Received: 18 August 2020 | Revised: 8 July 2021 | Accepted: 27 July 2021

DOI: 10.1111/psyp.13920

ORIGINAL ARTICLE

PSYCHOPHYSIOLOGY SPR WILEY

Performance-dependent reward hurts performance: The non-monotonic attentional load modulation on task-irrelevant distractor processing

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Funding information
National Natural Science Foundation of China, Grant/Award Number: 31571112, 31830037 and 31871104

Abstract

Selective attention is essential when we face sensory inputs with distractions. In the past decades, Lavie's load theory of selective attention delineates a complete picture of distractor suppression under different attentional control load. The present study was originally designed to explore how reward modulates the load effect of attentional selection. Unexpectedly, it revealed new findings under extended attentional load that was not involved in previous work. Participants were asked to complete a rewarded attentive visual tracking task while presented with irrelevant auditory oddball stimuli, with their behavioral performance, event-related potentials and pupillary responses recorded. We found that although the behavioral performance and pupil sizes varied unidirectionally with the attentional load, the processing of distractors as reflected by the mismatch negativity (MMN) increased first and then decreased. In contrast to the prediction of Lavie's theory that attentional control fails to effectively suppress distractor processing under high attentional control load, our finding suggests that extremely high attentional control load may instead require suppression of distractor processing at a stage as early as possible. Besides, P3a, a positive-polarity response sometimes following the MMN, was not affected by the attentional load, but both N1 (a negative-polarity component peaking ~100 ms from sound onset) and P3a were weakened at higher reward, indicating that reward leads to attenuated early processing of distractor and thus suppresses the attentional orienting towards distractors. These findings altogether complement Lavie's load theory of selective attention, presenting a more complex picture of how attentional load and reward affects selective attention.

KEYWORDS

attention, ERP, MMN, multiple object tracking, P3a, reward

1 | INTRODUCTION

Rarely can we get rid of external distractions when working. Drawing our attention more or less, distractions often affect our performance of executing a certain task and sometimes even lead to dangers. Hence, it is essential for the cognitive system to filter the sensory inputs and block the distractors. This function involves attentional selection.

The underlying mechanisms for attentional selection are relatively complicated. For example, it has been under debate for decades at which stage of processing the distractor filtering happens. Some researchers found that selective attention could prevent the distractors from being processed at an early perceptual stage (Treisman, 1969; Treisman & Geffen, 1967) while others suggested that only at a rather late, post-perceptual stage did selective attention take effect (Duncan, 1980; Eriksen & Eriksen, 1974).

Lavie and colleagues later proposed the load theory of selective attention (Lavie, 2000, 2005; Lavie et al., 2004), a hybrid model with two independent attentional mechanisms for distractor suppression that corresponded to two types of cognitive capacity and load. Under the high perceptual load that fills almost the whole perceptual capacity, an early attentional mechanism begins to work so that distractive task-irrelevant stimuli can be passively excluded from forming a perception (Lavie, 1995). However, when perceptual load is lower, which is a more common case, irrelevant stimuli may harness the available perceptual resource to be perceived. In this case, a second attentional mechanism will act to actively suppress the further processing on the irrelevant distractors. This second mechanism relies on the capacity for high-order control functions. Therefore, if a high load of cognitive control (e.g., attention or working memory) consumes excessive amount of resources, attentional control will fail to effectively suppress the distractor processing, resulting in stronger interference (Allen & Ueno, 2018; de Fockert et al., 2001; Lavie & de Fockert, 2005).

To further ascertain how attentional selection works at different stages of visual processing, measurements with high temporal resolutions are demanded. Thus, instead of psychophysical methods, event-related potentials (ERPs) are often adopted. For this goal, P. Zhang et al. (2006) designed an attentive visual tracking task with irrelevant auditory oddball stimuli, and found that the amplitude of mismatch negativity (MMN) increased with visual attentional load. Since MMN is considered to represent an automatic pre-attentive detection of an auditory deviant stimulus which is largely independent of attention (Näätänen et al., 1978, 1980; see, however, Näätänen et al., 1993; Woldorff et al., 1991), P. Zhang et al.'s (2006) finding suggested that the processing of distractors strengthened with the load. This was in line with the above-mentioned Lavie's load theory with respect to the active mechanism for distractor suppression. In contrast, P. Zhang et al. also found that only when the load was the lowest was P3a significantly evoked. This indicated that the high attentional load attenuated the attentional orienting towards salient but irrelevant stimuli, as P3a has been proposed to be associated with involuntary attentional capture by an auditory deviant (Polich, 2007; Squires et al., 1975).

From the findings of P. Zhang et al. (2006), we know that the load effect on attentional selection is present at both early and late stages. Like attentional selection, reward also plays an important role in filtering visual information (Allen & Ueno, 2018; Anderson et al., 2011; Anderson & Yantis, 2012; Baldassi & Simoncini, 2011; della Libera et al., 2011; Hickey et al., 2010; Massar et al., 2016; Zhan et al., 2016). One interesting question is whether reward can modulate the load effect on attentional selection or not. And, if so, at which stage(s) it takes effect. To answer this question, here we adopted basically the same paradigm of P. Zhang et al. (2006). Each participant performed the attentive tracking task under different visuospatial attentional loads while presented with task-irrelevant auditory oddball stimuli. In addition, we introduced two levels of performance-dependent reward to examine whether and how different levels of reward could affect the distractor processing. In order to assess our manipulations on the task difficulty and participants' attentional state, we simultaneously measured the pupillary responses in real time. Pupil dilation has been found to coincide with several attention-related processes such as arousal (Bradshaw, 1967; Unsworth & Robison, 2017; Watanabe et al., 2018), attentional state (Chiew & Braver, 2013; Gilzenrat et al., 2010; Robison & Unsworth, 2018; Wierda et al., 2012), and task load (Kahneman & Beatty, 1966). It could covary with perceptual load and predict the observer's performance (Oliva, 2018). Also, pupil dilation was found to be modulated by reward (Cash-Padgett et al., 2018; Chiew & Braver, 2013; Massar et al., 2016; Watanabe et al., 2018). Before conducting the study, we presumed that higher monetary reward might motivate the participants to make additional effort. Thus, their total available attentional resource might be more than usual. If this was the case, we would observe generally better tracking performance and weaker MMNs as compared to P. Zhang et al.'s (2006). However, the actual result patterns disagreed with our expectation, and surprisingly allowed us to disclose how attentional control mechanism worked confronting a relatively extreme high load situation. To explain the results, we amend Lavie's load theory of selective attention and present a descriptive toy model. By fitting the model to P. Zhang et al.'s (2006) data, we show that a non-monotonic pattern of MMN amplitude could occur if P. Zhang et al. used a higher attentional load than already in their study.

2 | METHOD

2.1 | Participants

The present study was approved by the Institutional Review Board of the Institute of Psychology, Chinese Academy of Sciences. Thirty-four healthy subjects (15 females) whose ages ranged from 18 to 29 years (mean ± SD = 22.0 ± 2.8 years) with normal or corrected-to-normal vision and normal hearing participated in the experiment. All the participants gave their written informed consent in accordance with the Declaration of Helsinki and got paid for their participation after the experiment.

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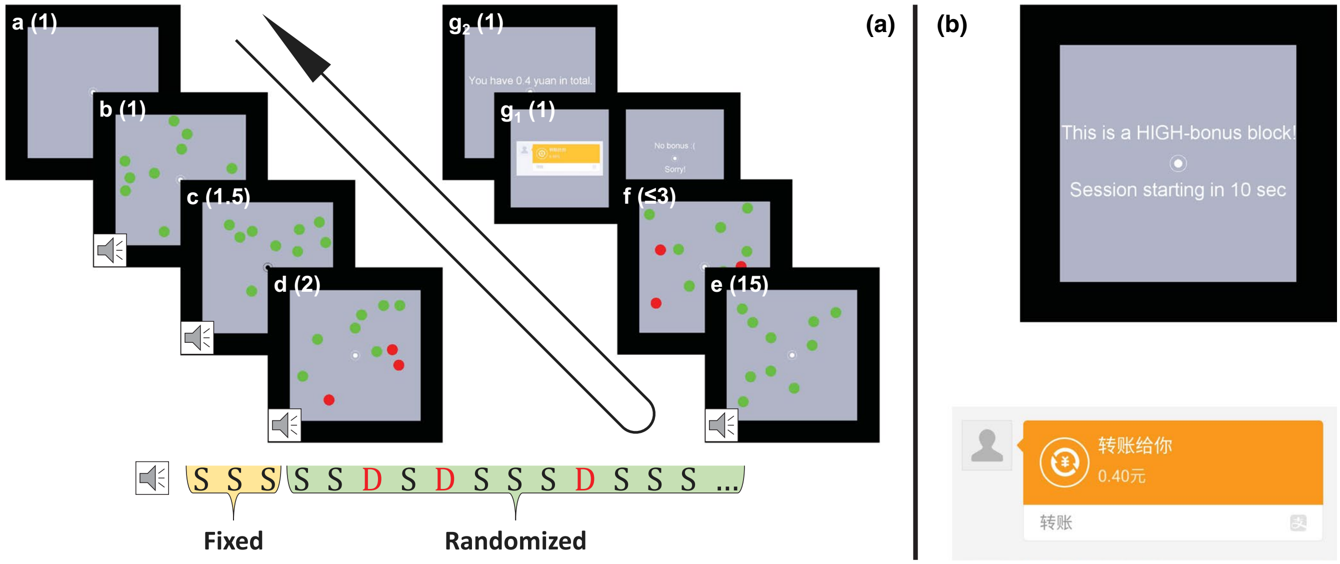

