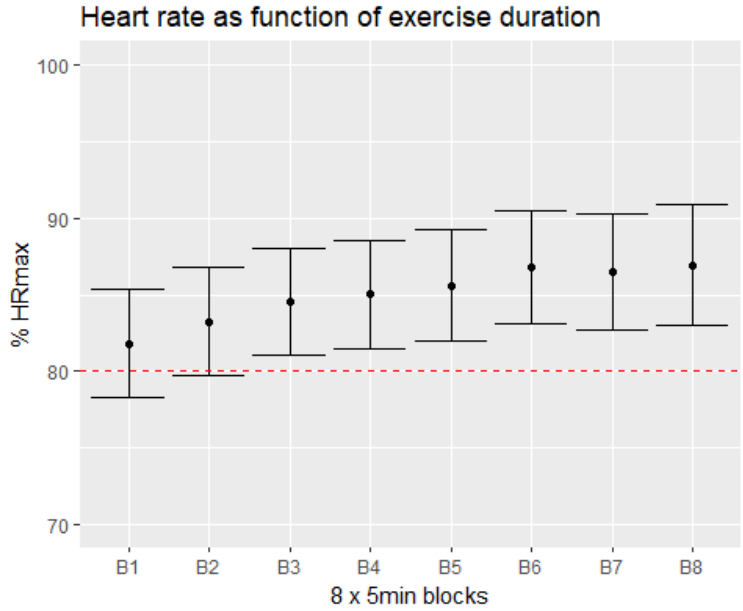


Figure 1. Heart rate as function of exercise duration (bmp/min)

The linear mixed model performed on blood sample analyses confirmed a significant impact of high-intensity interval exercise on glucose levels ($F(8, 143.03) = 6.2595$, $p < 0.001$) and on lactate levels ($F(8, 143.01) = 21.21$, $p < 0.001$) collected at the end of each block of exercise.
Bonferroni comparisons revealed lower glucose levels after each of the eight blocks than before exercising (PRE = 4.70 mmol/L ± 0.76 mmol/L). No other comparisons were found to be statistically significant on glucose levels (Figure 2).

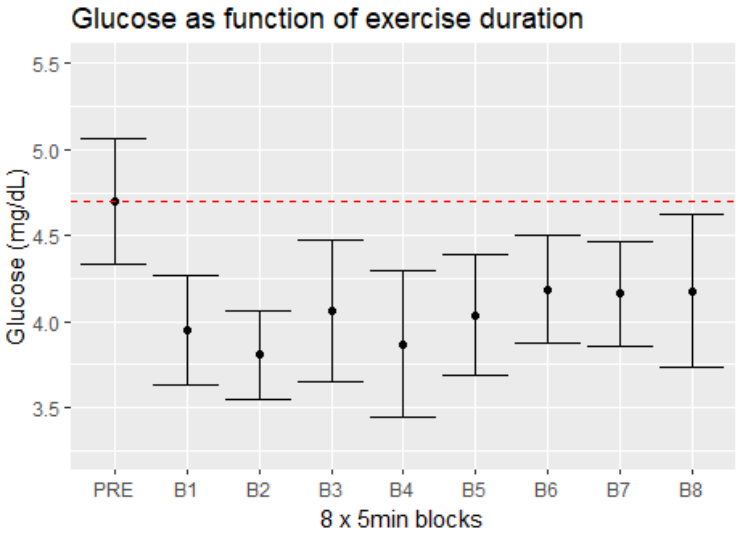


Figure 2. Glucose as function of exercise duration (mmol/L)

For the lactate concentration, higher lactate levels were observed after each of the eight blocks than before exercising (PRE = 1.66 ± 0.56 mmol/L). The lactate level after the first block (B1 = 6.05 ± 2.22 mmol/L) was also significantly higher from those collected after the blocks B4 (4.66 ± 2.47 mmol/L), B5 (4.42 ± 2.29 mmol/L), B6 (4.49 ± 2.50 mmol/L), B7 (4.47 ± 2.66 mmol/L) and B8 (4.14 ± 2.73 mmol/L). Higher lactate level was also observed after the second block (B2 = 5.66 ± 2.59 mmol/L) compared to the block B7 and B8. No other comparisons were found to be statistically significant (Figure 3).

