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## Influence of Mental Training of Attentional Control on Autonomic Arousal Within the Framework of the Temporal Preparation of a Force Task

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### Abstract

While temporal preparation has frequently been examined through the manipulation of foreperiods, the role of force level during temporal preparation remains underexplored. In our study, we propose to manipulate mental training of attentional control in order to shed light on the role of the force level and autonomic nervous system in the temporal preparation of an action. Forty subjects, divided into mental training group ( $n = 20$ ) and without mental training group ( $n = 20$ ), participated in this study. The influence of the attentional control and force levels on the autonomic nervous system were measured using the skin conductance response and the heart rate variability; the accuracy of the motor responses was measured using a method derived from machine learning. Behaviorally, only the mental training group reinforced its motor and attentional control. When using short foreperiod durations and high force level, motor and attentional control decreased, consistent with the dominant sympathetic system. This resulted in an increased anticipation rate of responses with a higher reaction time compared to the long foreperiods duration and low force level, in which the reaction time significantly decreased, with enhancement of the expected force level, showing consistency with the dominant parasympathetic system. Interestingly, results revealed a predictive relationship between the sympathovagal balance and motor and attentional control during the long foreperiods and low force level. Finally, results demonstrate that attentional mental training leads to the reinforcement of interactions between the autonomic nervous system and attentional processes which are involved in the temporal preparation of a force task.

**Keywords:** Attentional control; Force; Autonomic nervous system; Mental training; Machine learning

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## 1. Introduction

The ability to focus and exhibit selective attention is a fundamental aspect of human cognition. The pivotal role of attention becomes evident through its coordination function, which integrates information from diverse environmental sources. Our interactions with the environment are framed by a temporal dimension (Nobre & van Ede, 2023), which contributes to the selection of stimuli aimed at enhancing behaviors related to decisions and motor responses (Nobre, 2001). The relationship between attention and the temporal dimension is referred to as temporal attention, achieved through alertness mechanisms that reflect a state of attention control. Alertness mechanisms comprise two fundamental attentional components; exogenous attention and endogenous attention. Exogenous attentional mechanisms operate automatically, triggered reflexively by a salient sensory event and supported by bottom-up mechanisms. In contrast, endogenous attentional mechanisms are slower, goal-driven, involving a purposeful and effortful orienting process supported by top-down mechanisms (Daly et al., 2020; Klein, 2009; Lawrence & Klein, 2013; Posner, 1980; Posner et al., 1982). Behavioral studies have revealed enhanced performance in tasks involving exogenous attention when a warning stimulus precedes the imperative stimulus, thereby increasing response readiness. This effect corresponds to the temporal preparation phenomenon, which enables the preactivation of perceptual and motor systems by predicting the future occurrence of an event (Hackley, Schankin, Wohlschlaeger, & Wascher, 2007). Notably, Woodrow (1914) has postulated that temporal preparation develops during the foreperiod (FP), which is the temporal interval that separates the cue (warning stimulus) from the imperative stimulus (target). The warning signal serves as a temporal reference for response preparation, allowing subjects to estimate the occurrence of the imperative stimulus (Niemi & Naatanen, 1981).

Since these seminal works, researchers have been extensively investigated the FP within alertness tasks to study the phenomenon of temporal preparation (Daly et al., 2020; Los, Kruijne, & Meeter, 2014; McCormick, Redden, Hurst, & Klein, 2019; Périn, Godefroy, Fall, & de Marco, 2010; Vallesi et al., 2007). Two variants of the FP paradigm have been classically described in the literature (Schröter et al., 2015). The first variant refers to a constant FP duration within a block of trials but varies between different blocks of trials. The second, more widely used variant features a variable FP duration, randomly intermixed within a block of trials. Behavioral results were consequently different in both variants. The first variant highlights the constant FP effect which results in increased reaction time (RT) with increased FP. This result was explained by the inability of participants to maintain an optimal state of preparation for a long time. However, the second variant put forward the variable FP effect, which is manifested by a decreased RT with increased FP. This decreased RT was explained by an increased predictability of imperative stimulus with the increased FP duration. These findings have contributed to the development of various models aimed at explaining the underlying mechanisms of temporal preparation (Coull, Nobre, & Frith, 2001; Los & Heslenfeld, 2005; Los & Van den Heuvel, 2001; Los et al., 2014; Los, Knol, & Boers, 2001; Sturm & Willmes, 2001; Vallesi & Shallice, 2007; Vallesi et al., 2007; Vallesi et al., 2007).

The variable FP effect was widely used in simple RT tasks as well as in choice RT tasks. However, only a few studies have combined response force and RT task with variable FP

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2 paradigm. While FPs are important, they are not the only factors to consider. Importantly,  
3 multiple aspects of a task can contribute to RT responses (Nobre & coull, 2010). In fact, some  
4 RT theorists (e.g., Sanders, 1990) assume that manipulations of the FP influence the duration  
5 of motor processing, the motoric portion of RT. Given the motoric nature of FP factors, it  
6 prompts the question of whether these factors impact not only RT but also the exerted force  
7 when generating a response (Mattes & Ulrich, 1997).

8 Therefore, in addition to manipulating FP durations, we manipulate in our paradigm the  
9 force levels that allows us to investigate the interaction between the force levels and the FPs  
10 with and without mental training of attentional control. More precisely, we would like to  
11 demonstrate that if participants are mentally trained to attentional control, they can increase  
12 their physiological arousal improving thereby the temporal preparation of action.

13 In fact, mental training of attentional control serves to enhance performance optimization  
14 by stimulating working memory, increasing vigilance, and improving motor execution capa-  
15 bilities. Our training approach is a strategic methodology for improving performance out-  
16 comes (Daly et al., 2020; Decety & Grèzes, 1999; Jackson, Lafleur, Malouin, Richards, &  
17 Doyon, 2001). Interestingly, McCormick et al. (2019) introduced a task that effectively com-  
18 bined endogenous and exogenous attention mechanisms. Their findings revealed an improve-  
19 ment in response accuracy. The authors suggest that exposing participants to different alerting  
20 modes during the task could influence their overall mental state of responding and impact their  
21 tonic arousal levels. However, the physiological mechanism underlying the arousal levels in  
22 this kind of task has not been a focus of great interest.

23 According to the Neurovisceral Integration Model (Thayer & Lane, 2000; Thayer et al.,  
24 2009), there is an association between cardiac vagal tone and the functioning of emotional  
25 self-regulatory systems. This hypothesis could be extended to encompass the attentional  
26 functions. Previous research has demonstrated that cognitive functioning worsens under  
27 autonomic conditions (Thayer & Lane, 2000; Thayer et al., 2012; Thayer, Yamamoto, &  
28 Brosschot, 2010). A potentially underlying neurophysiological mechanism that can affect the  
29 tonic arousal levels are the interactions between attentional and motor functions and the sym-  
30 pathetic and parasympathetic components of the ANS. Notably, as early as 1969, Porges and  
31 Raskin, who were interested in the interactions between attention and the ANS, demonstrated  
32 that heart rate variability was significantly decreased during sustained attention. Further stud-  
33 ies, such as Backs and Ryan (1992), who manipulated memory load and temporal intervals in  
34 sustained attention task, found that vagal activity decreased as attentional demand increased.  
35 Additionally, other authors have related skin conductance responses (SCRs), an index of  
36 the sympathetic system, to attention in mental workload. Kahneman, Tursky, Shapiro, and  
37 Crider (1969) also demonstrated that during a cognitive task in which mental effort was  
38 manipulated, sympathetic responses, as reflected by SCRs, correlated with the cognitive load  
39 imposed by the task. Based on other evidence, Lacey (1967) has argued that a sympathetic  
40 component of the ANS would indicate the sensitization of the organism to external environ-  
41 mental stimuli. Consequently, the sympathetic system would reinforce autonomic arousal to  
42 ensure adaptation to situations that require a rapid reaction (Cannon, 1914; Critchley, 2002).

43 Despite prior studies aimed to elucidate the relationship between the ANS and the  
44 attentional functions, the question of the neurophysiological mechanisms underlying the

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2 attentional control remains largely unexplored. Temporal orienting experiments have revealed  
3 a tight link between temporal attention and behavioral response, but to our knowledge, no  
4 study has investigated attentional control in its temporal dimension, taking into account the  
5 autonomic and involuntary activity of the body as a dynamic source that constantly collects  
6 data from the environment (Nobre & van Ede, 2023; Tatler & Land, 2015).