FIGURE 1 Procedures and stimuli. Sizes of stimuli are not to scale for viewing convenience. (A) The procedure of a typical trial (under the high reward and medium attentional load condition here). It contained 7 phases (a–g). The number in the brackets on the upper left of each picture shows the duration of that phase in seconds. (a) Preparing. The blank screen was presented. (b) Initializing. Ten green balls appeared and started moving at a uniform speed but in random initial directions. (c) Warning. The fixation flickered to warn of the task about to begin. (d) Cueing. One, three, or five balls turned red as targets. (e) Tracking. Targets turned back green to be attentively tracked without eye movements. (f) Recognizing. The same amount of balls as targets turned red as probes to be judged whether they were identical to the targets. (g) Feedback. A trial feedback (g_1) showing the bonus gained by the response (or telling no bonus if it's incorrect) was presented, followed by a block feedback (g_2) showing the accumulative bonus of the current block. The speaker icon on the lower left of a picture means that the phase was coupled with auditory stimuli of oddball paradigm. A typical stimulus sequence is on the bottom where "S" stands for a standard tone and "D" for deviant. (B) The upper picture is a typical pre-block display which forecasts the reward level of the upcoming block with "HIGH" or "LOW". The lower picture shows the trial feedback after a correct judgment. The number shows the bonus amount and varies across conditions

2.2 | Apparatus

Experimental stimuli were programmed, generated and presented on a Lenovo ThinkVision E2054A 19.5″ LCD monitor (with 1,280 × 800 resolution & 60-Hz refresh rate) and a Lenovo M7150 PC with MATLAB R2013a (MathWorks Inc., USA) and Psychtoolbox 3.0.11 (Brainard, 1997). Pupillary responses and eye movements were continuously recorded throughout each trial using the EyeLink 1000 tower mount eye tracker (SR Research Ltd., Canada). Participants sat at a viewing distance of 50 cm using a chin-rest and forehead-rest on the eye tracker. Data analyses were also conducted with MATLAB.

2.3 | Stimuli & procedures

2.3.1 | Visual stimuli and task procedures

The current stimuli and procedures basically imitated P. Zhang et al.'s (2006) attentive tracking, or multiple object tracking (MOT) paradigm (Cavanagh & Alvarez, 2005; Pylyshyn & Storm, 1988). Ten bouncing balls (diameter = 1°) moved at the speed of 6 °/s inside a 20° × 20° middle-gray square centered on the black background. At the center of the square located a white bullseye fixation point (diameter = 0.4°). The balls moved independently and smoothly, which would rebound if colliding with each other, with any border of the square, or with the fixation. To relieve the visual crowding and lower the difficulty, rebounding would happen before the actual contact as if the balls had a transparent shell with a thickness of 10% diameter. The rebounding angle was calculated as in a real physical collision, but the speed was controlled constant always.

The paradigm is demonstrated in Figure 1. Each trial consisted of seven phases as listed below.

a. Preparing phase (1 s). The screen stayed blank with only the square and the fixation point.
b. Initializing phase (1 s). Ten green balls appeared and started moving with random initial directions.
c. Warning phase (1.5 s). The fixation point flickered at 2 Hz to warn the observer that the task was about to start.
d. Cueing phase (2 s). N out of the 10 balls (N = 1, 3, or 5; see the next paragraph) turned red, referred to as target balls.
e. Tracking phase (15 s). All target balls turned back green and the observer had to keep tracking attentively the target balls (though they were already undistinguishable from the non-target ones) while gazing the fixation point.

f. Recognizing phase (≤3 s). Again, *N* out of the 10 balls turned red (the same *N* as in phase (d)), referred to as probe balls. The probe balls were exactly the target balls in half of the trials, or contained one (and only one) non-target ball in the other half (here one target ball and one non-target ball were randomly selected and replaced with each other). On seeing the red probe balls, the observer had to judge whether the probe balls were completely identical to the target balls or not by pressing the Left Arrow for "identical" or the Right Arrow for "non-identical" within a time limit of 3 s. A trial with no response was regarded as incorrect.
g. Feedback phase (2 s). As soon as a response was made (or time was up), all balls disappeared and a trial feedback and a block feedback were presented in succession at the fixation. The trial feedback for a correct response was a screenshot (1,050 × 420 pixels) of a transfer proof (in Chinese characters, see Figure 1) from the common mobile payment application Alipay (Alipay Ltd., China) indicating the bonus amount for that trial, while for incorrect or absent responses it was a text cue "No bonus :(Sorry!". The block feedback was the text cue "You have # yuan in total." where "#" was the accumulative amount of bonus gained by the observer in that given block. Each feedback stimulus lasted for 1 s with no interval between.

The trial ended after the feedbacks, leaving the screen blank for 3 s during which observers took a brief break. Following 2 blocks of practice (6 trials for each block), the formal experiment comprised 8 blocks with each block containing 12 trials. Between-block breaks were mandatorily >1 min and ~2 min on average. Before each block, observers had 10 s to prepare themselves. Afterwards, they pressed the Spacebar to start the block.

Two experimental factors were involved in the experimental design, Reward (low / high) and attentional Load (low / medium / high), yielding 6 conditions. Each condition was repeated 16 times. Reward levels were equally randomized across blocks, so were Load levels across trials in each block. A text cue ("This is a #-bonus block!" where "#" was "LOW" or "HIGH") was presented throughout this 10-s pre-block preparation to indicate the Reward level of the upcoming block (Figure 1b). Bonus amount doubled between the Reward levels for each Load level. Higher Load meant more target balls (1, 3, and 5 balls, respectively) and also led to higher bonus for correct responses (low Reward: ¥0.20, ¥0.25, and ¥0.38, respectively; high Reward: ¥0.40, ¥0.50, and ¥0.76, respectively).

2.3.2 | Auditory distractors

Two kinds of sinusoidal pure tones were presented as auditory distractors with a pair of Edifier R10U USB2.0 Multimedia 2.0 Channels Speakers placed on both sides of the monitor. One was the standard (1,000 Hz, 80% probability) tone, and the other the deviant (1,500 Hz, 20% probability) tone. Each tone was presented for 50 ms, with the intensity of ~55 dB SPL and SOA of 600 ms. In each trial, tones were presented since the initializing phase started (i.e., all balls appeared) till the tracking phase ended (Figure 1). The first three in the tone sequence of each trial were always standard tones in order to contrast with deviant tones, and the remaining tone sequence was randomized. Participants were instructed in advance to ignore the sound and focus on the visual task.

2.4 | Data acquisition

2.4.1 | EEG

Electroencephalographic (EEG) data were recorded from 64 Ag/AgCl scalp electrodes positioned on a Quik-Cap elastic electrode cap according to the international 10–20 system and a SynAmps2 RT amplifier (Neuroscan Inc., USA). Signals were referenced online to the left mastoid (M1) electrode and digitized at a sampling rate of 1,000 Hz. The passband of EEG amplification was 0.05–100 Hz. Horizontal electrooculogram (HEOG) was recorded by two electrodes placed beyond the lateral canthi of eyes and vertical electrooculogram (VEOG) above and below the left eye. Impedances of all electrodes were kept below 5 kΩ.

2.4.2 | Pupillometry

Pupillary responses and eye movements were continuously recorded throughout each trial at a sampling rate of 1,000 Hz with the pupil size measured in the unit of pixel. Twenty-six participants had their right eyes recorded and eight had their left eyes. A five-point calibration was completed before each block (including the practice) and a drift correction (<1.5°) before each trial.

2.5 | Data pre-processing

2.5.1 | EEG

EEG data pre-processing was implemented with the EEGLAB v14.1.2 toolbox (Delorme & Makeig, 2004). Recordings were re-referenced offline to the right mastoid (M2) electrode, band-pass filtered at 1–30 Hz, epoched from −100 to +500 ms relative to the onset of each tone within the tracking phase, and baseline corrected over 100 ms prior to the onset. Epochs with any EOG exceeding ±50 μV were removed. Data on bad channels were replaced by the average of those on adjacent channels. There were 3 bad channels for 1 participant and 1 bad channel for 5 participants each. None of the bad channels was of interest or involved in subsequent analyses.

The time windows for MMN and P3a identifications were 120–240 and 250–350 ms after tone onsets, respectively. We first located the maximum peak (negative for MMN and positive for P3a) within the selected time window. Then, as in P. Zhang et al.'s (2006) analysis, we found the smallest time interval around the peak that surpassed 70% of its height, and determined the latency as the mean value of the two boundaries. As for the amplitude, we calculated the mean amplitude around the peak over a time interval whose length was the full-width at half-maximum of the peak.