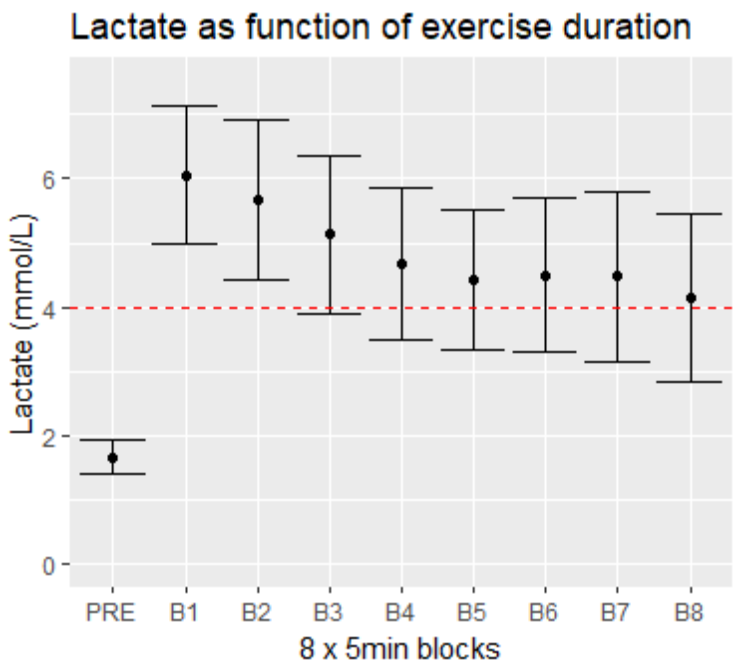


Figure 3. Lactate as function of exercise duration (mmol/L). Note: 4 mmol/L is a classical marker used to define the onset of blood lactate accumulation (OBLA), considered a valid indicator for transition from aerobic to anaerobic performance.

Behavioral data

Accuracy. The mixed-effects generalized logistic regression analysis conducted on accuracy did not reveal any significant exercise-induced effects. The accuracy was not significantly different following exercise compared to before (PRE = 85.07% vs POST = 83.94%, $p = 0.891$), nor during exercise compared to the baseline (Baseline = 85.91%; Middle of exercise = 86.28%, $p = 0.917$), nor to the End of exercise (86.21%, $p = 0.525$).

Correct reaction time (RT). The linear mixed model conducted on correct RTs collected before exercise (PRE = 996 ms ± 634 ms) and after exercise (POST = 929 ms ± 625 ms) revealed a trend toward an effect that did not reach the level of significance ($F(1, 17.316) = 3.9154$, $p = 0.064$). The linear mixed model conducted on correct RTs collected during exercise revealed a significant effect of block ($F(2, 16.597) = 8.0106$, $p < 0.01$). Tukey comparisons showed that RTs were faster at the End of the exercise (covering minutes 37 to 48, B7-B8: 910 ms ± 562 ms, $p < 0.001$) compared to the first exercise block (covering minutes 1 to 6, B1: 1001 ms ± 631 ms). Reaction times in the Middle of the exercise (covering minutes 19 to 29, B4-B5: 942 ms ± 602 ms) were not significantly different from those in the first exercise block ($p = 0.269$).

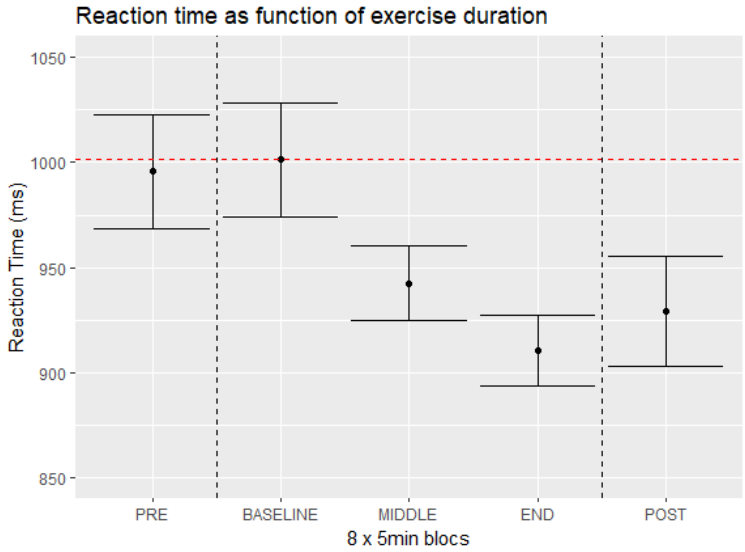


Figure 4. Reaction time (ms) as function of exercise duration Error bar represent SD.

DDM parameters. We investigated which component of the perceptual decision-making process was impact by exercise by comparing the best-fitting parameters of the DDM across conditions at the group level (detailed results of the fitting procedure are available in the Supplementary Data).

Post-Exercise Effects. We observed significant changes in the parameters of DDM after exercise compared to before. The results indicated a general improvement in cognitive processes associated with perceptual decision-making. The drift rate (v) increased significantly after exercise compared to before, the boundary (a) increased, and the non-decision time (Ter) decreased by approximately 64 milliseconds (Figure 5).

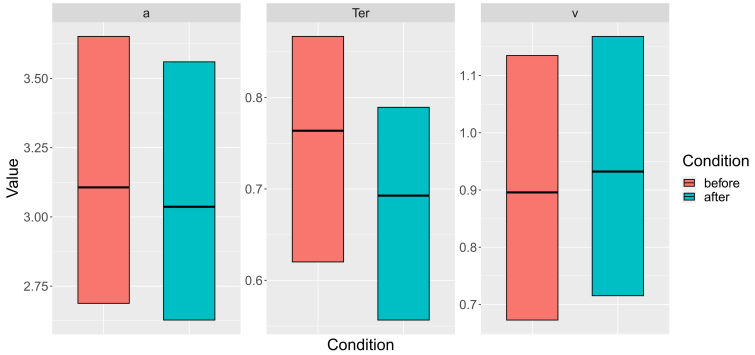


Figure 5. Diffusion model best-fitting parameters before and after intense exercise

In order to quantify the effect of the modulation of the v and a, we performed simulations, using best fitting parameters before exercise as a baseline, and varying each parameter separately to its best-fitting value after exercise. According to the results of these simulations, the increase of the drift rate led to a decrease in RT by approximately 48 ms and an increase in accuracy by 1.1 percentage points. Conversely, the boundary increase resulted in an RT increase of 31 ms while improving accuracy by 0.48 percentage points.