7 Our study aims to investigate the influence of mental training of attentional control on  
8 autonomic arousal within the framework of the temporal preparation of a force task. We pro-  
9 pose from alerting tasks (exogenous and endogenous), by manipulating the duration of the  
10 foreperiods (short FPs and long FPs) and the force levels (low and high) to study the inter-  
11 actions between the attentional (temporal preparation) and motor (force levels) functions and  
12 autonomic nervous system. We hypothesize that undergoing mental training session involv-  
13 ing both endogenous and exogenous alertness will show improved attentional performance  
14 in exogenous condition and will affect both sympathetic and parasympathetic systems. Dur-  
15 ing the conditions of short FP and high force level, participants will further anticipate the  
16 target (imperative stimulus) due to a lack of temporal preparation and will deviate from the  
17 expected value of strength (80% of the maximum voluntary strength); this lack of accuracy  
18 will be accompanied by an increased sympathetic activity. Conversely, during the condition  
19 of long FP and low force level, we expect participants to reduce their RT and respect further  
20 the required force value (20% of the maximum voluntary strength), due to a better attentional  
21 and motor control, accompanied by an increased parasympathetic activity.

## 24 2. Methods

### 26 2.1. Participants

27 Forty healthy participants (20 females and 20 males) aged between 20 and 35 years (mean  
28 = 26.92;  $SD = 4.14$ ) with no known history of neurological, psychiatric, or sensorimotor dis-  
29 orders were recruited. All participants were right-handed, as assessed by the Edinburgh inven-  
30 tory for right-handedness. Before the screening process, all participants were provided with  
31 a detailed explanation of the study's purpose and procedures. They signed an informed con-  
32 sent form before participating in the study. The participants were randomly assigned within  
33 two groups: the mental training group (MT group) ( $n = 20$ ), who received mental training  
34 before the physical task, and the without mental training group (without MT group) ( $n = 20$ ),  
35 who performed only the physical task. The study protocol was approved by the institutional  
36 research board of the CPP Ile-de-France.

### 38 2.2. Procedure

40 Participants sat comfortably in a chair and performed three trials of force reaching the  
41 maximum voluntary strength by squeezing a handgrip during 2 s maximum using their right  
42 hand; the instruction given was to "squeeze the dynamometer as stronger as possible and  
43 release the pressure at the moment indicated by the experimenter"; each trial was followed by  
44 30 s of rest. The maximum voluntary strength was determined by calculating the mean of the

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three consecutive trials and allowed for normalization of the force levels of each participant at 20% (low force) and 80% (high force) of the maximum voluntary strength. Participants were asked to retain the 20% and 80% force values, each converted into a numerical value on a gauge (see Fig. 1).

### 2.3. Paradigm

The experimental task consisted of four blocks of an exogenous alertness task, which included a warning stimulus (beep signal) preceding the imperative stimulus (Go signal) and four blocks of an endogenous alertness task without a warning stimulus. The blocks alternated between endogenous and exogenous alertness conditions. In the exogenous alertness task, each block was composed of 14 trials with two force levels (low and high) and two FPs (short [650 ms] and long [710 ms]) that alternated. The FP interval separated the warning stimulus (auditive signal “beep”) from the target stimulus (auditive signal “GO”) to prepare temporally the participants to respond by squeezing the handgrip as quickly and accurately as possible. Participants had to reach the force level (low or high) by adjusting the needle of the gauge projected on the screen (see Fig. 1). The visual feedback (see Fig. 1) enabled the subject to control the precision of the motor responses in producing the appropriate force level (20% or 80% of voluntary maximal force) that participants kept in memory. In the endogenous alertness task, each block was composed of 14 trials; before each block, participants were instructed to squeeze the handgrip as quickly and accurately as possible when they heard the imperative stimulus (GO signal) by reaching the requested force level (low or high). The purpose of using two opposite force levels (low and high) was to modulate the autonomic arousal level underlying the mental and physical effort of the subject.

The duration of the stimulus instructing the force level was 2 s, the duration of the warning stimulus (sound) was 50 ms, and the duration of the auditory imperative stimulus was 200 ms. The duration of trials and blocks was the same for the endogenous and exogenous alerting tasks, the duration of a block was 60 s including the duration stimulus instructions. The overall duration of the tasks was about 8 min.

All groups, with and without mental training, performed the same experimental task, and they had the same number of trials to prevent temporal expectation. We proposed a mental training task that combines the exogenous and endogenous alertness with the same duration, about 8 min (McCormick et al., 2019). Half of the participants were instructed to perform mentally the alerting task (MT group) during the mental training session, before physically performing it (attentional control reinforcement). They were requested to perform the task by imagining the handgrip squeezing without any motor output. The remaining participants (without MT group) did not receive any attentional control reinforcement before physically performing the task. Nonetheless, all participants were familiarized with the physical task in order to prevent the development of temporal expectations during the initial trials of the physical task.

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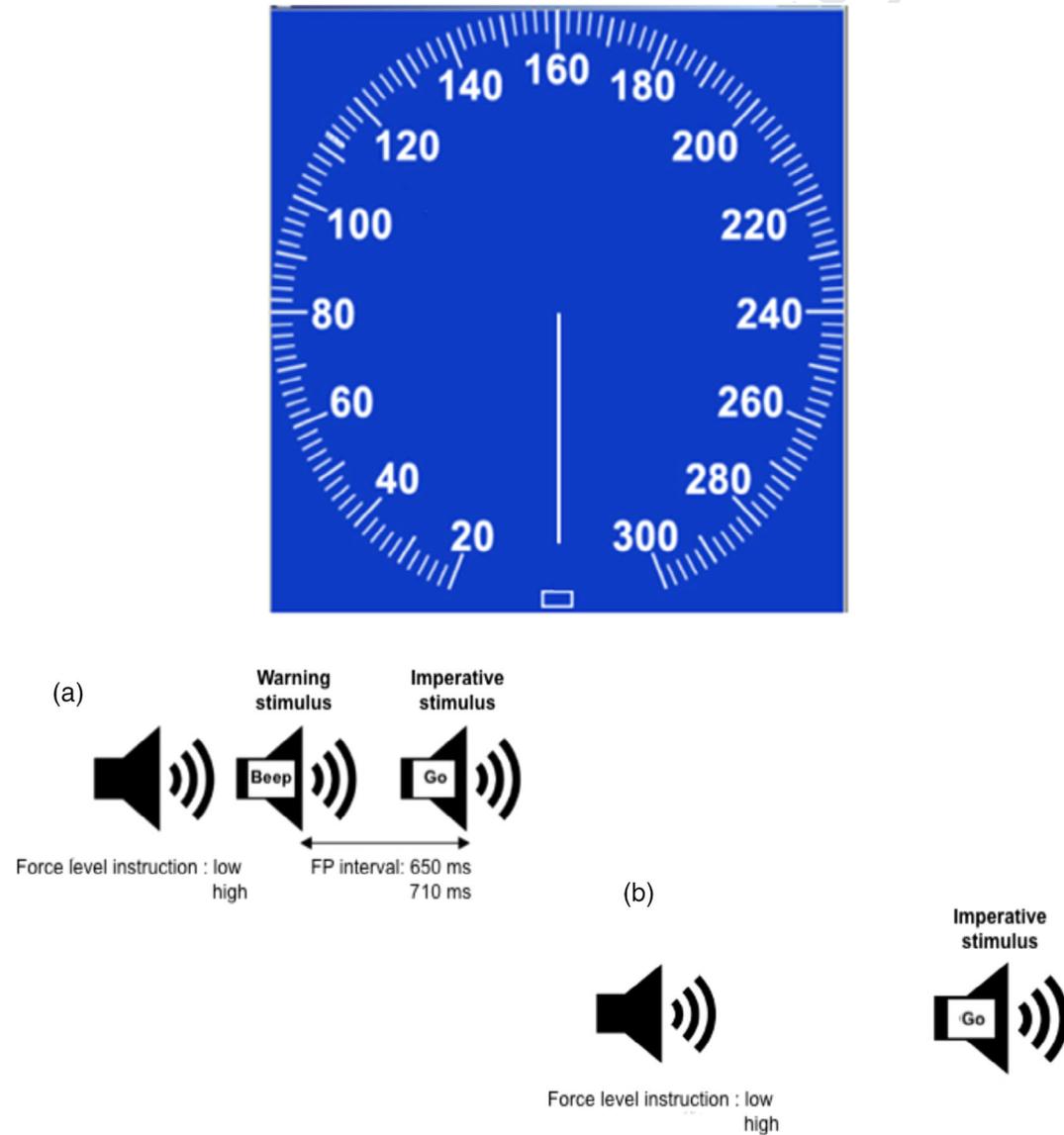


Fig. 1. Experimental task: (A) Exogenous condition: participants had to respond when they hear the target GO by squeezing the handgrip and positioning the needle of the gauge to the numerical value corresponding to 20% (low) or 80% (high) of their voluntary maximal force. The warning sound stimulus was transmitted during 50 ms and preceded the imperative stimulus with varying FPs. (B) Endogenous condition: participants had to respond when they hear the target GO by squeezing the handgrip and positioning the needle of the gauge to the numerical value corresponding to 20% or 80% of their maximum voluntary strength.