2.5.2 | Pupillometry

Pupillary recordings of each trial were exported as sample reports with Data Viewer (SR Research Ltd., Canada). Preprocessing consisted of epoching, blinking artifact removal, linear interpolation, and baseline correction. One hundred samples (i.e., 100 ms) before and after each blink were discarded. Discarded and missing values were substituted by linear interpolation. We were only interested in the signals during the tracking. Thus we discarded the initial 1,500 samples (i.e., 1.5 s) of the tracking phase in order to remove any influence from the color altering of the balls. Data within the remaining 1,350 ms were averaged by using a 150-ms time window, resulting in 9 data points.

2.6 | Data analysis

Analyses were conducted on MATLAB. We mainly used the rmANOVA (repeated measures analysis of variance) to assess the differential effects across experimental conditions. All p-values were Greenhouse-Geisser corrected when required. Post-hoc pairwise comparisons were conducted with the HSD method. Effect sizes were calculated for one-sample t-tests (Cohen's d) with G*Power 3.1 (Faul et al., 2007) and for ANOVAs (partial eta squared, η_p^2; see Keppel, 1991) via the formula:

$$\eta_p^2 = \frac{F \cdot df_1}{F \cdot df_1 + df_2}$$

3 | RESULTS

3.1 | Behavior

We calculated the accuracy, the sensitivity (d'), and the criterion (or bias, likelihood ratio β) in each condition for each participant by considering each target ball replacement as a signal defined in the signal detection theory. In each condition, participants' performance was significantly better than the chance level (50% for accuracy and 0 for d', see Table 1). We then conducted a two-way rmANOVA on the accuracy with Reward (low / high) and Load (low / medium / high) as the within-subject factors (Figure 2), and found a significant main effect of Load ($F(2, 66) = 143.03$, $p < 10^{-23}$, $\eta_p^2 = 0.81$) which indicated deteriorating performance with increasing attentional load (L vs. M: $p < 10^{-9}$; L vs. H: $p < 10^{-9}$; M vs. H: $p < .001$). Similar results were obtained for d' ($F(2, 66) = 151.88$, $p < 10^{-24}$, $\eta_p^2 = 0.82$; L vs. M: $p < 10^{-9}$; L vs. H: $p < 10^{-9}$; M vs. H: $p < .001$). In addition, the Reward × Load interaction was marginal for both accuracy ($F(2, 66) = 3.30$, $p = .057$, $\eta_p^2 = 0.09$) and d' ($F(2, 66) = 3.09$, $p = .066$, $\eta_p^2 = 0.09$). Specifically, the performance difference between the medium and high load was significant for low ($ps < .001$) but not for high reward ($ps > .36$). The main effect of Reward was insignificant ($Fs < 1$).

TABLE 1 Results of the behavioral performance

		Low reward			High reward		
	Load	$M \pm SD$	$t(33)$	d	$M \pm SD$	$t(33)$	d
Acc (%)	L	90.63 ± 8.74***	27.11	4.65	88.42 ± 9.25***	24.22	4.15
	M	69.85 ± 14.96***	7.74	1.33	64.52 ± 14.25***	5.94	1.02
	H	55.70 ± 14.13*	2.35	0.40	60.48 ± 13.21***	4.62	0.79
d'	L	2.53 ± 0.61***	24.14	4.15	2.37 ± 0.65***	21.27	3.65
	M	1.20 ± 0.94***	7.47	1.28	0.85 ± 0.84***	5.90	1.01
	H	0.33 ± 0.84*	2.30	0.39	0.58 ± 0.80**	4.25	0.73
β	L	1.47 ± 0.79			1.33 ± 0.86		
	M	1.32 ± 0.86			1.09 ± 0.65		
	H	1.05 ± 0.57			0.92 ± 0.48		

*$p < .05$, **$p < .001$, and ***$p < 10^{-4}$ for comparisons of the behavioral performance against chance levels (50% for accuracy and 0 for d').
Abbreviations: Acc, accuracy; d, Cohen's d; L/M/H, low/medium/high load condition.

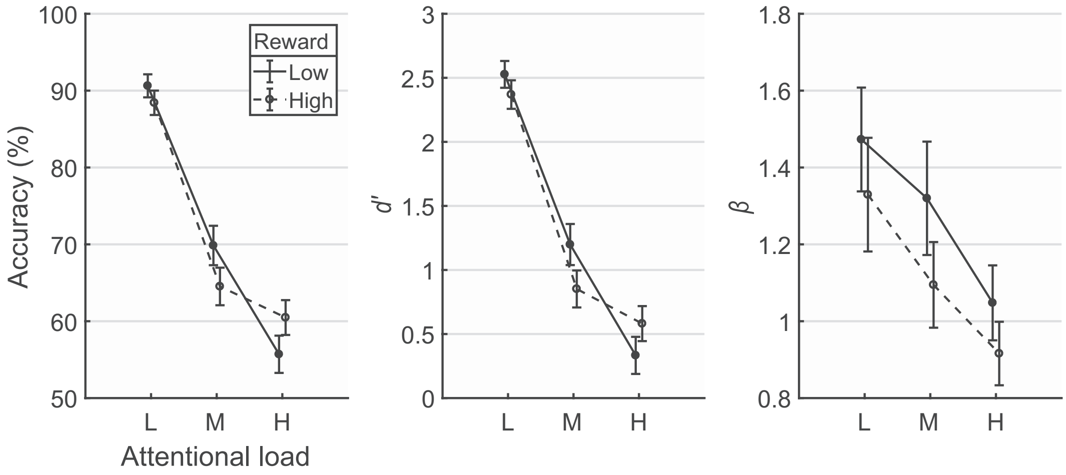

FIGURE 2 Results of the behavioral performance. The error bar denotes 1 *SEM*

We conducted the same rmANOVA on β (Figure 2). The main effect of Load was also significant ($F(2, 66) = 4.63$, $p = .017$, $\eta_p^2 = 0.12$). Participants were less conservative (i.e., more likely to report the target ball replacement) as the attentional load increased although only between low and high load was the difference significant ($p = .010$).

3.2 | ERP

Two participants' data were excluded from all the ERP-related (i.e., MMN & P3a) analyses because they had too few epochs (<100 repetitions for the standard tone and <60 for the deviant) that survived the pre-processing. Another two participants with especially noisy data (with <220 repetitions for the standard tone and <65 for the deviant; fewer than the mean by >2.9 *SD*) were also excluded from the ERP-related analyses. After removing the data of these four participants (i.e., $N = 30$), there were on average 283 ± 13 ($M \pm SD$) repetitions for the standard tone and 85 ± 4 for the deviant in each participant. For further analyses, ERP differences waves were calculated by subtracting the ERPs to standard tones from the ERPs to deviant tones separately for each participant and condition. The grand averaged difference waves are presented in Figure 3.

3.2.1 | MMN

We chose FZ, FCZ, and CZ as the channels of interests where the amplitude of MMN was the highest. We first confirmed that there was a significant MMN component under each experimental condition on each channel (Table 2). We then conducted a three-way rmANOVA on the amplitude of MMN, with Reward (low/high), Load (low/medium/high) and Channel (FZ / FCZ / CZ) as factors. There was a significant main effect of Channel ($F(2, 58) = 64.75$, $p < 10^{-9}$, $\eta_p^2 = 0.69$), indicating that the MMN amplitude decreased from the frontal to the central area (all pairwise ps $< 10^{-5}$). However, neither Reward nor Load showed a significant main effect or interaction between them (Figure 4).

The same analyses on the latency of MMN (Figure 4) revealed a significant main effect of Load ($F(2, 58) = 8.02$, $p = .001$, $\eta_p^2 = 0.22$). MMN latency was the shortest under the medium load condition and the longest under the low load condition. The differences between the low and medium load ($p = .003$) and between the low and high load ($p = .018$) were significant. Other pairwise differences did not reach statistical significance, neither did the overall effects of the factors reward or channel, or interactions between the factors.