Parameters	Before	After	Proba
v: drift rate	1.780	1.982	Delta : +0.202
	[1.695, 1.867]	[1.896, 2.068]	p<0.001
a: upper decision threshold	1.943	2.040	Delta : +0.096
	[1.880, 2.011]	[1.973, 2.111]	p < 0.05
Ter: non-decision time	0.504	0.445	Delta : -0.058
	[0.489, 0.516]	[0.431, 0.457]	p<0.001

Table2. Diffusion model best-fitting parameters before and after exercise, with 95% credible intervals and p values.

During-Exercise Effects. We did not observe any modulation of the drift rate (v) in either the first or second part of exercise completion. The boundary (a) decreased gradually as time passed, and the non-decision time (Ter) increased in the Middle of exercise by 18 ms and decreased afterward by 14 ms (see Figure 6 and Table 1, for details).

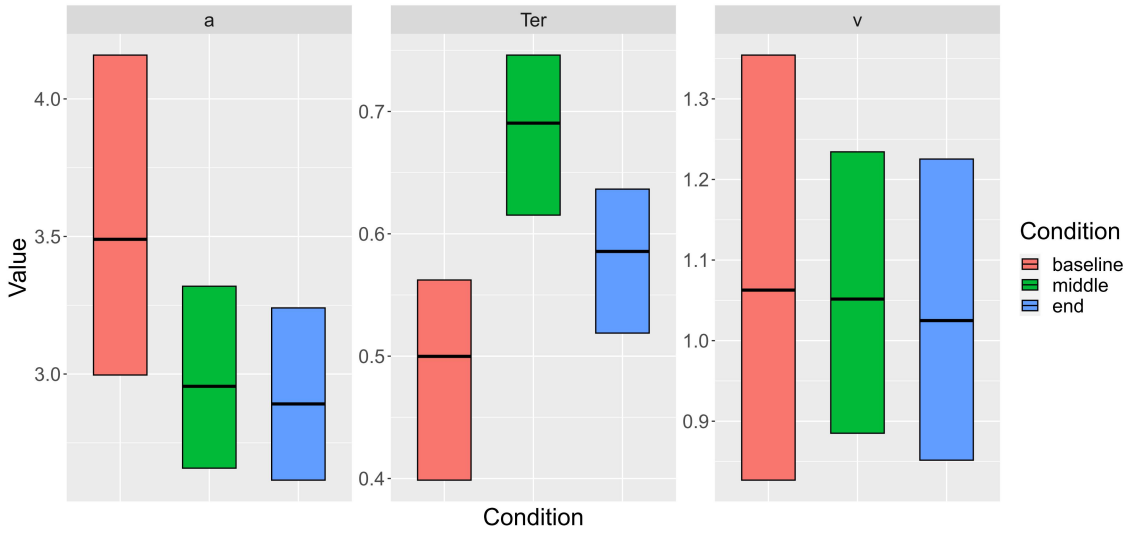


Figure 6. Diffusion model best-fitting parameters during exercise

Parameters	Baseline	Middle	End	Proba
v: drift rate	1.862	1.860	1.926	Baseline vs End (-0.064):
	[1.758, 1.968]	[1.790, 1.934]	[1.852, 2.001]	p=0.163
				Middle vs End (-0.066): p=0.1
				Baseline vs Middle (+0.002):
				p=0.488
a: upper decision	2.158	2.027	1.959	Baseline vs End (+0.198):
threshold	[2.077, 2.243]	[1.973, 2.086]	[1.911, 2.011]	p<0.001
				Middle vs End (+0.067):
				p=0.038
				Baseline vs Middle (+0.131):
				p=0.005
Ter: non decision time	0.451	0.469	0.455	Baseline vs End (-0.003):
	[0.438, 0.463]	[0.459, 0.478]	[0.447, 0.462]	p=0.314
				Middle vs End (+0.014):
				p=0.006
				Baseline vs Middle (-0.018):
				p=0.008

Table 3. Diffusion model best-fitting parameters during exercise, with 95% credible intervals and p values.

Simulations show that the decrease of the boundary between the baseline block and the Middle of exercise resulted in a reduction of RT of 37 ms and a decrease of accuracy by 0.49 percentage points. The decrease of the boundary between the Middle of exercise and the End of exercise induced a further reduction of RT of 19 ms and an additional decrease of accuracy by 0.24 percentage points.

Discussion

Summary. The present study aimed to investigate the impact of high-intensity interval exercise on cognitive processes related to perceptual decision-making. To achieve this, participants completed a perceptual decision task before, after, and while exercising at high-intensity. Cognitive processes were assessed by determining the best-fitting parameters of a drift diffusion model (DDM) based on behavioral data collected during these time periods.