## 2.4. Behavioral indices

### 2.4.1. RT, force measures, and anticipation

RT in ms and force in kg measures were recorded by E-prime (version 2.0.8.22) and Acqknowledge software (5.0.4), respectively. The auditory stimuli were programmed using E-prime and synchronized with Acqknowledge to appear as digital inputs in separate channels. The force was measured by a handgrip (TSD121B Hand Dynamometer) which was connected to Acqknowledge and the force signal acquisition was recorded in a separate channel. Force values corresponded to the peak of the force signal.

RTs were extracted from the force signal for each trial by capturing the initial moments of the response that corresponded to 10–15% above the baseline. All responses less than 100 ms after the go signal are categorized as anticipation.

### 2.4.2. Accuracy of force levels

The success of the motor task was determined by how close the realized force level is to the desired one. Therefore, to investigate the ability to achieve the required force level, machine learning techniques automatically infer the different classes of force levels. These inferences automatically examine the statistical properties of the force peak and create a model which is used to predict the level of realized force and compares it to the desired one. In contrast, conventional approaches, that do not use artificial intelligence, are based on deterministic systems in which a set of rules are explicitly specified to perform the specific task. These rules are either determined by mathematical models or formally made explicit by the designer. This task is not obvious in this case. That is why, machine learning, a branch of artificial intelligence, was useful in our study. To ensure subjects compliance with the instructions and verify the relationship between speed and accuracy of responses, we measured the accuracy of the subject's answers for the different FPs and force levels. The criteria, used to evaluate the precision of the requested forces level depending on FPs, was the percentage of force level respect. The methodology to study the aptitude of the subjects to respect the force instructions was the following. First, the two force levels (low and high) were described through the normalized force percentage and reorganized according to the realized force levels. A classification approach based on the method of "Radial Basis Function Kernel Based Support Vector Machine" (Wang et al., 2004) was carried, yielding to two real classes which were not effectively equal to those requested. A comparison between the requested level of force and the realized one was analyzed and expressed in terms of the percentage of the respected force level. Second, we analyzed how the peak of the force was changing according to the required instruction. The mean values of normalized force percentage were determined for each force level in both groups of MT and without MT. The best precision was achieved when the mean value of each class (low, high) was close to the recommended one (0.2, 0.8).

## 2.5. Neurophysiological markers

Our methodological approach was chosen to capture fragments of the time course of the SCR, electrocardiogram, and respiration signals. More specifically, we have segmented the signals into time windows corresponding to the FPs duration and motor responses of

2 participants, which allows us to analyze the correlations between the autonomic nervous  
3 system components and the RTs.

#### 4 2.5.1. *Skin conductance responses*

5 The SCR signals have been used as tonic activity markers of the sympathetic nervous sys-  
6 tem. SCRs were recorded with the sensor positioned on the middle finger and the distal (first)  
7 phalanges of the index of the nondominant hand, using an electrodermal GEL101 to facilitate  
8 the contact between the sensor and the skin. SCRs data were analyzed according to the SPR  
9 Ad Hoc Committee on Electrodermal Measures (2012) as described in the AcqKnowledge  
10 software manual. The criterion for the smallest acceptable SCR was set at 0.03 microsiemens.  
11 The SCRs were recorded continuously and simultaneously during the experimental task  
12 using the BIOPAC MP160 system with the version 5.0.4 of AcqKnowledge. A period of  
13 5 min was recorded before initiating the experimental task to allow the participant to famil-  
14 iarize with the recording equipment.

#### 15 2.5.2. *Respiration*

16 We have controlled respiration by paced breathing to remove any possibility of influenc-  
17 ing the heart rate variability. We instructed the participants to breathe naturally during the  
18 task (Denver, Reed, & Porges, 2007). Respiration was recorded using a pneumatic respira-  
19 tion transducer (TSD221). Respiratory rate was extracted as described in the AcqKnowledge  
20 software manual (Grossman, van Beek, & Wientjes, 1990; Ritz et al., 2002). The respiration  
21 signal was recorded continuously and simultaneously during the experimental task using the  
22 BIOPAC MP160 system with the version 5.0.4 of AcqKnowledge. A period of 5 min was  
23 recorded before initiating the experimental task to allow the participant to familiarize with  
24 the recording equipment.

#### 25 2.5.3. *Electrocardiogram*

26 We have measured the heart rate variability using EL500 series disposable electrodes. The  
27 electrode positions have been applied according to the common Lead II configuration using  
28 GEL 100 to facilitate the contact. After filtering the signal, we decomposed the heart rate  
29 variability into two frequential components using a spectral analysis: low frequencies (LF)  
30 and high frequencies (HF). As (Malliani, Pagani, Lombardi, & Cerutti, 1991; Montano et al.,  
31 1994), we calculated the relative value of each component in proportion to the total power.  
32 The ratio of LF over HF in normalized units provided a balanced index allowing to control  
33 the behavior of the sympathetic and parasympathetic branches of the ANS (Malliani et al.,  
34 1991; Pagani et al., 1984). In addition, the normalization allows to reduce the impact of the  
35 changes in total power. The LF component has a frequency range between 0.04 and 0.15 Hz,  
36 whereas the HF component occurs at 0.15–0.4 Hz. LF/HF ratio was calculated as an index of  
37 sympathovagal balance, resulting from the sympathetic and parasympathetic (vagal) pathways  
38 of the ANS (Task Force of the European Society of Cardiology and The North American  
39 Society of Pacing and Electrophysiology, 1996). The details of the calculations are described  
40 in the international guidelines (Berntson et al., 1997; Task Force of the European Society of  
41 Cardiology and The North American Society of Pacing and Electrophysiology, 1996). The

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2 ECG signals were recorded continuously and simultaneously during the experimental task  
3 using the BIOPAC MP160 system with the version 5.0.4 of AcqKnowledge. A period of 5  
4 min was recorded before initiating the experimental task to allow the participant to familiarize  
5 with the recording equipment.

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## 2.6. Statistical analysis

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## 3. Results

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### 3.1. Behavioral indices

#### 3.1.1. Reaction times

First, RTs have been measured between both groups (MT and without MT) during the whole exogenous alertness task without separating the different FP and force levels. ANOVA [MT group  $\times$  without MT group] showed a significant interaction  $F = 456.7, p < .001, df = 1$  with a large effect size: partial  $\eta^2 = 0.21$ , between the MT group {mean = 307.08,  $SD = 56.9$ }; the 95% confidence interval = [305.17; 308.99] and the without MT group {mean = 342.56,  $SD = 59.60$ }; the 95% confidence interval = [340.56; 344.57].

Second, we have compared the force levels at FP 650 and 710 between both groups; we showed a significant interaction [Force level  $\times$  FPs  $\times$  Groups]  $F = 122.03, p < .001$  with a medium effect size: partial  $\eta^2 = 0.07$  (see Fig. 2).

Within the MT group, at FP 650, Bonferroni post-hoc comparisons showed a significant difference,  $p < .001$  between the RTs at low force level {mean = 344.61,  $SD = 49.41$ }, 95% confidence interval = [341.29; 347.65] and high force level {mean = 323.80,  $SD = 49.78$ }; the 95% confidence interval = [320.47; 327.14]. Within the without MT group, at FP 650, no significant difference between the force levels was observed. Within the MT group, at FP 710, Bonferroni post-hoc comparisons showed a significant difference,  $p < .001$  between low force level {mean = 268.27,  $SD = 47.68$ }, 95% confidence interval = [265.07; 271.47] and high force level {mean = 291.63,  $SD = 48.29$ }, 95% confidence interval = [288.39; 294.87].