Although we observed significant differences on latency between load levels, we did not find corresponding amplitude changes (though there was a non-significant trend: main effect of Load on MMN amplitude: $F(2, 58) = 2.45$, $p = .097$, $\eta_p^2 = 0.08$, with the largest amplitude (absolute value) under the medium load). Thus, to make a scrutiny into the Load effect on the auditory processing, we directly compared the amplitude of N1 component evoked by the standard tones and that by the deviant tones (Figure 5). For negative peaks falling within the time window of 75–235 ms after a tone onset, we determined the amplitudes in the same way as for MMN and took them into a four-way rmANOVA with an additional factor of Tone (standard / deviant). Consistent with the observation of MMN, there was a significant main effect of Tone ($F(1, 29) = 183.00$, $p < 10^{-13}$, $\eta_p^2 = 0.86$, with deviant tones (-3.86 ± 1.86 μV) eliciting stronger N1 ($p < 10^{-9}$) than standard tones (-2.22 ± 1.34 μV)), a significant main effect of Channel ($F(2, 58) = 61.60$, $p < 10^{-8}$, $\eta_p^2 = 0.68$, with N1 becoming less negative from FZ to CZ (all ps $< 10^{-6}$)), and a significant Tone × Channel interaction ($F(2, 58) = 49.68$, $p < 10^{-7}$, $\eta_p^2 = 0.63$), where the deviant-standard difference of N1 amplitude was found to be smaller from FZ to CZ (all

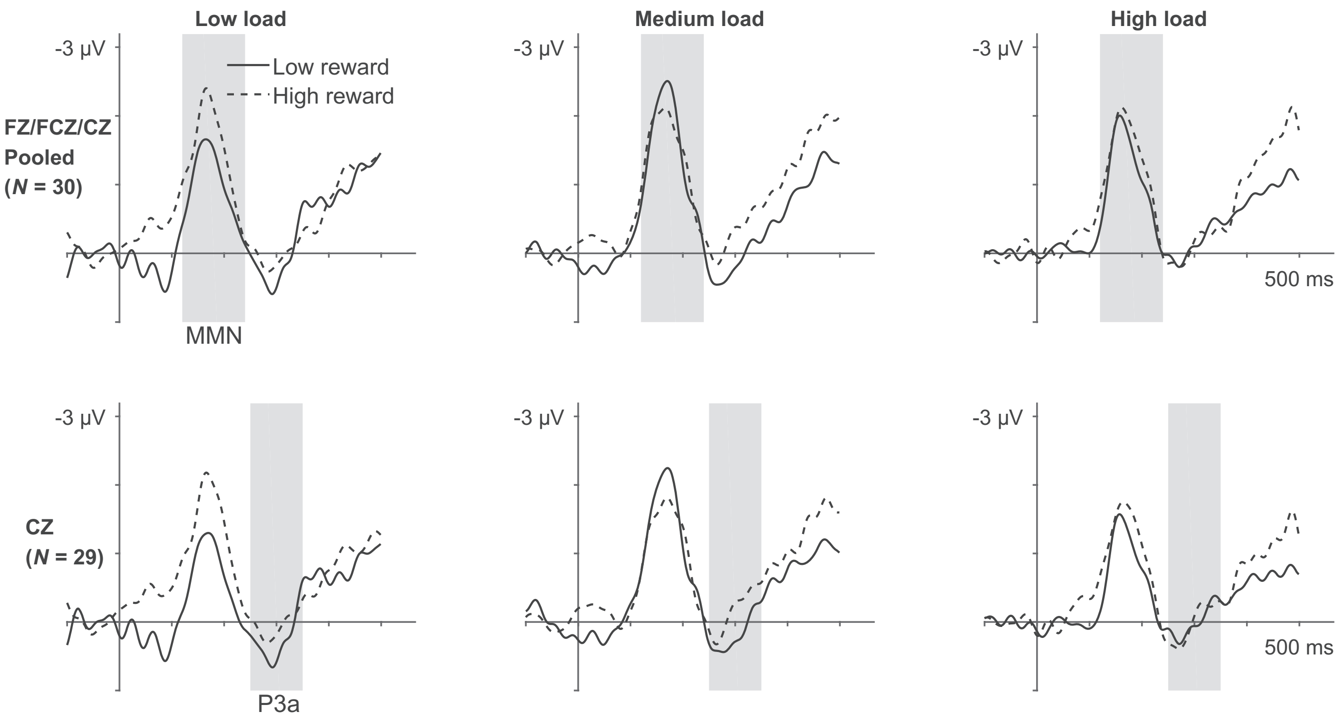

FIGURE 3 Difference waves used in the analyses of MMN (upper row) and P3a (lower row), generated by subtracting the ERP signals elicited by the standard tones from those by the deviant tones. The first row shows the averaged signal across FZ, FCZ, and CZ, and the second shows the signal at CZ. The shadow areas indicate the time windows to identify MMN and P3a in, respectively. The columns correspond to three levels of attentional load, respectively

TABLE 2 Results of MMN amplitudes and latencies (in $M \pm SD$)

		Low reward			High reward			
	Load	**Amp (μV)**	***t*(29)**	***d***	**Amp (μV)**	***t*(29)**	***d***	**Overall mean**
FZ	L	−2.08 ± 1.35	8.44	1.54	−2.40 ± 1.22	10.82	1.97	
	M	−2.58 ± 1.33	10.68	1.94	−2.55 ± 1.64	8.54	1.55	−2.36 ± 0.70
	H	−2.22 ± 1.11	10.94	2.00	−2.31 ± 1.14	11.10	2.03	
FCZ	L	−1.78 ± 1.15	8.46	1.55	−2.28 ± 1.18	10.63	1.93	
	M	−2.36 ± 1.14	11.34	2.07	−2.39 ± 1.40	9.36	1.71	−2.13 ± 0.61
	H	−1.92 ± 1.01	10.38	1.90	−2.04 ± 1.07	10.48	1.91	
CZ	L	−1.45 ± 1.02	7.77	1.42	−2.02 ± 1.09	10.16	1.85	
	M	−1.99 ± 1.00	10.86	1.99	−1.97 ± 1.22	8.85	1.61	−1.78 ± 0.54
	H	−1.53 ± 0.95	8.82	1.61	−1.71 ± 0.93	10.02	1.84	
		Latency (ms)			Latency (ms)			
FZ	L	172.50 ± 27.44			180.38 ± 27.47			
	M	168.67 ± 18.91			169.78 ± 25.25			171.37 ± 16.96
	H	168.27 ± 21.04			168.62 ± 20.07			
FCZ	L	180.95 ± 25.52			177.83 ± 23.63			
	M	167.80 ± 20.42			169.37 ± 25.22			172.49 ± 16.57
	H	168.47 ± 21.35			170.55 ± 20.91			
CZ	L	179.07 ± 26.37			175.45 ± 22.96			
	M	166.37 ± 19.75			170.03 ± 26.00			172.19 ± 16.82
	H	168.78 ± 22.13			173.45 ± 23.85			

Note: All *ps* $< 10^{-7}$ for comparisons of amplitudes against 0.

Abbreviations: Amp, amplitude; *d*, Cohen's *d*; L/M/H, low/medium/high load condition.

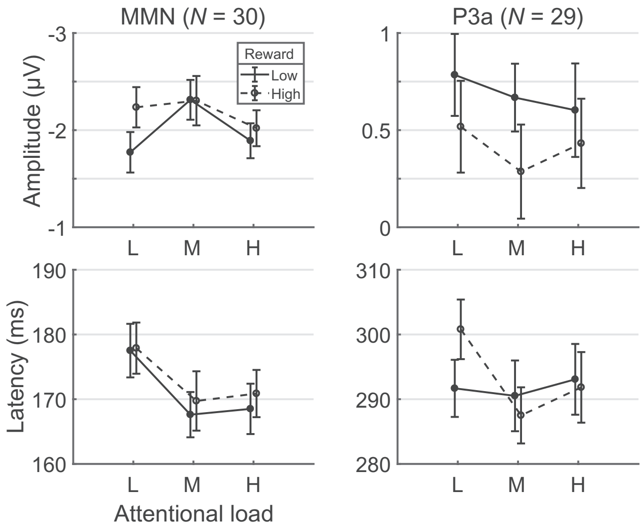

FIGURE 4 Results of the amplitudes (upper row) and latencies (lower row) of MMN (left column) and P3a (right column). The results of MMN were pooled from three channels (FZ, FCZ, and CZ), and those of P3a obtained at CZ. The ordinates point upwards to the larger absolute value. The error bar denotes 1 *SEM*

ps < 10^{-9}). Moreover, we found a significant interaction of Load × Tone ($F(2,58) = 3.24, p = .049, \eta_p^2 = 0.10$). Specifically, the deviant-standard difference of N1 amplitude was significant under all three load levels (all *ps* < 10^{-8}), but it was larger under the medium (−1.89 μV) than the low (−1.46 μV) or high load (−1.55 μV). Besides, the Reward × Load interaction also reached significance ($F(2, 58) = 6.61$, $p = .004$, $\eta_p^2 = 0.19$). Under low reward, N1 showed higher amplitude for the medium than for the high load level ($p = .015$), which was not evident under high reward.

3.2.2 | P3a

Analyses on P3a slightly differed from above because the data of several participants did not show a peak within the given time window on certain channel(s) or in certain condition(s) due to a monotonically in-/decremental difference wave throughout the time window, and thus no P3a component could be identified for those participants. Therefore, for each channel separately, the participants for whom P3a was absent in all conditions were excluded, causing varied number of included participants across channels. The final sample sizes for FZ, FCZ, and CZ were respectively 26, 30, and 29. Still, we first tested whether P3a was observed under each condition on each channel. It turned out that on all channels, the P3a was evident under low and medium load with low reward but not significant under medium and high load with high reward (Table 3). Also, the three-way rmANOVA was skipped. Instead, we conducted a two-way rmANOVA on CZ which had the largest overall P3a amplitude. The grand average ERPs obtained at CZ are showed in Figure 6.