Behavioral data results indicated faster RTs while exercising and suggested a trend toward enhanced cognitive performance immedialtelly following exercise. Moreover, the DDM model provided new insights into the underlying processes of this enhancement by revealing that the main parameters of the diffusion model were impacted immediately post-exercise compared to pre-exercise. The exercise-induced impacts during exercise completion presented a more intricate pattern, as detailed in the following discussion. This complexity warrants further exploration and clarification to deepen our understanding of the interplay between high-intensity exercise and cognitive processes.

Ongoing exercise impact on cognitive processes. Behavioral data results indicated faster RTs during exercise (-91 ms), with no modulation of accuracy, suggesting a facilitating effect of intense exercise. Inspection of DDM parameters allows to identify more specifically the underlying cognitive process at work.
First, we observed a decrease of the decision threshold over the course of the exercise, which means that participants become less cautious. Note that, while the time gain induced by this change is substantial (56 ms between the baseline and the final blocks), the related loss in terms of accuracy is relatively small (0.73 percentage points).
Second, the evolution of the non-decision time (Ter) show that the mean duration time required for processes unrelated to the perceptual decision increased in the first part of exercise and diminished between the Middle and the End of exercise. We hypothesize that the initial rise of Ter could be due to competition for biomechanical, physiological, and/or attentional resources (e.g., McMorris, 2021; Sudo et al., 2022). The implementation of adaptations, potentially coupled with improved lactate clearance and a shift in the dominance of energy metabolism in the second part of the exercise, could explain the subsequent decrease in the Ter (Herold et al., 2022; Hashimoto et al., 2018). Finally, we found no modulation of the drift rate. This means that we did not observe any impact of exercise on subjects' perceptual discrimination abilities.

Our results contrast with recent reviews showing that cognitive performance is more likely to be impaired during and after high-intensity exercise (Sudo et al., 2022; Zheng et al., 2021). This suggests that the impact of intense exercise on cognitive processes is highly dependent on the specifics of the experimental protocol. It therefore requires cautious interpretation and calls for standardisation and replication of experimental studies (Pontifex et al., 2019).

Post-exercise modulation of cognitive processes. Reaction time recorded after exercise completion tended to be faster (-70 ms), without change in accuracy. This trend was confirmed by the computational modelling approach, which revealed that the main parameters of the diffusion model were impacted immediately post-exercise compared to pre-exercise, suggesting an improvement of perceptual discrimination, more efficient non-decisional processes (perceptual encoding and motor execution), associated with a more cautious decision strategy. These findings are in line with the fact that (i) high-intensity physical activity is positively associated with changes in brain-indices associated with arousal levels and attention allocated to the task (Du Rietz et al., 2019) and (ii) vigilance state induced by sleep-deprivation modulates the drift rate in DDM (Ratcliff & Van Dongen, 2011).

Despite numerous studies investigating the effects of exercise on cognition, the impact of high-intensity exercise on subsequent cognitive performance is not yet fully understood (Browne et al., 2017; McMorris, 2016; Moreau & Chou, 2019). One reason for this lack of clarity is that neurochemical explanations, while providing insights into the impact of exercise on cognitive function during physical activity, may not completely elucidate the effects that occur after exercise. Notably, because the pronounced cellular and molecular changes induced by intense stress are temporary, and the rapid return to baseline after exercise cessation cannot solely account for the subsequent effects observed following exercise. Further research is thus necessary to determine the extent to which pronounced cellular and molecular changes induced by intense exercise may underlie the differences in decision-making cognitive processes observed after completion.

Among the hypotheses currently under investigation, the increase in cerebral blood flow is an adaptive mechanism induced by intense exercise that could potentially play a role in the observed cognitive improvement after intense exercise. Indeed, in contrast to light to moderate physical activities, higher levels of cerebral blood flow and oxygenation have been reported during high-intensity exercises (Rooks, Thom, McCully, & Dishman, 2010). Another hypothesis currently under investigation involves the metabolism of catecholamines. Specifically, the changes induced by increased demand during intense exercise could persist for a certain period after exercise cessation, potentially explaining an enhancement in certain cognitive processes (Moreau & Chou, 2019, McMorris et al., 2016).

Limitations. The first limitation in this study is the variability across subjects in physiological responses induced by exercising at 90% of the first ventilatory threshold (ranging from 71% to 99% of HRmax). This variability might contribute to discrepancies in results, as the exercise-induced effects on cognition may depend on the degree to which aerobic relative to anaerobic energetic metabolism is required. After completing the study, we examined individual lactate levels to determine how many subjects were above and below 4 mmol/L, commonly known as the onset of blood lactate accumulation (OBLA). OBLA is a valid indicator for the transition from predominantly aerobic to anaerobic energy production. Participants exhibited different levels, with half the subjects above and the others below the threshold level of 4mmol/L of blood lactate concentration. Future experiments should be upgraded to avoid such discrepancies in physiological responses across subjects. Improving the understanding of individual responses, such as examining lactate levels, could contribute to a better understanding of the biochemical factors influencing cognitive changes during and following exercise.