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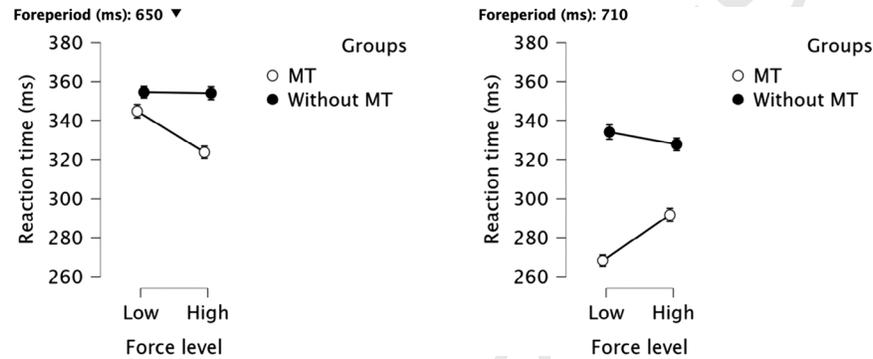


Fig. 2. Results of ANOVA [Groups × Foreperiods × force levels] in exogenous alertness task.

Within without MT group, at FP 710, no significant difference between the force levels was observed.

In the endogenous alertness task without separation of the two force levels, there is no significant difference in RTs, between groups with MT {mean = 372.01,  $SD = 57.63$ }, 95% confidence interval = [368.62; 375.40], and without MT {mean = 368.45,  $SD = 63.55$ }, 95% confidence interval = [364.71; 372.86]. Regarding the force levels, within MT group, there is no significant difference in RTs between low force level {mean = 370.85,  $SD = 51.7$ }, 95% confidence interval = [366.55; 375.14], and high force level {mean = 373.15,  $SD = 63.02$ }, 95% confidence interval = [367.91; 378.38]. Within without MT group, there is no significant difference in RTs between low force level {mean = 368.6,  $SD = 42.93$ }, 95% confidence interval = [365.03; 375.14], and high force level {mean = 368.29,  $SD = 79.01$ }, 95% confidence interval = [361.72; 374.85].

### 3.1.2. Anticipations

First, anticipations have been measured between both groups (MT and without MT) during the whole exogenous alerting task without separating the different FPs and force levels. ANOVA analysis showed a significant difference  $F = 11.23$ ,  $p < .001$ ,  $df = 1$  with a large effect size: partial  $\eta^2 = 0.13$  between the MT group {mean = 53.16,  $SD = 22.59$ }; the 95% confidence interval = [50.42; 55.91] and the without MT group {mean = 61.4,  $SD = 24.34$ }; the 95% confidence interval = [57.48; 65.33]. This result suggested that the subjects significantly anticipated the target after mental training, regardless of FP and force levels. Second, a more detailed analysis of anticipations depending on FPs and force levels within the MT group and the without MT was applied.

Within the MT group, we showed only a significant difference between FP 650 and high force level and FP 710 and low force level, the results are presented in Table 1. The warning stimulus further accelerates the responses at FP 650, a high force level.

Within the without MT group, regardless of FP and force levels, no significant difference was found between FP. Also, no significant difference during the endogenous alertness task between the two groups (MT and without MT) was observed.

Table 1  
Results of anticipation (ms) within the MT group at FP 650 and high force level, and FP 710 and low force level

Condition	Mean	SD	95% confidence interval	<i>p</i> Bonferroni
FP 650 and high force level	43.84	18.99	[42.25; 45.43]	< .001
FP 710 and low force level	65.43	20.96	[63.67; 67.18]	< .001

Table 2  
Results of force level respect within the MT group at FP 710 and low force level

Group	Percentage of force level respect (%)	Chi-squared	<i>p</i> Bonferroni
MT group	99.4	237.41	< .001
Without MT	90.87		< .001

### 3.1.3. Accuracy of force levels

The results are presented in Table 2. Reflecting within the MT group, at FP 710 and low force level, a higher accuracy of the force level requested was observed. No significant difference was found between the two groups at FP 710 and high force level. Additionally, no significant difference was found between the groups at FP 650, regardless of the force levels.

## 3.2. Neurophysiological markers

### 3.2.1. Correlational analysis between sympathetic (LF, SCR)/parasympathetic (HF component) indices and RTs in MT group

We performed a correlational analysis to study the relationship between the ANS markers and the RTs. At FP 650 and for a high force level, the sympathetic component of ANS dominated within the MT group. The RTs were positively and significantly correlated with LF {Pearson's  $r = .43$   $p < .001$ } and SCR activity {Pearson's  $r = .51$   $p < .001$ } and negatively and weakly correlated with HF {Pearson's  $r = -.20$   $p < .001$ } (see Fig. 3).

No significant correlation was found between the ANS markers and RTs within the without MT group.

At FP 710 and for a low force level, the parasympathetic component of ANS dominated within the MT group. The RTs were positively and weakly correlated with LF {Pearson's  $r = .30$   $p < .001$ } and SCRs activity {Pearson's  $r = .40$   $p < .001$ } and negatively and strongly correlated with HF {Pearson's  $r = -.56$   $p < .001$ } (see Fig. 4). No significant correlation was found between the ANS markers and RTs in the without MT group.

### 3.2.2. Sympathovagal balance

We did not find any significant differences in respiration rate across conditions (FPs and force levels) among the MT and without MT groups; therefore, we have calculated the LF/HF ratio, a metric of the sympathovagal balance.

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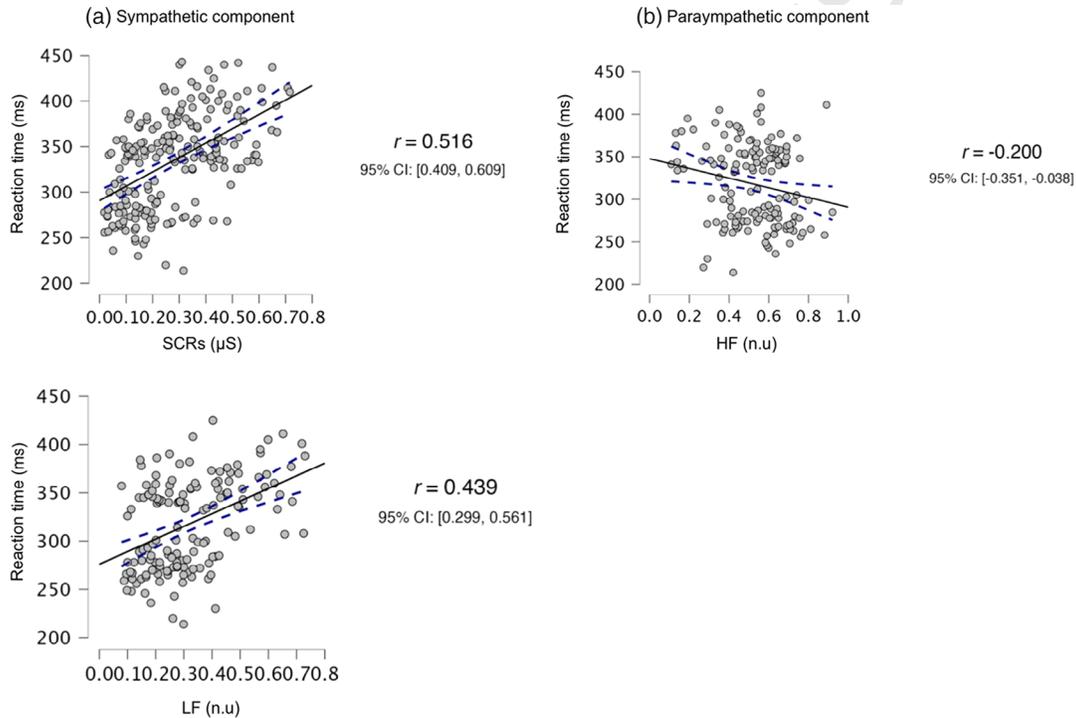


Fig. 3. (A) Correlation between LF and SCRs (sympathetic component) and reaction time and (B) correlation between HF (parasympathetic component) and reaction time during FP 650 and high force level.

A linear regression analysis at FP 710 and for a low force level allowed us to predict a significant relationship between LF/HF ratio and RTs within the MT group,  $R^2 = .21$ ,  $\{F = 35.33; p < .001\}$  (see Fig. 5).