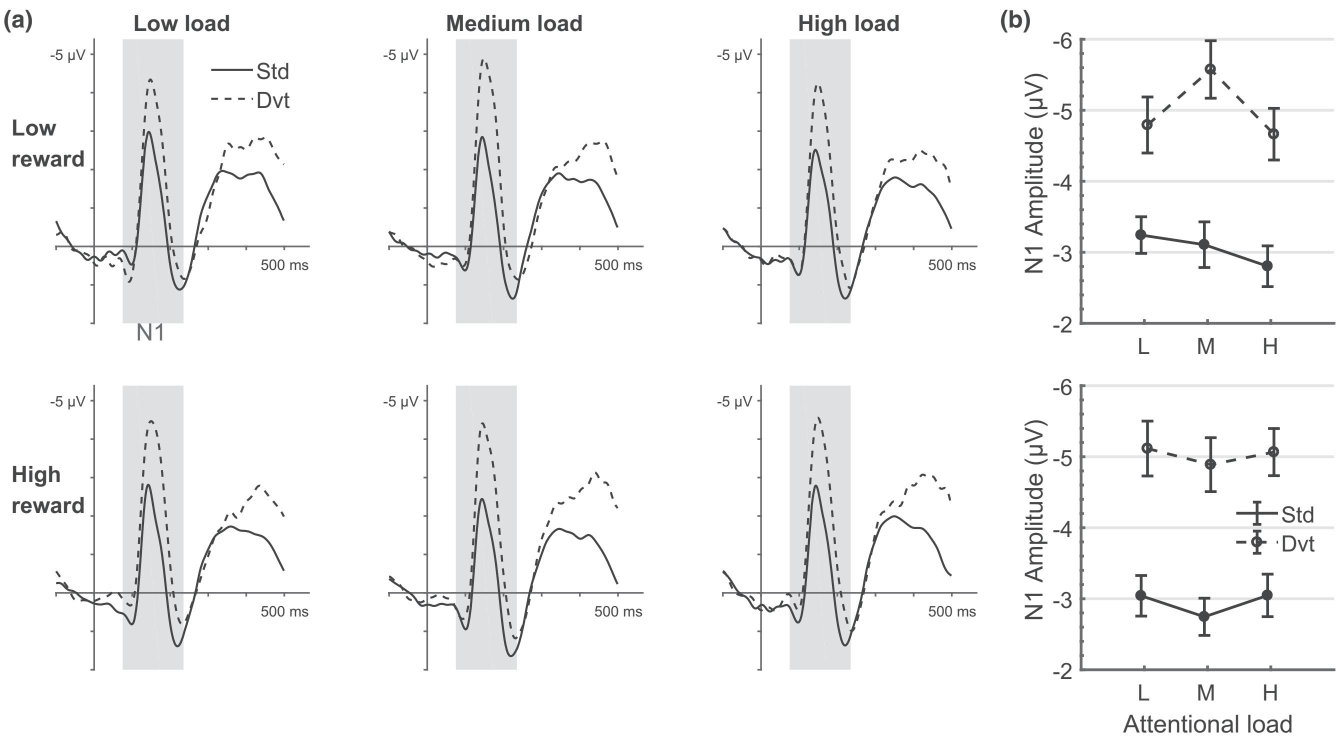

FIGURE 5 (a) Grand average ERP signals showing the N1 component across all 30 participants (pooled from channels FZ, FCZ, and CZ). The shadow area indicates the time window to identify N1 in. (b) Results of N1 amplitudes. The ordinates point upwards to the larger absolute value. For both (a) and (b), the upper row shows the results for the low reward conditions and the lower shows the high reward

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TABLE 3 Results of P3a amplitudes and latencies (in $M \pm SD$)

		Low reward			High reward			
	Load	Amp (μV)	*t*	*d*	Amp (μV)	*t*	*d*	Overall mean
FZ (*N* = 26)	L	0.60 ± 1.21*	2.55	0.50	0.44 ± 1.23	1.81	0.36	
	M	0.63 ± 1.39*	2.32	0.45	0.36 ± 1.48	1.26	0.24	0.42 ± 0.81
	H	0.47 ± 1.79	1.34	0.26	0.00 ± 1.41	0.00	0.00	
FCZ (*N* = 30)	L	0.64 ± 1.12**	3.12	0.57	0.58 ± 1.33*	2.38	0.44	
	M	0.70 ± 1.23**	3.13	0.57	0.23 ± 1.41	0.89	0.16	0.51 ± 0.74
	H	0.42 ± 1.50	1.52	0.28	0.47 ± 1.39	1.87	0.34	
CZ (*N* = 29)	L	0.78 ± 1.14***	3.72	0.68	0.52 ± 1.27*	2.19	0.41	
	M	0.67 ± 0.94***	3.82	0.71	0.29 ± 1.30	1.18	0.22	0.55 ± 0.67
	H	0.60 ± 1.30*	2.50	0.46	0.43 ± 1.24	1.88	0.35	
		Latency (ms)			Latency (ms)			
FZ (*N* = 26)	L	291.54 ± 21.84			300.96 ± 25.36			
	M	293.67 ± 27.64			289.42 ± 27.69			293.45 ± 13.77
	H	292.04 ± 27.04			293.06 ± 28.48			
FCZ (*N* = 30)	L	293.15 ± 24.34			298.70 ± 25.19			
	M	290.28 ± 29.97			286.30 ± 27.24			291.20 ± 13.21
	H	289.00 ± 27.08			289.77 ± 25.46			
CZ (*N* = 29)	L	291.67 ± 23.75			300.79 ± 24.79			
	M	290.52 ± 29.43			287.50 ± 23.35			292.56 ± 13.97
	H	293.07 ± 29.44			291.83 ± 29.37			

*$p < .05$, **$p < .01$, and ***$p < .001$ for comparisons of amplitudes against 0.

Abbreviations: Amp, amplitude; *d*, Cohen's *d*; L/M/H, low/medium/high load condition.

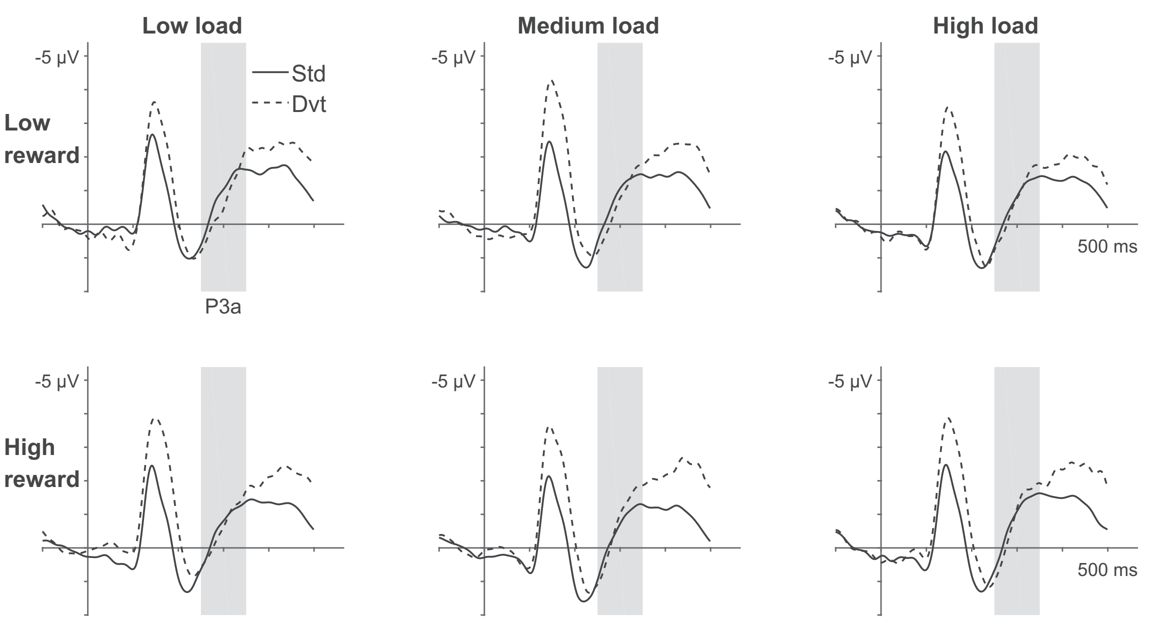

FIGURE 6 Grand average ERP signals for the participants included in the P3a analyses at CZ (*N* = 29). The shadow area indicates the time window to identify P3a in

As shown in Figure 4, the main effect of Reward on P3a amplitude was significant on CZ ($F(1, 28) = 5.48$, $p = .027$, $\eta_p^2 = 0.16$). P3a amplitude was lower under high reward than under low reward ($p = .027$). Neither the main effect of Load nor the Reward × Load interaction was significant. No significant effect on P3a latency was found.