Finally, it should be stressed that we compared cognitive performance during specific time windows using cognitive data recorded during the first 5-minute exercise block as a baseline. However, according to Moreau and Chou's meta-analysis (2019), high-intensity exercise more often leads to cognitive enhancement (at least after the bout) when performance is compared with rest rather than when it is compared with lower-intensity exercise. As a result, our chosen baseline, corresponding to cognitive performance recorded while cycling at a time when exercise-induced effects were not yet fully established, could potentially introduce Type I errors. Therefore, in future experiments, we will benefit from designing protocols to perform comparisons with resting conditions and conducting cognitive tasks during the recovery phase of intermittent exercise, immediately following the completion of each block.

Conclusion. By applying DDM model on a perceptual decision-making task, the present results provide a new insight into cognitive mechanisms underlying high-intensity exercise-induced changes. Less time-consuming, more ecological and particularly efficient, high-intensity exercises appear a very promising alternative to traditional light- to moderate- exercises.

References

Ando, S., Komiyama, T., Tanoue, Y., Sudo, M., Costello, J. T., Uehara, Y., & Higaki, Y. (2022). Cognitive Improvement After Aerobic and Resistance Exercise Is Not Associated With Peripheral Biomarkers. Frontiers in Behavioral Neuroscience, 16, 853150. https://doi.org/10.3389/fnbeh.2022.853150

Ballester-Ferrer, J. A., Bonete-López, B., Roldan, A., Cervelló, E., & Pastor, D. (2022). Effect of acute exercise intensity on cognitive inhibition and well-being: Role of lactate and BDNF polymorphism in the

dose-response relationship. Frontiers in Psychology, 13. https://www.frontiersin.org/articles/10.3389/fpsyg.2022.1057475

Bogacz, R., Brown, E., Moehlis, J., Holmes, P., & Cohen, J. D. (2006). The physics of optimal decision making: A formal analysis of models of performance in two-alternative forced-choice tasks. Psychological Review, 113, 700-765. https://doi.org/10.1037/0033-295X.113.4.700

Brooks, S. P., & Gelman, A. (1998). General Methods for Monitoring Convergence of Iterative Simulations. Journal of Computational and Graphical Statistics, 7(4), 434-455. https://doi.org/10.1080/10618600.1998.10474787

Davranche, K., Burle, B., Audiffren, M., & Hasbroucq, T. (2005). Information processing during physical exercise: a chronometric and electromyographic study. Experimental Brain Research, 165(4), 532-540. https://doi.org/10.1007/s00221-005-2331-9

Davranche, K., Burle, B., Audiffren, M., & Hasbroucq, T. (2006). Physical exercise facilitates motor processes in simple reaction time performance: An electromyographic analysis. Neuroscience Letters, 396(1), 54-56. https://doi.org/10.1016/j.neulet.2005.11.008

Davranche, K., Temesi, J., Verges, S., & Hasbroucq, T. (2015). Transcranial magnetic stimulation probes the excitability of the primary motor cortex: A framework to account for the facilitating effects of acute whole-body exercise on motor processes. Journal of Sport and Health Science, 4(1), 24–29.

Du Rietz, E., Barker, A. R., Michelini, G., Rommel, A.-S., Vainieri, I., Asherson, P., & Kuntsi, J. (2019). Beneficial effects of acute high-intensity exercise on electrophysiological indices of attention processes in young adult men. Behavioural Brain Research, 359, 474-484. https://doi.org/10.1016/j.bbr.2018.11.024

Hashimoto, T., Tsukamoto, H., Ando, S., & Ogoh, S. (2021). Effect of Exercise on Brain Health: The Potential Role of Lactate as a Myokine. Metabolites, 11(12), 813. https://doi.org/10.3390/metabo11120813

Hashimoto, T., Tsukamoto, H., Takenaka, S., Olesen, N. D., Petersen, L. G., Sorensen, H., et al. (2018). Maintained exercise-enhanced brain executive function related to cerebral lactate metabolism in men. FASEB J. 32, 1417–1427. doi: 10.1096/fj.201700381RR

Heathcote, A., Lin, Y.-S., Reynolds, A., Strickland, L., Gretton, M., & Matzke, D. (2019). Dynamic models of choice. Behavior Research Methods, 51(2), 961-985. https://doi.org/10.3758/s13428-018-1067-y

Herold F, Behrendt T, Meißner C, Müller NG, Schega L. The Influence of Acute Sprint Interval Training on Cognitive Performance of Healthy Younger Adults. Int J Environ Res Public Health. 2022 Jan 5;19(1):613. doi: 10.3390/ijerph19010613. PMID: 35010873; PMCID: PMC8745010.

Herold, F., Müller, P., Gronwald, T., & Müller, N. G. (2019). Dose–Response Matters! A Perspective on the Exercise Prescription in Exercise–Cognition Research. Frontiers in Psychology, 10, 2338. https://doi.org/10.3389/fpsyg.2019.02338

Kao, S.-C., Cadenas-Sanchez, C., Shigeta, T. T., Walk, A. M., Chang, Y.-K., Pontifex, M. B., & Hillman, C. H. (2020). A systematic review of physical activity and cardiorespiratory fitness on P3b. Psychophysiology, 57(7), e13425.