#### 4. Discussion

The ability to selectively and rapidly allocate attentional resources in time and implement attentional and motor control is fundamental in the regulation of human behavior. The aim of our study was to investigate the role of force level and ANS during the temporal preparation process after attentional control reinforcement induced by a short session of mental training. The mental training allows to maintain a high state of arousal improving the interaction between ANS activity and attentional and motor control.

Our behavioral results demonstrate an improvement in RTs, notably at long FP (710 ms) compared to the short FP (650 ms) within the MT group. The increased probability and thus the predictability of imperative stimulus, induced by the FP, leads to decreased RT with increased FP duration (Schröter et al., 2015). This FP effect observed during the exogenous alertness task can be explained by increased attentional focus, allowing an efficient

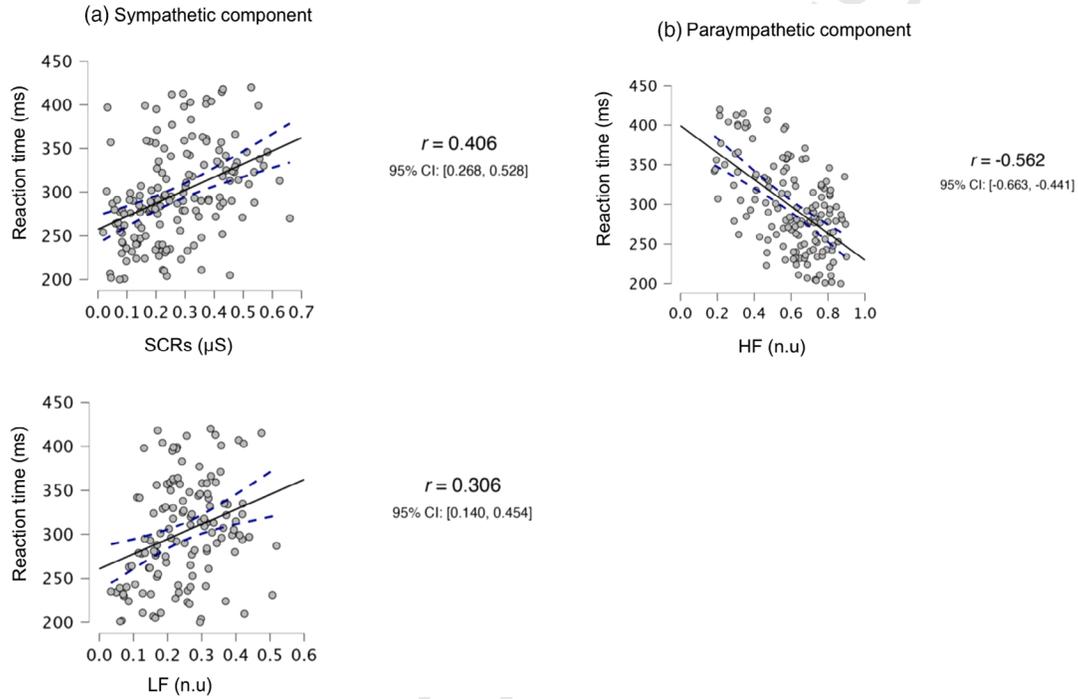


Fig. 4. (A) Correlation between LF and SCRs (sympathetic component) and reaction time and (B) correlation between HF (parasympathetic component) and reaction time (right) during FP 710 and low force level.

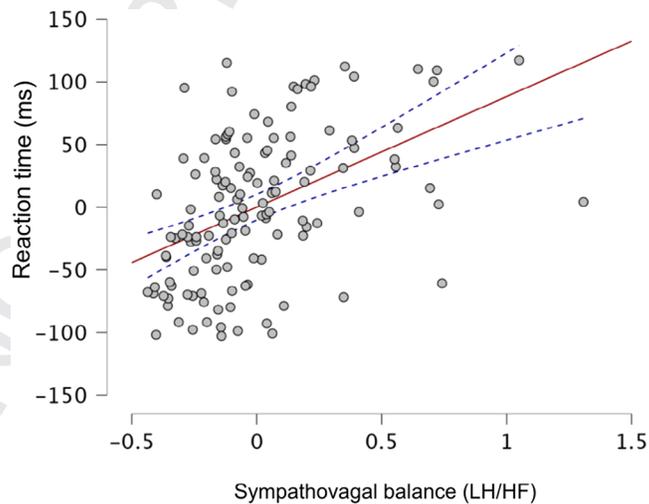


Fig. 5. Results of the linear regression sympathovagal balance (LH/HF) and RTs in FP 710 low force level. The graph is a residual plot resulting from the Durbin–Watson statistic to test the autocorrelation of the residuals (Field, Miles, & Field, 2012).

2 allocation of attentional resources to respond at the prominent moment (Elithorn & Lawrence,  
3 1955). Participants were more efficient at long FPs where the top-down control takes time  
4 during the alerting task to mobilize higher cognitive functions (Connor, Lithari, Collignon,  
5 Leonardelli, & Weisz, 2004; Posner et al., 1982). Also, the concomitant reinforcement of the  
6 autonomic arousal seems to facilitate and accelerate the response of the subjects. In contrast,  
7 no significant improvement in RTs was observed during the endogenous alertness task. This  
8 result is consistent with the idea that the autonomic arousal does not appear to contribute  
9 to an improvement in response to endogenous arousal. A novel part of our study is that we  
10 have combined attentional and force response to examine temporal preparation as well as the  
11 relationship between ANS and attentional performance, in particular after a mental training  
12 session.

13 During the short FP (650 ms) in the MT group, we observed that the high force level dom-  
14 inated RTs. This result is consistent with the Los's trace-conditioning model (2001), which  
15 suggests that the amount of preparation during short FP is less than at long FPs because  
16 short FPs are often associated with nonresponding or uncontrolled responses. This reduced  
17 response readiness might enable an optimal premotor regulation of force response and gives  
18 rise to more forceful responses that were more difficult to inhibit (Li, Krystal, & Mathalon,  
19 2005). Reduced FPs and increasing force levels induced a decline in attentional task perfor-  
20 mance manifested by increasing RTs and anticipation.

21 Additionally, during the short FP, mental training did not lead to a significant improvement  
22 in force response accuracy, and anticipations were widely increased. Consequently, we may  
23 suggest that when the attention is divided between mental effort, warning cue, and imperative  
24 stimulus, anticipations extensively increase, and the accuracy of responses decreases signif-  
25 icantly; the mental training does not seem effective in increasing the accuracy of the motor  
26 responses. This interpretation is supported by Kahneman (1973) and Daly et al. (2020), which  
27 consider the interference between signals is due to a lack of temporal deployment of atten-  
28 tion to task cognitive demands. In a similar vein, we suppose that time pressure related to  
29 the mental effort at short FPs with a high force level may mobilize suddenly and rapidly the  
30 autonomic arousal (notably the sympathetic component) and subjects cannot reach an opti-  
31 mal attentional level during short FP intervals. Thereby, the increased sudden mental effort  
32 during short time scales (FP) produces cognitive interference, which reduces the allocation  
33 of resources to moments of the target, giving rise to a phenomenon of inability to control the  
34 engagement of exogenous temporal attention.

35 During the long FP (710 ms) in the MT group, we observed that the low force level domi-  
36 nated RTs. Our results showed that lower force levels resulted in short RTs and more accurate  
37 responses compared to the higher force level. This result suggests that the low force does not  
38 require a substantial mental and physical effort, so participants are more constantly focused  
39 on the target arrival. The significant improvement in motor response accuracy demonstrates  
40 that mental training which associates endogenous and exogenous alertness tasks would ame-  
41 liorate the speed and accuracy of responses as shown in a previous study (McCormick et al.,  
42 2019). Moreover, the improvement of attentional performance could be explained by an auto-  
43 nomic arousal modulation produced during the MT session, which would help to ensure an  
44 optimal arousal reinforcing the attention control. Thereby, long FPs and low force make a

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2 state of optimal sustained attention where arousal is prolonged for a period of time and the  
3 mind maintains focus with a constant effort to efficiently solicit attention resources (Helge  
4 Johnsen, Christian Laberg, Eid, & Hugdahl, 2002, Petersen & Posner, 2012).

5 With mental training, subjects showed a significant increase of the anticipations, an effect  
6 most pronounced at short FP and high force level. This heightened anticipation is linked to  
7 the participant's lack of temporal preparation. Also, as Cravo, Rohenkohl, Santos, and Nobre  
8 (2017) have shown, it can be attributed to the memory, known for its dynamic and temporal  
9 nature, which enables the active and dynamic guidance of attention based on learned temporal  
10 associations.