3.3 | Pupillometry

We conducted a three-way rmANOVA on the pupil size with Time, Reward, and Load as factors. The main effect of Load was significant ($F(2, 66) = 8.77$, $p = .002$, $\eta_p^2 = 0.21$). The pupil size generally increased with the attentional load (L: 2,103.50 ± 674.48 pixel; M: 2,178.92 ± 729.82 pixel; H: 2,182.05 ± 752.74 pixel). However, significant differences were only observed between the low and medium load ($p = .003$) and between the low and high load ($p = .016$). We also found a marginal main effect of Reward ($F(1, 33) = 3.97$, $p = .055$, $\eta_p^2 = 0.11$) indicating a trend of larger pupil size for high (2,176.72 ± 747.97 pixel) versus low (2,133.60 ± 688.66 pixel) reward. The Reward × Load interaction was not significant.

Moreover, the main effect of Time was significant ($F(8, 264) = 6.55$, $p = .009$, $\eta_p^2 = 0.17$), manifesting as the declining pupil size with tracking. To verify this pattern, we conducted a Pearson's correlation analysis on the pupil size against time and found a highly significant negative correlation ($r = -0.96$, $p < 10^{-4}$). Furthermore, a significant Time × Load interaction ($F(16, 528) = 8.15$, $p < 10^{-5}$, $\eta_p^2 = 0.20$) disclosed that the effect of Load decreased over time and basically ceased ~9 s after the tracking started. We then calculated the decaying slope of the pupil size against time using linear regression for each participant in each condition and conducted a two-way rmANOVA (Reward × Load) on the slope values. The results showed a significant main effect of Load ($F(2, 66) = 13.42$, $p < 10^{-4}$, $\eta_p^2 = 0.29$). That is, higher attentional load resulted in higher decay rate (L: 2.53 ± 14.01 pixel/s, M: 6.96 ± 16.76 pixel/s, H: 10.39 ± 15.00 pixel/s; L vs. M: $p = .020$, L vs. H: $p < .001$, M vs. H: $p = .012$). None of the Reward-related effects was significant.

3.4 | Modelling

As attentional load grew, the difference of N1 amplitude between the deviant and standard tones first increased (from −1.46 to −1.89 μV), but then decreased (to −1.55 μV), suggesting that the effect of load on attentional selection and distractor processing was non-monotonic. This non-monotonic pattern disagrees with the prediction of a monotonic pattern by Lavie's load theory of selective attention: higher load (costing more resources) would lead to reduced available resources for suppression on distractors, which, in turn, would cause increased early processing of distractors.

Therefore, to amend Lavie's theory, here we propose a simple, descriptive model that allows a non-monotonic pattern of MMN amplitude to occur. As shown in Figure 7, we divide the total available attentional resource (ρ_0) during the MOT task into four components: one part allocated for the early (ρ_1) and one for the late (ρ_3) suppression of the auditory distraction, one part occupied by the final representation of

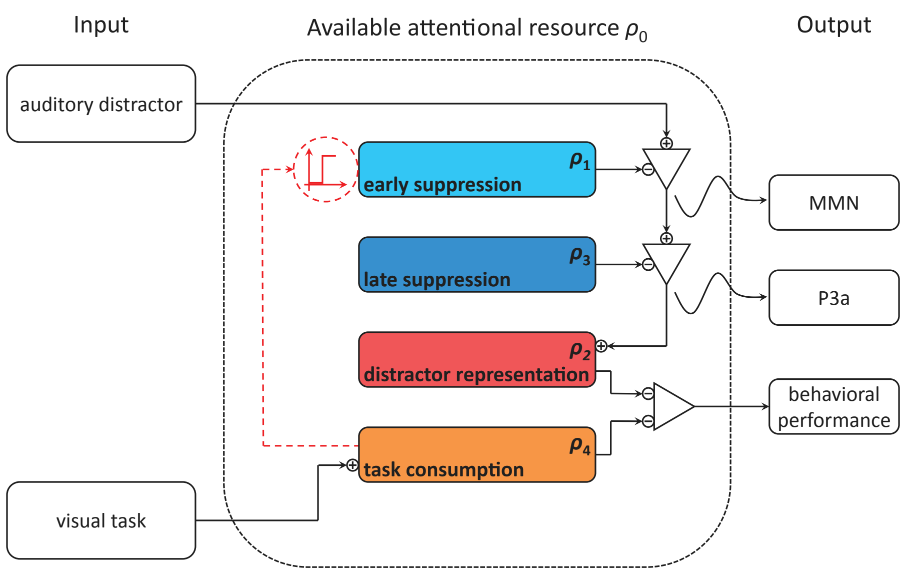

FIGURE 7 Illustration of the model. The signal of auditory distractor receives suppression on two successive stages before it is finally represented and interferes with the MOT task. The output signals after the early and late suppression are reflected by the MMN and P3a (curved arrows), respectively. The behavioral performance is affected by both the attentional load of the MOT task and the distractor representation. Here we use ρ_1, ρ_3, ρ_2, and ρ_4 to represent the attentional resource allocated to the corresponding processes, with ρ_1 for the early suppression, ρ_3 for the late suppression, ρ_2 for the distractor representation, and ρ_4 for the MOT task. Note that the ρ_3 box (dark blue) is above the ρ_2 (red). The circled "+" / "−" indicates a positive/negative effect of the input on the output. Processes ρ_1 to ρ_4 share and compete for the total available attentional resource (ρ_0). The dashed red arrow with a circled step-function sign ending at the ρ_1 box shows our account for the current result of non-monotonic MMN, hypothesizing an abrupt enhancement of the early suppression when the attentional load keeps rising. However, it should not be viewed as a direct causality between the two processes

the auditory distraction (ρ_2), and one part consumed by the main task of visual attentive tracking (ρ_4). The outputs after the early and late suppression are reflected by the MMN and P3a, respectively. The behavioral performance is affected by both ρ_4 and ρ_2. The model is constituted based on the following assumptions:

1. ρ_1 is the attentional resource allocated for the early suppression of the auditory distraction (referred to as the ρ_1-process). Considering that the MMN amplitude, A, reflects the early representation of the distraction, we assume it is inversely proportional to the effectiveness or output of the ρ_1-process:

$$A \propto \frac{1}{\rho_1}.$$

Therefore,

$$\rho_1 = \frac{\gamma}{A}.$$

2. ρ_2 is the attentional resource occupied by the final representation of the auditory distraction (referred to as the ρ_2-process) after the two stages of suppressions, which interferes with the main task. The P3a amplitude, B, which reflects the involuntary attentional orienting towards irrelevant distractors, should increase with ρ_2 but at a gradually lowering rate, e.g., logarithmically, considering the capacity-limited metabolism. Thus, we assume

$$B \propto \ln(\rho_2).$$

And when ρ_2 tends to 0, so should B. Then, this relationship is modified and we have

$$\rho_2 = \omega\left(e^B - 1\right).$$

3. ρ_3 is the attention allocated for the late suppression of the auditory distraction (referred to as the ρ_3-process) that takes place after ρ_1- and before ρ_2-process. According to Lavie's theory, the effectiveness of attentional suppression increases with the allocated resource on the suppression mechanism, so we describe the effectiveness of the ρ_3-process as $\sigma\rho_3$. On the other hand, the input for ρ_2-process is what remains after the effect of ρ_3-process is subtracted from the output of ρ_1-process (reflected by A, the MMN amplitude) which we assume is βA^m. Therefore, we have

$$\rho_2 = \beta A^m - \sigma\rho_3.$$

That is,

$$\rho_3 = \frac{\beta A^m - \omega\left(e^B - 1\right)}{\sigma}.$$

4. ρ_4 is, finally, the attention resource consumed by the main task of visual attentive tracking:

$$\rho_4 = 2 + 0.2N,$$

where N is the attentional load represented by the amount of target balls.

5. Besides the available attentional resource ρ_0 that ρ_1 to ρ_4 compete for, we additionally assume an unavailable portion of attention, ε, that cannot be allocated to any of the processes above. ε was set as 5% of the total attentional resource ρ_0.
6. Lastly, we describe the accuracy of behavioral performance y of the main task as a logistic-based function:

$$y = 0.5 \times \left(1 + \frac{1}{1 + fe^{gN}} \times \frac{1}{1 + k\rho_2 e^{lN}}\right),$$

where y varies from 0.5 (i.e., the chance level, when $N \to \infty$) to $0.5 + \frac{1}{2(1+f)(1+k\rho_2)}$ (when $N = 0$), a value less than 1. The term $\left(1 + fe^{gN}\right)$ represents the mere performance of the MOT task, while the term $\left(1 + k\rho_2 e^{lN}\right)$ represents the interference of the auditory distraction with a non-zero ρ_2.

In the formulas above, γ, ω, σ, β, m, f, g, k, and l are all positive parameters to be estimated. We first fitted the results of P. Zhang et al.'s study using the ordinary least square (OLS) method with $N = 1$, 3, and 5. The term to be minimized covered not only the residual sums of squares for MMN amplitude (A), P3a amplitude (B), and accuracy (y) but also the ρ_0 variance across different Ns because we assumed that the total available attentional resource ρ_0 ($= \rho_1 + \rho_2 + \rho_3 + \rho_4$) would not vary much despite the change of attentional load.