McMorris, T. (2021). The acute exercise-cognition interaction: From the catecholamines hypothesis to an interoception model. Int. J. Psychophysiol. 170,75–88. doi: 101016/j.ijpsycho.2021.10.005

Moreau, D., & Chou, E. (2019). The Acute Effect of High-Intensity Exercise on Executive Function: A Meta-Analysis. Perspectives on Psychological Science, 14(5), 734-764. https://doi.org/10.1177/1745691619850568

Moxon, K. A., Devilbiss, D. M., Chapin, J. K., & Waterhouse, B. D. (2007). Influence of norepinephrine on somatosensory neuronal responses in the rat thalamus: A combined modeling and in vivo multi-channel, multi-neuron recording study. Brain Research, 1147, 105-123. https://doi.org/10.1016/j.brainres.2007.02.006

Peirce, J., Gray, J. R., Simpson, S., MacAskill, M., Höchenberger, R., Sogo, H., Kastman, E., & Lindeløv, J. K. (2019). PsychoPy2: Experiments in behavior made easy. Behavior Research Methods, 51(1), 195-203.

https://doi.org/10.3758/s13428-018-01193-y

Pilly, P. K., & Seitz, A. R. (2009). What a difference a parameter makes: A psychophysical comparison of random dot motion algorithms. Vision Research, 49(13), 1599-1612. https://doi.org/10.1016/j.visres.2009.03.019

Pontifex, M. B., McGowan, A. L., Chandler, M. C., Gwizdala, K. L., Parks, A. C., Fenn, K., & Kamijo, K. (2019). A primer on investigating the after effects of acute bouts of physical activity on cognition. Psychology of Sport and Exercise, 40, 1-22. https://doi.org/10.1016/j.psychsport.2018.08.015

Ramdani, C., Sagui, E., Schmid, B., Castagna, O., Davranche, K., Vidal, F., & Hasbroucq, T. (2021). Action monitoring fails when motor execution is too fast: no time for correction. Journal of Systems and Integrative Neuroscience, 7(3). https://doi.org/10.15761/JSIN.1000246

Ratcliff, R. (1978). A theory of memory retrieval. Psychological review, 85(2), 59.

Ratcliff, R., Smith, P. L., Brown, S. D., & McKoon, G. (2016). Diffusion Decision Model: Current Issues and History. Trends in Cognitive Sciences, 20(4), 260-281. https://doi.org/10.1016/j.tics.2016.01.007

Ratcliff, R., & Van Dongen, H. P. A. (2011). Diffusion model for one-choice reaction-time tasks and the cognitive effects of sleep deprivation. Proceedings of the National Academy of Sciences, 108(27), 11285-11290. https://doi.org/10.1073/pnas.1100483108

Singh, A. M., & Staines, W. R. (2015). The effects of acute aerobic exercise on the primary motor cortex. Journal of motor behavior, 47(4), 328–339.

Sudo, M., Costello, J. T., McMorris, T., & Ando, S. (2022). The effects of acute high-intensity aerobic exercise on cognitive performance: A structured narrative review. Frontiers in Behavioral Neuroscience, 16, 957677. https://doi.org/10.3389/fnbeh.2022.957677

Wasserman, K. (2012). Principles of Exercise Testing and Interpretation: Including Pathophysiology and Clinical Applications. Wolters Kluwer Health/Lippincott Williams & Wilkins.

Winkel, J., Van Maanen, L., Ratcliff, R., Van der Schaaf, M. E., Van Schouwenburg, M. R., Cools, R., & Forstmann, B. U. (2012). Bromocriptine does not alter speed–accuracy tradeoff. Frontiers in neuroscience, 6, 126.