11 With regard to our results, it could be interesting to study the oculomotor system activity.  
12 According to Badde, Myers, Yuval-Greenberg, and Carrasco (2020), oculomotor freezing can  
13 be indicative of temporal expectation in the tactile stimulus, and microsaccades occurring  
14 during tactile target presentation are linked with decreased task performance. Furthermore,  
15 research in the auditory domain has revealed a connection between temporal expectation and  
16 oculomotor freezing. Therefore, in the case of our study, it would be interesting to explore  
17 if microsaccade rates decrease with temporal attention to visual targets, increased attentional  
18 and working memory load, and elevated task complexity in both visual and nonvisual tasks.

19 Interestingly, our study managed to show significant cognitive and neurophysiological  
20 interactions between ANS components and cognitive index (RTs) during the temporal prepa-  
21 ration task. At short FPs and for a high force level, our results showed that increasing RTs  
22 were positively correlated with the increasing of sympathetic activity (LF and SCR), and neg-  
23 atively correlated with the decreasing of parasympathetic activity (HF). This result suggests  
24 that the sympathetic component would be dominantly mobilized when participants speed up  
25 their response with little precision. Previous studies showed that the impaired sympathetic  
26 vagal balance and changes in heart rate variability are associated with changes in the dorso-  
27 lateral prefrontal cortex (Thayer et al., 2012) and influence working memory (Forte, Favieri,  
28 & Casagrande, 2019), attention (Alba, Vila, Rey, Montoya, & Muñoz, 2019), and cognitive  
29 flexibility (Alasfour, Jiang, Gonzalez-Martinez, Gilja, & Halgren, 2021). Therefore, suddenly  
30 increased mental effort induced by short FPs and high force level heightens the sympathetic  
31 component of the autonomic arousal which disrupts attentional performance and leads to  
32 decreased force accuracy and increased RTs. From a neurobiological point of view, reduced  
33 FPs duration and increased force level mobilize a sympathetic system which may inhibit  
34 the visceral vagus to stimulate the mobilization of behaviors that are necessary for "fight or  
35 flight" (Cannon, 1928; Porges, 2001). This sympathetic activity abruptly increases, leading to  
36 the release of adrenaline and noradrenaline which facilitate the use of energy and prepare the  
37 body for rapid reactions (Sved et al., 2001).

38 More interestingly, at long FPs and low force, our results indicate that the decreasing of RTs  
39 was negatively correlated with the increasing parasympathetic activity (HF) and positively  
40 correlated with the sympathetic activity (LF and SCRs). This result suggests that the parasymp-  
41 pathetic component of the autonomic arousal is consistent with an optimal (critical) state of  
42 attention, reflecting a better attentional performance. Previous reports showed that a combina-  
43 tion of inhibition and excitation states occurs during FPs interval (Posner & Boies, 1971; Salet  
44 et al., 2022); consequently, the parasympathetic dominance during long FPs and low force

condition might reflect an inhibition process of irrelevant and premature responses to facilitate the speed and the efficiency of the response (Graham & Clifton, 1966). From a neurobiological point of view, reduced RTs and enhanced force response accuracy could be explained by the activation of cholinergic neurons which modulate the attentional and motor control and thinking capacity (Parikh & Sarter, 2008). Finally, we showed in our study that the attentional performance during long FPs and low force level can be predicted by the sympathovagal balance (LF/HF) which is in line with a previous study demonstrating that the speed-accuracy trade-off can be predicted through a high vagal activity (Hansen, Johnsen, & Thayer, 2003).

## 5. Advantage of machine learning in our study

The use of machine learning techniques, such as a support vector machine model, to assess grip accuracy offers several advantages over conventional approaches based on exploratory or statistical analysis of force. In fact, common approaches use descriptive analysis, data visualization or define, heuristically, the range within which the recorded force measurements should fall to be considered respectful of the level. Statistical tests compare the recorded force measurements with the specified force levels by defining null (resp., alternative) hypothesis that the 'participants' force does not differ (resp., differ) significantly from the specified force level. The difficulty appears in the way to define quantitatively how force level differs significantly or not. In contrast, machine learning can offer several advantages over traditional statistical tests or tolerance limit methods. It can capture complex relationships and nonlinear patterns that might be missed by simple statistical tests or predefined tolerance limit. If the dataset includes a diverse range of parameters (features) and experimental conditions as is the case in our study, machine learning algorithms have the potential to achieve higher accuracy in classifying force levels compared to simpler statistical methods.

## 6. Methodological limits

In our study, we have controlled the respiration and analyzed the heart rate variability data using mainly a spectral analysis method where we extracted HF as an indicator widely used to quantify the parasympathetic vagal tonus and LF as a dominant sympathetic component. Also, we assumed in our results that the LF/HF ratio may vary linearly with the RT. However, it is likely that the two sympathetic and parasympathetic systems interact in a nonlinear manner due to the complex interactions that occur between them. Accordingly, to this remark, we should be careful using the LF/HF ratio to quantify the sympathovagal balance (Malliani et al., 1991; Pagani et al., 1984). An alternative solution would be to consider nonlinear methods as, for example, the Poincare plot which makes it possible to index the complexity and the adaptation of the systems (Roy & Ghatak, 2013; Schubert et al., 2009). Also, a measurement of the entropy of the system using the Approximate Entropy index (Pincus, 2001) could be another option that allows a measure of the amount of information needed to predict the evolution of the state of the system. Finally, another limitation of this study was the small number of participants. Future studies with a larger sample size should be performed to confirm our findings.

## 7. Conclusion

The present results show that the benefit of temporal preparation can be optimized with mental training. We demonstrated that mental training modulates the dynamic interaction between sympathetic and parasympathetic components of ANS and improves attentional performance by decreasing RT and anticipation, in particular during the exogenous alertness condition. The short FPs and high force-induced time pressure increased sympathetic activity, leading to poorer attentional performance. Conversely, long FPs and low force level increased the parasympathetic component of autonomic arousal making it possible to optimize attentional performance.

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## Conflict of interest statement

The authors of this manuscript declare that they have no conflict of interest to disclose.

## References

- Alasfour, A., Jiang, X., Gonzalez-Martinez, J., Gilja, V., & Halgren, E. (2021). High activity in cortex and hippocampus is correlated with autonomic tone during sleep. *eNeuro*, 8(6). <https://doi.org/10.1523/ENEURO.0194-21>
- Alba, G., Vila, J., Rey, B., Montoya, P., & Muñoz, M. Á. (2019). The relationship between heart rate variability and electroencephalography functional connectivity variability is associated with cognitive flexibility. *Frontiers in Human Neuroscience*, 13, 64. <https://doi.org/10.3389/fnhum.2019.00064>
- Backs, R. W., & Ryan, A. M. (1992). Multimodal measures of mental workload during dual-task performance: Energetic demands of cognitive processes. In Proceedings of the Human Factors Society Annual Meeting. Los Angeles, CA: SAGE Publications. <https://doi.org/10.1177/154193129203601811>
- Badde, S., Myers, C. F., Yuval-Greenberg, S., & Carrasco, M. (2020). Oculomotor freezing reflects tactile temporal expectation and aids tactile perception. *Nature Communications*, 11(1), 3341. <https://doi.org/10.1038/s41467-020-17160-1>
- Berntson, G. G., Thomas Bigger, J., Eckberg, D. L., Grossman, P., Kaufmann, P. G., Malik, M., Nagaraja, H. N., Porges, S. W., Saul, J. P., Stone, P. H., & Van Der Molen, M. W. (1997). Heart rate variability: Origins, methods, and interpretive caveats. *Psychophysiology*, 34(6), 623–648. <https://doi.org/10.1111/j.1469-8986.1997.tb02140.x>
- Cannon, W. B. (1914). The emergency function of the adrenal medulla in pain and the major emotions. *American Journal of Physiology-Legacy Content*, 33(2), 356–372.
- Cannon, W. B. (1928). Neural organization for emotional expression.
- Connor, C. E., Lithari, C., Collignon, O., Leonardelli, E., & Weisz, N. (2004). Visual attention: Bottom-up versus top-down. *Current Biology*, 14(19), R850–R852. <https://doi.org/10.1016/j.cub.2004.09.041>