It turned out that the best fit explained 94.87% of the data variance. As shown in Figure 8, ρ_1 decreased as the attentional load rose, suggesting the weakening early suppression of auditory distractors which caused the increasing MMN amplitude in their study. In contrast, ρ_3 (i.e., late suppression) increased with the attentional load (especially from nearly zero suppression at the low load level), and thus ρ_2 (i.e., auditory distractor representation) gradually shrunk, which corresponded to the decreasing P3a amplitude. Finally, ρ_4, the task consumption, also rose with the attentional load, but at a lower rate from medium to high load than from low to medium, just as the accuracy did.

Based on the proposed model and fitting results, we further increased N beyond 5 to simulate an even higher attentional load for P. Zhang et al.'s study to see how the MMN or

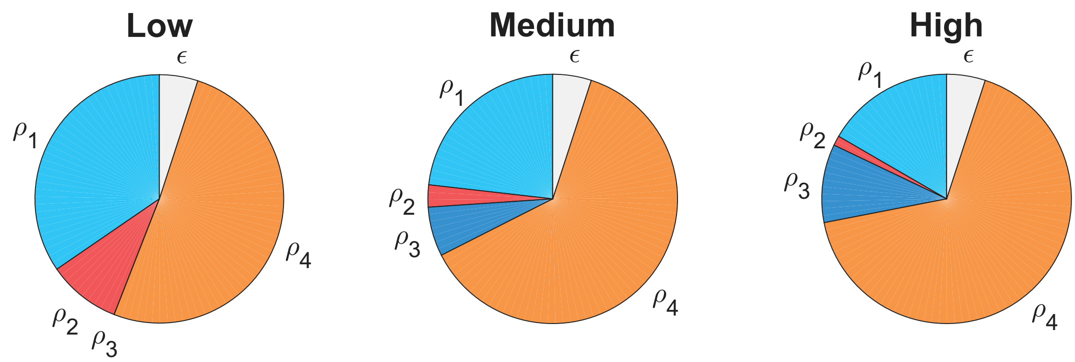

FIGURE 8 The result of model fitting using P. Zhang et al.'s (2006) data. The pie chart on the left, middle, and right shows the result under the low, medium, and high attentional load, respectively. The light blue, red, dark blue, and orange sectors represent the proportions in the total available attentional resource ρ_0 occupied by ρ_1 to ρ_4, respectively. The gray sector represents the unavailable part of the attentional resource, ε, which was preset at a fixed level of 5%

P3a amplitudes and accuracies would change.[1] Surprisingly, as shown in Figure 9, when the attentional load went on rising ($N = 7$ or 9), the P3a amplitude and accuracy kept dropping until around zero and chance level (50%), respectively, while the MMN amplitude stopped increasing and fell back instead. Based on the estimation, we inferred that if P. Zhang et al.'s study involved a higher attentional load than already in their study, a non-monotonic pattern of MMN amplitude would be quite likely to occur.

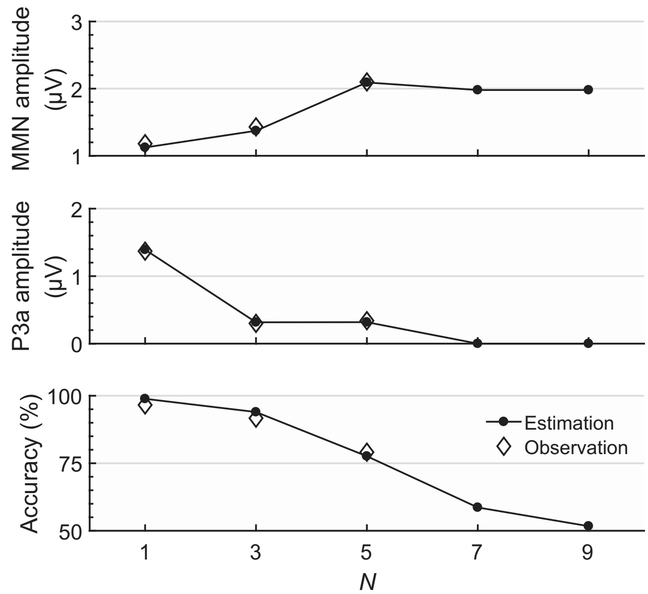

FIGURE 9 The estimation of results of P. Zhang et al.'s study with even higher attentional loads. The dots and solid lines represent the estimation of our model and the diamonds represent the data of P. Zhang et al. (2006)

4 | DISCUSSION

According to the load theory of selective attention by Lavie and colleagues (Lavie, 2005; Lavie et al., 2004), the active suppression of distractor processing requires enough attentional control resources. Therefore, increasing attentional control load will cost more such resources, leading to a scarcity of available resources for suppressing distractors. This will, in turn, cause a stronger processing of distractors. Lavie's theory was initially proposed to account for the findings in the unimodal visual search tasks. It was then proved by P. Zhang et al. (2006) in the multimodal domain. Nevertheless, this theory in its original form cannot completely explain our results, given the discrepant pattern between our results and P. Zhang et al.'s findings (2006), even if the two studies used closely resemblant paradigms and parameters. Indeed, some of the present findings are in line with the literature. For example, the behavioral performance deteriorated and the pupil size expanded as the attentional load increased; the pupil contracted during the tracking and the contraction also accelerated with higher attentional load, which has also been reported before (Kahneman & Beatty, 1966). All these present findings suggest that our manipulations on the attentional load were effective. However, in P. Zhang et al.'s study, MMN amplitude grew monotonically as the attentional load increased, whereas in the present study, the effect of load on the attentional selection and distractor processing was non-monotonic.

First, we found a non-monotonic effect of load on the MMN latency. It was under the medium load that the MMN evoked by the irrelevant tones showed the shortest latency. Thus, the MMN under the high load was delayed relative to that under the medium load. Although latency of MMN is not always found to covary with amplitude of MMN,

[1]Note that the *N* here, as stated above, represented rather the abstract level of attentional load than the specific amount of target balls. So, further increasing *N* does not literally mean having >5 target balls in the 10-ball MOT paradigm, which would make no sense.

some studies report their covariation, with shorter latency usually corresponding to greater amplitude (Näätänen & Gaillard, 1983; Pakarinen et al., 2007; Tiitinen et al., 1994, 1997; Vaz Pato et al., 2002; Näätänen's 1992 book cited in Näätänen et al., 2005). We then examined the non-monotonic load effect on the MMN amplitude. Unfortunately, the MMN amplitude only showed a non-significant tendency of the non-monotonic pattern. However, when we analyzed the amplitude of N1 component elicited by either tone, as expected, the deviant tone elicited stronger N1 amplitude than the standard tone, an indication of processing novel auditory distractor. Interestingly, the significant Tone × Load interaction on the N1 amplitude revealed that the amplitude enhancement for deviant relative to standard tones was larger under the medium load than under the low or high load conditions. This result, in line with the effect on MMN latency, reinforces the tendency of non-monotonic load effect on the MMN amplitude. This non-monotonic pattern was not reported in P. Zhang et al.'s (2006) work or, to our knowledge, by any other study pertinent to Lavie's theory. Taken together, the results of all the three indices jointly point to the discovery that attentional load modulated the task-irrelevant auditory processing non-monotonically in our paradigm, which contradicts with P. Zhang et al.'s previous finding (2006).

Then what caused the non-monotonic pattern? One might contend that the participants gave up the task under the high load, allowing some attentional resource to be released for suppressing the distractors. However, this notion is poorly supported by the fact that the behavioral performance under the high load conditions were significantly above the chance level. Meanwhile, the pupil dilation evidently diminished when the load level rose from medium to high. This pupillometric result probably reflected a limit or ceiling effect of some executive function such as attentional allocation. Combining the behavioral, pupillometric, and ERP results, we speculate that P. Zhang et al.'s (2006) study likely missed an apparently "extremely high" load level that our work happened to cover. Such an extremely high load level may require the system to actively suppress the processing of distractors at a stage as early as possible. It should be noted that the extremely high load does not necessarily mean a concrete load (e.g., number of target balls) or difficulty level, but could vary dependent on the context of a task. We will address this in more detail after describing a new model in the following paragraphs.

To deal with the extremely high load circumstances and explain the non-monotonic pattern, we tried to propose a descriptive toy model and make an attempt to amend Lavie's theory (see Figure 7). When attentional control load is high (but not extremely), more resources will be allocated to the ongoing task processing (ρ_4). As a result, available resources for suppressing the distractors (ρ_1) decrease. Then the processing of distractors becomes stronger (as reflected by greater MMN amplitude), leading to stronger distracting input signals ready to intrude the system. However, we propose that the final representations of auditory distractors is the consequence after a second round of suppression by the ρ_3-process, which then interfere with the ongoing task processing.