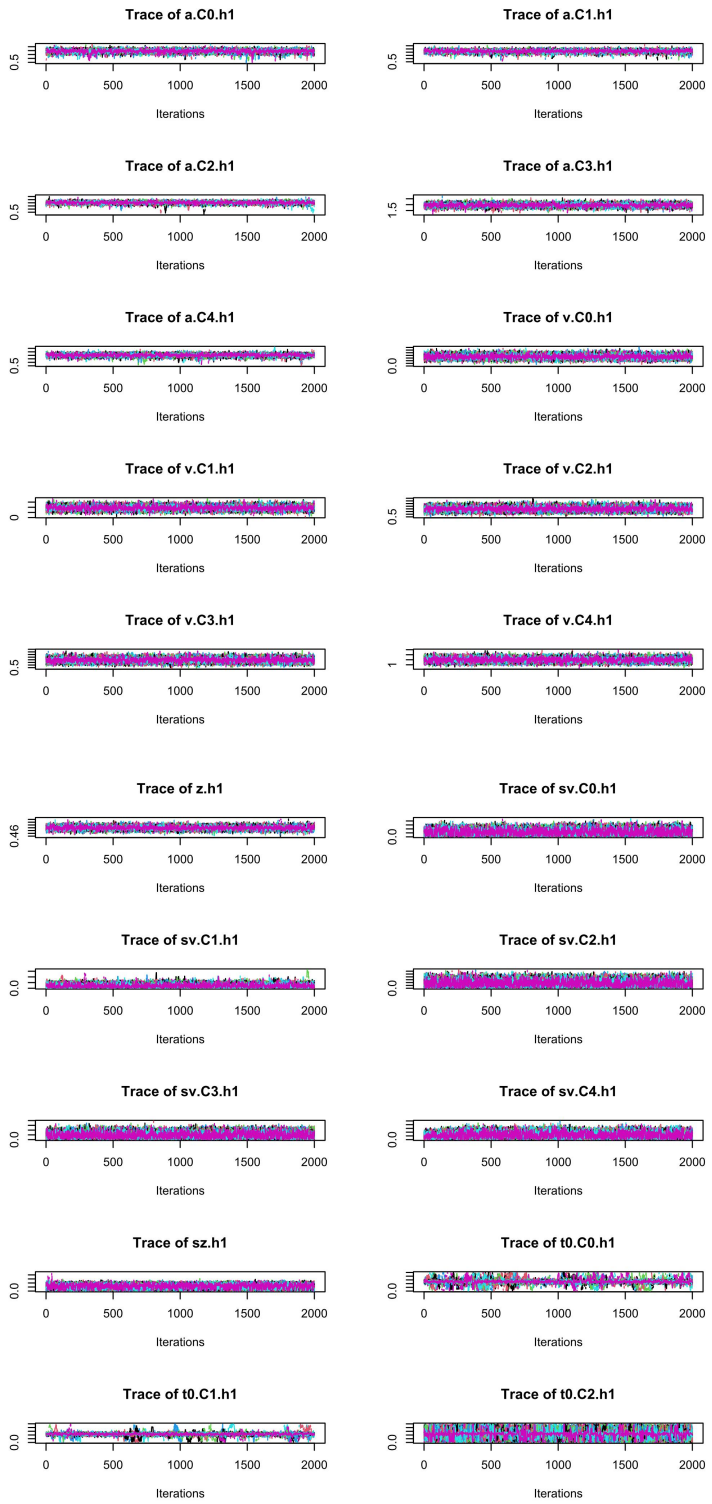
Appendix

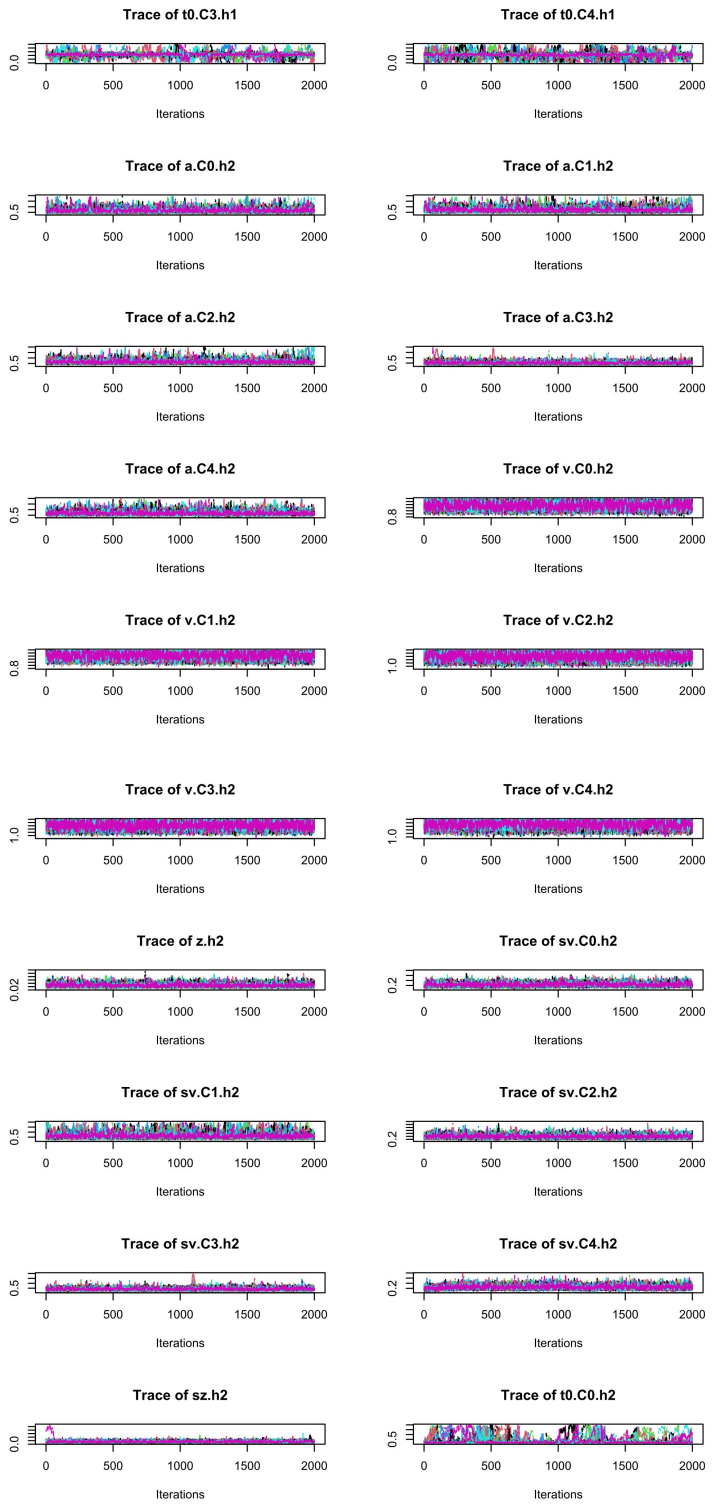
Appendix 1. Group parameters. Estimated parameters: threshold (a), drift (v), drift variability (sv), starting point (z), starting point variability (sz), non-decision time (t0). C0, C1, C2, C3 and C4 represent before, baseline, middle, end and after blocks. h1 stands for posterior location parameters and h2 for posterior scale parameters. Rhats represent Brooks and Gelman's R statistics.