- Coull, J. T., Nobre, A. C., & Frith, C. D. (2001). The noradrenergic  $\alpha 2$  agonist clonidine modulates behavioural and neuroanatomical correlates of human attentional orienting and alerting. *Cerebral Cortex*, *11*(1), 73–84. <https://doi.org/10.1093/cercor/11.1.73>
- Cravo, A. M., Rohenkohl, G., Santos, K. M., & Nobre, A. C. (2017). Temporal anticipation based on memory. *Journal of Cognitive Neuroscience*, *29*(12), 2081–2089. [https://doi.org/10.1162/jocn\\_a\\_01172](https://doi.org/10.1162/jocn_a_01172)
- Critchley, H. D. (2002). Electrodermal responses: What happens in the brain. *Neuroscientist*, *8*(2), 132–142. <https://doi.org/10.1177/107385840200800>
- Daly, S., Thai, J., Belkhiria, C., Langley, C., Le Blanche, A., & de Marco, G. (2020). Temporal deployment of attention by mental training: An fMRI study. *Cognitive, Affective, & Behavioral Neuroscience*, *20*(4), 669–683. <https://doi.org/10.3758/s13415-020-00795-4>
- Decety, J., & Grèzes, J. (1999). Neural mechanisms subserving the perception of human actions. *Trends in Cognitive Sciences*, *3*(5), 172–178. [https://doi.org/10.1016/s1364-6613\(99\)01312-1](https://doi.org/10.1016/s1364-6613(99)01312-1)
- Denver, J. W., Reed, S. F., & Porges, S. W. (2007). Methodological issues in the quantification of respiratory sinus arrhythmia. *Biological Psychology*, *74*(2), 286–294. <https://doi.org/10.1016/j.biopsycho.2005.09.005>
- Task Force of the European Society of Cardiology and The North American Society of Pacing and Electrophysiology. (1996). Heart rate variability: Standards of measurement, physiological interpretation, and clinical use. *Circulation*, *93*(5), 1043–1065. <https://doi.org/10.1161/01.CIR.93.5.1043>
- Elithorn, A., & Lawrence, C. (1955). Central inhibition—Some refractory observations. *Quarterly Journal of Experimental Psychology*, *7*(3), 116–127. <https://doi.org/10.1080/17470215508416684>
- Field, A. P., Miles, J., & Field, Z. (2012). *Discovering statistics using R*. London: Sage.
- Forte, G., Favieri, F., & Casagrande, M. (2019). Heart rate variability and cognitive function: A systematic review. *Frontiers in Neuroscience*, *13*, 710. <https://doi.org/10.3389/fnins.2019.00710>
- Graham, F. K., & Clifton, R. K. (1966). Heart-rate change as a component of the orienting response. *Psychological Bulletin*, *65*(5), 305. <https://doi.org/10.1037/h0023258>
- Grossman, P., van Beek, J., & Wientjes, C. (1990). A comparison of three quantification methods for estimation of respiratory sinus arrhythmia. *Psychophysiology*, *27*(6), 702–714. <https://doi.org/10.1111/j.1469-8986.1990.tb03198.x>
- Hackley, S. A., Schankin, A., Wohlschlaeger, A., & Wascher, E. (2007). Localization of temporal preparation effects via trisected reaction time. *Psychophysiology*, *44*(2), 334–338. <https://doi.org/10.1111/j.1469-8986.2007.00500.x>
- Hansen, A. L., Johnsen, B. H., & Thayer, J. F. (2003). Vagal influence on working memory and attention. *International Journal of Psychophysiology*, *48*(3), 263–274. [https://doi.org/10.1016/S0167-8760\(03\)00073-4](https://doi.org/10.1016/S0167-8760(03)00073-4)
- Helge Johnsen, B., Christian Laberg, J., Eid, J., & Hugdahl, K. (2002). Dichotic listening and sleep deprivation: Vigilance effects. *Scandinavian Journal of Psychology*, *43*(5), 413–417. <https://doi.org/10.1111/1467-9450.00309>
- Jackson, P. L., Lafleur, M. F., Malouin, F., Richards, C., & Doyon, J. (2001). Potential role of mental practice using motor imagery in neurologic rehabilitation. *Archives of Physical Medicine and Rehabilitation*, *82*(8), 1133–1141. <https://doi.org/10.1053/apmr.2001.24286>
- Kahneman, D. (1973). *Attention and effort* (Vol. 1063, pp. 218–226). Englewood Cliffs, NJ: Prentice-Hall.
- Kahneman, D., Tursky, B., Shapiro, D., & Crider, A. (1969). Pupillary, heart rate, and skin resistance changes during a mental task. *Journal of Experimental Psychology*, *79*(1p1), 164. <https://doi.org/10.1037/h0026952>
- Klein, R. M. (2009). On the control of attention. *Canadian Journal of Experimental Psychology*, *63*, 240–252. <https://doi.org/10.1037/a0015807>
- Lacey, J. I. (1967). Somatic response patterning and stress: Some revisions of activation theory. *Psychological Stress: Issues in Research*, 14–37.
- Lawrence, M. A., & Klein, R. M. (2013). Isolating exogenous and endogenous modes of temporal attention. *Journal of Experimental Psychology: General*, *142*(2), 560. <https://doi.org/10.1037/a0029023>
- Li, C.-S. R., Krystal, J. H., & Mathalon, D. H. (2005). Fore-period effect and stop-signal reaction time. *Experimental Brain Research*, *167*(2), 305–309. <https://doi.org/10.1007/s00221-005-0110-2>

- 2 Los, S. A., & Heslenfeld, D. J. (2005). Intentional and unintentional contributions to nonspecific preparation:  
3 Electrophysiological evidence. *Journal of Experimental Psychology: General*, *134*, 52–72. <https://doi.org/10.1037/0096-3445.134.1.52>
- 4 Los, S. A., & Van den Heuvel, C. E. (2001). Intentional and unintentional contributions to nonspecific preparation  
5 during reaction time foreperiods. *Journal of Experimental Psychology: Human Perception and Performance*,  
6 *27*, 370–386. <https://doi.org/10.1037/0096-1523.27.2.370>
- 7 Los, S. A., Knol, D. L., & Boers, R. M. (2001). The foreperiod effect revisited: Conditioning as a basis for non-  
8 specific preparation. *Acta Psychologica*, *106*(1–2), 121–145. [https://doi.org/10.1016/S0001-6918\(00\)00029-9](https://doi.org/10.1016/S0001-6918(00)00029-9)
- 9 Los, S. A., Kruijne, W., & Meeter, M. (2014). Outlines of a multiple trace theory of temporal preparation. *Frontiers*  
10 *in Psychology*, *5*, 1058. <https://doi.org/10.3389/fpsyg.2014.01058>
- 11 Malliani, A., Pagani, M., Lombardi, F., & Cerutti, S. (1991). Cardiovascular neural regulation explored in the  
12 frequency domain. *Circulation*, *84*(2), 482–492. <https://doi.org/10.1161/01.CIR.84.2.482>
- 13 Mattes, S., & Ulrich, R. (1997). Response force is sensitive to the temporal uncertainty of response stimuli. *Per-*  
14 *ception & Psychophysics*, *59*(7), 1089–1097. <https://doi.org/10.3758/BF03205523>
- 15 McCormick, C., Redden, R. S., Hurst, A. J., & Klein, R. M. (2019). On the selection of endogenous and exogenous  
16 signals. *Royal Society Open Science*, *6*(11), 190134. <https://doi.org/10.1098/rsos.190134>
- 17 Montano, N., Ruscone, T. G., Porta, A., Lombardi, F., Pagani, M., & Malliani, A. (1994). Sympathovagal balance  
18 during graded orthostatic tilt. <https://doi.org/10.1161/01.CIR.90.4.1826>
- 19 Niemi, P. N. R., & Näätänen, R. (1981). Foreperiod and simple reaction time. *Psychological Bulletin*, *89*, 133–162.  
20 <https://doi.org/10.1037/0033-2909.89.1.133>
- 21 Nobre, A. C. (2001). Orienting attention to instants in time. *Neuropsychologia*, *39*(12), 1317–1328. [https://doi.org/10.1016/S0028-3932\(01\)00120-8](https://doi.org/10.1016/S0028-3932(01)00120-8)
- 22 Nobre, A. C., & van Ede, F. (2023). Attention in flux. *Neuron*, *111*(7), 971–986.
- 23 Nobre, K., & Coull, J. T. (2010). *Attention and time*. Oxford University Press.
- 24 Pagani, M., Lombardi, F., Guzzetti, S., Sandrone, G., Rimoldi, O., Malfatto, G., Cerutti, S., & Malliani, A. (1984).  
25 Power spectral density of heart rate variability as an index of sympatho-vagal interaction in normal and hyper-  
26 tensive subjects. *Journal of Hypertension*, *2*(3), S383–S385.
- 27 Parikh, V., & Sarter, M. (2008). Cholinergic mediation of attention: Contributions of phasic and tonic increases  
28 in prefrontal cholinergic activity. *Annals of the New York Academy of Sciences*, *1129*(1), 225–235. <https://doi.org/10.1196/annals.1417.021>
- 29 Périn, B., Godefroy, O., Fall, S., & de Marco, G. (2010). Alertness in young healthy subjects: An fMRI study of  
30 brain region interactivity enhanced by a warning signal. *Brain and Cognition*, *72*(2), 271–281. <https://doi.org/10.1016/j.bandc.2009.09.010>
- 31 Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Review of*  
32 *Neuroscience*, *35*, 73. <https://doi.org/10.1146/annurev.ne.13.030190.000325>
- 33 Pincus, S. M. (2001). Assessing serial irregularity and its implications for health. *Annals of the New York Academy*  
34 *of Sciences*, *954*(1), 245–267. <https://doi.org/10.1111/j.1749-6632.2001.tb02755.x>
- 35 Porges, S. W. (2001). The polyvagal theory: Phylogenetic substrates of a social nervous system. *International*  
36 *Journal of Psychophysiology*, *42*(2), 123–146. [https://doi.org/10.1016/S0167-8760\(01\)00162-3](https://doi.org/10.1016/S0167-8760(01)00162-3)
- 37 Porges, S. W., & Raskin, D. C. (1969). Respiratory and heart rate components of attention. *Journal of Experimental*  
38 *Psychology*, *81*(3), 497. <https://doi.org/10.1037/h0027921>
- 39 Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, *32*, 3–25. <https://doi.org/10.1080/0033558008248231>
- 40 Posner, M. I., & Boies, S. J. (1971). Components of attention. *Psychological Review*, *78*(5), 391. <https://doi.org/10.1037/h0031333>
- 41 Posner, M. I., Cohen, Y., & Rafal, R. D. (1982). Neural systems control of spatial orienting. *Philosophical Trans-*  
42 *actions of the Royal Society of London. B, Biological Sciences*, *298*(1089), 187–198. <https://doi.org/10.1098/rstb.1982.0081>
- 43
- 44