The functional role of this late suppression is to reduce the distractor representations' interferences towards a level that the system can tolerate. This tolerance hypothesis is supported by the finding of P3a, a component indicating the involuntary orienting of attention to distractors, in P. Zhang et al.'s (2006) work (especially in their low load condition). So, what determines if the system keeps or gives up its tolerance of the growing processing of distractors? As Lavie et al. (2004) noted, sufficient resources for attentional control is the basis or premise for the active suppression mechanism to work efficiently which ensures a reasonably high *priority* for the current task processing in attentional allocation. Otherwise, intrusions of distractors would possibly compete for the insufficient resources with the current task processing, causing the task performance inevitably to somehow degrade. We have seen this picture in P. Zhang et al.'s (2006) high load condition and our medium load conditions. However, when the load is further increased to an extremely high level, maintaining a decent priority for the ongoing task processing becomes too challenging. This is because now the task processing per se demands so large amount of resources, leaving super low tolerance to the intrusions of distractors. In this case, to resist the intrusions of the distractors as effectively as possible, the active suppression mechanism would turn to block the distractors at an early stage, resulting in lower MMN amplitude (or smaller deviant-standard difference in N1 amplitude), as shown by the red dashed arrow in Figure 7.

This explanation was further evidenced by a simulation of higher attentional load levels in P. Zhang et al.'s study. As shown in Figure 9, the MMN amplitude at first increased with attentional load, indicating that early suppression of auditory distractors descended with attentional load according to Lavie's theory. Nevertheless, the early suppression of distractors would get an abrupt, inverted enhancement if the attentional load kept rising, leading to the fall of the MMN amplitude.

As we mentioned, the extremely high load does not necessarily mean a concrete load or difficulty level, but could vary dependent on the context of a task. To be more specific, an extremely high load would correspond to a status of the system that intrusions of distractors would severely degrade the performance of the ongoing task performance. So why could our experiment cover the extremely high load yet P. Zhang et al.'s (2006) did not, though the experimental paradigms of the two studies closely resemble each other?

A closer comparison between P. Zhang et al.'s (2006) study and ours can disclose more discrepancies even in the behavioral results. Despite similar experimental configurations and settings, the tracking accuracy in our work was substantially lower than that in P. Zhang et al.'s (2006) work under each load level (low: 89.5% vs. 96.6%; medium: 67.2% vs. 91.7%; high: 58.1% vs. 79.1%). Intuitively, one might ascribe the worse performance in our work to the greater task difficulty. However, this is not very likely because the current task was considered even easier in terms of several key parameters related to difficulty. In fact, we adopted weaker intensity of auditory distractors (55 vs. 85 dB SPL) and shorter duration of tracking (15 vs. 21 s) than in P. Zhang et al.'s (2006).

A more likely account may be the Yerkes–Dodson law (Yerkes & Dodson, 1908). According to this theory, arousal enhances thd performance accuracy of a task only within a limited scope, and beyond this scope the performance will be deteriorated by hyperarousal, which yields an inverted-U relationship. Besides, the inflection point varies with task difficulty (Kahneman, 1973). P. Zhang et al. (2006) mentioned that the attentive tracking task itself was more attention-consuming than many other visual attention paradigms. When reward introduced in our (but not P. Zhang et al.'s) work invoked extra effort on the task, adverse effects like hyperarousal and anxiety might arise, pushing the participant's status into the right side of the Performance-Arousal inverted U-shaped curve. In other words, the raised arousal by reward might make participants more susceptible to irrelevant stimuli (e.g., reward might substantially enhance the effectiveness of the ρ_2 process, i.e., the circled "-" from the ρ_2 box, in Figure 7), considering that the similar phenomenon has been found in the previous work where high-reward-associated items in working memory were more susceptible to interference (Allen & Ueno, 2018).

Our notion receives supports from the finding of significant Reward × Load interaction on N1 amplitude. Under low reward, the N1 amplitude, which indexed the early processing of task-irrelevant auditory stimuli, was generally higher in the medium load condition than in the high load condition. However, when reward was high, this difference became absent, indicating that higher reward urged the system to be less tolerant of early processing of auditory distractor even at the medium load level. After all, suppressing the early auditory processing might alleviate the intrusions of distractors into the system at the later stage. And this is verified by our findings on P3a, too.

P3a in P. Zhang et al.'s (2006) study sharply faded with the growing attentional load and even became non-significant in their medium and high load conditions, which is consistent with previous findings that attentional capture elicited by deviant auditory stimuli is obviously weakened by high working memory loads (Hughes et al., 2013; Marsh et al., 2019). In our work, the presence of P3a displayed a more complex but interesting picture. Under low reward, P3a was evident in the low and medium load conditions. However, when reward was high, P3a became non-significant in the medium load condition. Combined with the significant Reward × Load interaction on N1 amplitude, the P3a results strengthen our explanation above—under high reward, early processing of auditory distractors in the medium load condition was suppressed, which, in turn, guaranteed less attentional orienting towards the distractors in the later stage.

Our account for the non-monotonic modulation of distractor processing also holds when we compare the present work as a whole with P. Zhang et al.'s (2006) work. Because of reward, our subjects could be more aroused than P. Zhang et al.'s subjects, making our subjects more susceptible to irrelevant stimuli. Moreover, pursuing rewards could also lead our subjects to spend more attentional resources on the tracking task than P. Zhang et al.'s subjects. Therefore, intrusions of distractors would become more severe when reward is present (in our work) than when reward is absent (in P. Zhang et al.'s work), causing the tolerance of intrusions to be lower in our study than in P. Zhang et al.'s.

One limitation of our model is that we did not integrate the data of P. Zhang et al. (2006) and ours in a unified framework by including an additional variable of Reward in the model. Two major reasons result in this limitation. First, different samples of subjects participated in our study and in P. Zhang et al.'s. Second, their study did not include a rewarded condition while ours lacked an unrewarded condition. Thus, the data of the two studies were not mutually complementary. Since the inter-individual differences between the two studies likely bring non-negligible variance, it is unrealistic to combine P. Zhang et al.'s unrewarded and our rewarded data and build a unified quantitative model taking the effect of Reward into consideration.

Previous work has tested whether increasing working memory load affected distractor processings and obtained fairly mixed results (for review see Simon et al., 2016). Although attention and working memory have ever been found to be intertwined (Labar et al., 1999), more recent work has indicated that storage of an item in working memory should be dissociated from attending to that item (Awh et al., 2006; Olivers et al., 2011). Rather than working memory, the current study focused on the role of visual attentional load on cross-modal distractor processings, just as P. Zhang et al.'s study (2006) did. More than that, the experimental design of our work bears much resemblance to P. Zhang et al.'s except for only one additional factor of reward. Therefore, it is easy to show the impact of reward by directly comparing the present study with P. Zhang et al.'s. With this basis, we can further propose new perspectives about the early-late argument when amending the load theory of selective attention (Lavie, 2005; Lavie et al., 2004).

5 | CONCLUSION

In the current study, we investigated the effects of attentional control load and reward on the MMN and P3a components elicited by auditory oddball distractors in a rewarded attentive tracking task. We found that the processing of irrelevant distractors (as reflected by MMN) increased when the attentional load became higher, but then showed an unanticipated reduction when the load continued to rise. This nonmonotopic pattern was at odds with the previous findings by P. Zhang et al. (2006). We thereby argue that an additional patching mechanism for pre-attentive distractor suppression can keep distractors from occupying excessive attentional resources when the cognitive control resources are nearly exhausted by an extra-highly demanding task. The role of this additional patching mechanism is to maintain an ordered priority of attentional allocation in favor of the ongoing task. On the contrary, no load effect was found on P3a. Yet P3a was weakened by higher reward, suggesting reduced attentional orienting towards irrelevant distractors under higher reward. This reduced distraction at the later processing stage is thought to benefit from stronger suppression of early processing of auditory distractors under higher reward.

Our findings delineate a more complicated but complete picture than the previous landmark studies on Lavie's load theory of selective attention (Lavie, 2000, 2005; Lavie et al., 2004; P. Zhang et al., 2006). As shown in our work, the way that selective attention operates is far more complicated than previously expected if some social factors in real life (e.g., monetary incentives) are considered. Our work also implies that monetary reward is not necessarily an optimal means to boost performance especially for difficult tasks (M. Zhang et al., 2017).

ACKNOWLEDGMENTS

The authors would like to thank Dr. Yiran Yuan & Dr. Chuguang Wei for their technical support and Xinxin Du, Qiu Han, Yaqun Wang, Xiaojing Qin, & Licong An for their assistance in data collection. This research was supported by the National Natural Science Foundation of China (31871104, 31571112 and 31830037).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Xin He: Formal analysis; Investigation; Methodology; Software; Writing-original draft; Writing-review & editing. **Weilin Liu:** Investigation. **Nan Qin:** Investigation. **Lili Lyu:** Investigation. **Xue Dong:** Investigation. **Min Bao:** Conceptualization; Funding acquisition; Methodology; Project administration; Resources; Supervision; Writing-review & editing.

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How to cite this article: He, X., Liu, W., Qin, N., Lyu, L., Dong, X., & Bao, M. (2021). Performance-dependent reward hurts performance: The non-monotonic attentional load modulation on task-irrelevant distractor processing. *Psychophysiology*, 58, e13920. https://doi.org/10.1111/psyp.13920