Group parameters

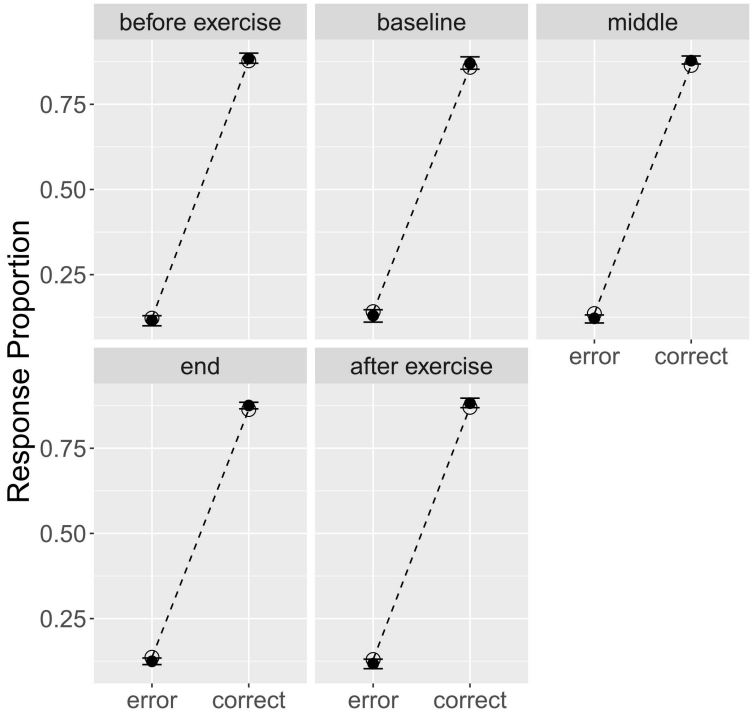
	2.5%	50%	97.5%	Rhat
a.C0.h1	1.586	1.936	2.249	1.001
a.C1.h1	1.772	2.145	2.488	1.001
a.C2.h1	1.691	2.021	2.324	1.002
a.C3.h1	1.711	1.959	2.205	1.001
a.C4.h1	1.677	2.030	2.353	1.001
v.C0.h1	1.088	1.761	2.484	1.001
v.C1.h1	1.121	1.854	2.636	1.001
v.C2.h1	1.282	1.981	2.798	1.001
v.C3.h1	1.195	1.918	2.700	1.001
v.C4.h1	1.226	1.987	2.803	1.001
z.h1	0.497	0.520	0.543	1.001
sv.C0.h1	0.006	0.122	0.280	1.001
sv.C1.h1	0.009	0.201	0.572	1.001
sv.C2.h1	0.008	0.163	0.417	1.001
sv.C3.h1	0.009	0.184	0.451	1.001
sv.C4.h1	0.006	0.121	0.288	1.001
sz.h1	0.011	0.131	0.216	1.001
t0.C0.h1	0.387	0.503	0.630	1.009
t0.C1.h1	0.347	0.449	0.533	1.013
t0.C2.h1	0.069	0.457	0.858	1.002
t0.C3.h1	0.310	0.451	0.551	1.010
t0.C4.h1	0.196	0.439	0.584	1.005
a.C0.h2	0.459	0.649	1.041	1.002
a.C1.h2	0.486	0.691	1.138	1.002
a.C2.h2	0.448	0.628	0.997	1.001
a.C3.h2	0.363	0.505	0.765	1.002
a.C4.h2	0.472	0.662	1.067	1.001
v.C0.h2	1.097	1.518	1.958	1
v.C1.h2	1.200	1.641	1.977	1.001
v.C2.h2	1.156	1.601	1.973	1.001
v.C3.h2	1.203	1.642	1.978	1.001
v.C4.h2	1.295	1.727	1.986	1.001
z.h2	0.035	0.048	0.070	1.001
sv.C0.h2	0.124	0.229	0.387	1.005
sv.C1.h2	0.350	0.595	1.218	1.001
sv.C2.h2	0.227	0.391	0.640	1.001
sv.C3.h2	0.238	0.410	0.684	1.002
sv.C4.h2	0.133	0.244	0.408	1.001
sz.h2	0.076	0.137	0.246	1.002
t0.C0.h2	0.118	0.169	0.780	1.020
t0.C1.h2	0.109	0.156	0.337	1.025
t0.C2.h2	0.152	0.284	1.834	1.007
t0.C3.h2	0.118	0.168	0.743	1.026
t0.C4.h2	0.122	0.183	1.275	1.013

Appendix 2. Markov chain Monte Carlo traces.





Appendix 3. Model predictions.



predictions.jpg predictions.bb

Legend: Open points: data; solid points: model prediction; error bars show the corresponding 95% credible intervals.