1 20 of

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- 2 Ritz, T., Dahme, B., Dubois, A. B., Folgering, H., Fritz, G. K., Harver, A., Kotses, H., Lehrer, P. M., Ring,  
3 C., Steptoe, A., & van de Woestijne, K. P. (2002). Guidelines for mechanical lung function measurements in  
4 psychophysiology. *Psychophysiology*, *39*(5), 546–567. <https://doi.org/10.1111/1469-8986.3950546>
- 5 Roy, B., & Ghatak, S. (2013). Nonlinear methods to assess changes in heart rate variability in type 2 diabetic  
6 patients. *Arquivos Brasileiros De Cardiologia*, *101*, 317–327. <https://doi.org/10.5935/abc.20130181>
- 7 Salet, J. M., Kruijne, W., van Rijn, H., Los, S. A., Meeter, M. (2022). FMTP: A unifying computational framework  
8 of temporal preparation across time scales. *Psychological Review*, <https://doi.org/10.1037/rev0000356>
- 9 Sanders, A. F. (1990). Issues and trends in the debate on discrete vs. continuous processing of information. *Acta*  
10 *Psychologica*, *74*(2–3), 123–167. [https://doi.org/10.1016/0001-6918\(90\)90004-Y](https://doi.org/10.1016/0001-6918(90)90004-Y)
- 11 Schröter, H., Birngruber, T., Bratzke, D., Miller, J., & Ulrich, R. (2015). Task predictability influences the variable  
12 foreperiod effect: Evidence of task-specific temporal preparation. *Psychological Research*, *79*(2), 230–237.  
13 <https://doi.org/10.1007/s00426-014-0550-z>
- 14 Schubert, C., Lambertz, M., Nelesen, R. A., Bardwell, W., Choi, J.-B., & Dimsdale, J. E. (2009). Effects of stress  
15 on heart rate complexity—A comparison between short-term and chronic stress. *Biological Psychology*, *80*(3),  
16 325–332. <https://doi.org/10.1016/j.biopsycho.2008.11.005>
- 17 SPR Ad Hoc Committee on Electrodermal Measures. (2012). Publication recommendations for electrodermal  
18 measurements. *Psychophysiology*, *49*(8), 1017–1034. <https://doi.org/10.1111/j.1469-8986.2012.01384.x>
- 19 Sturm, W., & Willmes, K. (2001). On the functional neuroanatomy of intrinsic and phasic alertness. *Neuroimage*,  
20 *14*(1), S76–S84. <https://doi.org/10.1006/nimg.2001.0839>
- 21 Sved, A., Cano, G., & Card, J. P. (2001). Neuroanatomical specificity of the circuits controlling sympathetic  
22 outflow to different targets. *Clinical and Experimental Pharmacology & Physiology*, *28*(1–2), 115–119. <https://doi.org/10.1046/j.1440-1681.2001.03403.x>
- 23 Q11 Tatler, B. W., & Land, M. F. (2015). Everyday visual attention. In *The handbook of attention* (pp. 391–421).  
24 <https://doi.org/10.7551/mitpress/10033.003.0020>
- 25 Thayer, J. F., & Lane, R. D. (2000). A model of neurovisceral integration in emotion regulation and dysregulation.  
26 *Journal of Affective Disorders*, *61*(3), 201–216. [https://doi.org/10.1016/S0165-0327\(00\)00338-4](https://doi.org/10.1016/S0165-0327(00)00338-4)
- 27 Thayer, J. F., Hansen, A. L., Saus-Rose, E., & Johnsen, B. H. (2009). Heart rate variability, prefrontal neural  
28 function, and cognitive performance: The neurovisceral integration perspective on self-regulation, adaptation,  
29 and health. *Annals of Behavioral Medicine*, *37*(2), 141–153. <https://doi.org/10.1007/s12160-009-9101-z>
- 30 Thayer, J. F., Ahs, F., Fredrikson, M., Sollers 3rd, J. J., & Wager, T. D. (2012). A meta-analysis of heart rate  
31 variability and neuroimaging studies: Implications for heart rate variability as a marker of stress and health.  
32 *Neuroscience & Biobehavioral Reviews*, *36*(2), 747–756. <https://doi.org/10.1016/j.neubiorev.2011.11.009>
- 33 Thayer, J. F., Yamamoto, S. S., & Brosschot, J. F. (2010). The relationship of autonomic imbalance, heart rate  
34 variability and cardiovascular disease risk factors. *International Journal of Cardiology*, *141*(2), 122–131. <https://doi.org/10.1016/j.ijcard.2009.09.543>
- 35 Vallesi, A., & Shallice, T. (2007). Developmental dissociations of preparation: Deconstructing variable foreperiod  
36 phenomena. *Journal of Experimental Psychology: Human Perception and Performance*, *33*, 1377–1388. <https://doi.org/10.1037/0096-1523.33.6.1377>
- 37 Vallesi, A., Mussoni, A., Mondani, M., Budai, R., Skrap, M., & Shallice, T. (2007). The neural basis of temporal  
38 preparation: Insights from brain tumor patients. *Neuropsychologia*, *45*, 2755–2763. <https://doi.org/10.1016/j.neuropsychologia.2007.04.017>
- 39 Vallesi, A., Shallice, T., & Walsh, V. (2007). Role of the prefrontal cortex in the foreperiod effect: TMS evidence  
40 for dual mechanisms in temporal preparation. *Cerebral Cortex*, *17*, 466–474. <https://doi.org/10.1093/cercor/bhj163>
- 41 Q12 Wang, J., Chen, Q., & Chen, Y. (2004). RBF kernel based support vector machine with universal approxima-  
42 tion and its application. In *International Symposium on Neural Networks* (pp. 512–517). Berlin, Heidelberg:  
43 Springer. [https://doi.org/10.1007/978-3-540-28647-9\\_85](https://doi.org/10.1007/978-3-540-28647-9_85)
- 44 Woodrow, H. (1914). The measurement of attention. *Psychological Monographs*, *17*(5). <https://doi.org/10.1037/h0093087>