Target Decision versus Motor Elicitation: The Influence of Motor Responses in Target Detection on the Attentional Facilitation Effect

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Abstract

The Attentional Boost Effect (ABE) refers to the phenomenon wherein, under dual-task conditions, memory performance for background information presented concurrently with target stimuli in a detection task is superior to that for background information presented with distractor stimuli. Previous research has posited that the emergence of ABE primarily stems from attentional enhancement elicited during target decision-making. However, given that target detection is often accompanied by motor responses, and extant studies have demonstrated that motor responses alone can directly elicit memory enhancement effects for background information, ABE may also originate from motor-induced memory enhancement effects. To this end, the present study implemented NoGo target detection conditions and Go target detection conditions, systematically examining the roles and relationship of motor responses and target decision-making in the generation of ABE through four experiments. The results indicated that ABE under Go target detection conditions was robust, whereas ABE under NoGo target detection conditions was influenced by the effect of motor response frequency on distractor words. Furthermore, cross-condition ABE in NoGo target detection was also highly stable. These findings suggest that the attentional promotional effect generated by target decision-making is relatively stable, but the emergence of ABE is largely the outcome of a dynamic trade-off between the promotional effect of target decision-making and motor-induced memory enhancement effects.

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detection is often accompanied by motor responses, and extant studies have demonstrated that motor responses alone can directly elicit memory enhancement effects for background information, ABE may also originate from motor-induced memory enhancement effects. To this end, the present study implemented NoGo target detection conditions and Go target detection conditions, systematically examining the roles and relationship of motor responses and target decision-making in the generation of ABE through four experiments. The results indicated that ABE under Go target detection conditions was robust, whereas ABE under NoGo target detection conditions was influenced by the effect of motor response frequency on distractor words. Furthermore, cross-condition ABE in NoGo target detection was also highly stable. These findings suggest that the attentional promotional effect generated by target decision-making is relatively stable, but the emergence of ABE is largely the outcome of a dynamic trade-off between the promotional effect of target decision-making and motor-induced memory enhancement effects.

Full Text

Preamble

Goal Decision vs. Action Elicitation: The Influence of Action Responses in Target Detection on the Attentional Boost Effect

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Abstract

The Attentional Boost Effect (ABE) refers to the phenomenon where, under dual-task conditions, memory performance for background information presented concurrently with target stimuli in a detection task is better than that for background information presented with distractor stimuli. Previous research has argued that ABE primarily arises from attentional enhancement triggered during target decision-making. However, since target detection is often accompanied by action responses, and existing studies have found that action responses alone can directly induce memory enhancement effects for background information, ABE may also originate from action-induced memory enhancement. To investigate this, the present study established both NoGo target detection conditions and Go target detection conditions, systematically examining the roles and relationship of action responses and target decision-making in ABE generation through four experiments. The results indicate that ABE under Go target detection conditions is stable, whereas ABE under NoGo target detection conditions is influenced by the frequency of action responses to distractor words. Additionally, cross-condition ABE for NoGo target detection is also highly stable. These findings demonstrate that the attentional facilitation effect produced by target decision-making is relatively

stable, but ABE generation is more accurately characterized as the result of dynamic trade-offs between the facilitative effect of target decision-making and action-induced memory enhancement effects.

Keywords: Attentional Boost Effect, Action-Induced Memory Enhancement, Dual-Task Interaction Model, Go Target Detection, NoGo Target Detection

1 Introduction

In daily life, we often find ourselves in dual-task situations. For example, while driving, one must simultaneously monitor traffic light changes and attend to road conditions. Since attentional resources are limited, increased allocation to one task typically reduces resources available to another, thereby affecting behavioral responses and manifesting as dual-task interference effects (Pashler, 1994; Kinchla, 1992). However, some studies have found that dual tasks do not necessarily produce interference. Swallow and Jiang (2010) were the first to explore this phenomenon. Their experiment employed a learning-test paradigm in which, during the learning phase, participants were required to memorize a series of pictures while simultaneously performing a color detection task on squares presented at the center of each picture. Participants pressed a key in response to white squares (targets) and ignored black squares (distractors) without responding. The target-to-distractor ratio was 1:6. Stimuli were presented using a rapid serial visual presentation (RSVP) paradigm at a rate of 500 ms per item, with squares and pictures appearing simultaneously for 100 ms before the square disappeared while the picture remained for an additional 400 ms.

A recognition test for the pictures was administered two minutes after the learning phase. Conventional wisdom suggests that target detection consumes more attentional resources than distractor rejection (Duncan et al., 1994), leading to the prediction that pictures presented with targets would receive fewer attentional resources during encoding and thus show poorer recognition performance compared to those presented with distractors. Contrary to this expectation, however, pictures presented with targets showed significantly better memory performance than those presented with distractors. Swallow and Jiang named this phenomenon the Attentional Boost Effect (ABE). Subsequent research using different background materials (faces: Swallow & Jiang, 2011; words: Mulligan et al., 2014; Mulligan et al., 2016) and various memory tests (short-term memory tests: Makovski et al., 2011; implicit memory tests: Spataro et al., 2013) has consistently demonstrated the robust existence of this effect.

To better explain ABE generation, Swallow and Jiang (2013) proposed the dual-task interaction model. This model extends attentional resource limitation theory by suggesting that perceptual resources are allocated more flexibly. Specifically, when the central executive system categorizes rapidly presented detection stimuli as target stimuli requiring a response (such as key presses, counting, or maintenance in memory)—that is, during the target decision process of the detection task—it triggers a time-based selective attention mechanism. This mechanism is typically accompanied by locus coeruleus-norepinephrine (LC-NE) release, producing transient activity enhancement. This excitation projects diffusely to cortical sensory areas, facilitating perceptual processing of background information presented simultaneously with targets and thereby generating ABE. Further research has shown that distractors with high perceptual similarity to target stimuli do not exhibit similar facilitation effects (Swallow & Jiang, 2014a), and that adding perceptual or semantic load before target decision-making (Swallow & Jiang, 2014a; Zheng et al., 2020) does not affect ABE generation, providing additional support for the dual-task interaction model and indicating that ABE primarily originates from target decision-making regarding detection stimuli.

Nevertheless, in ABE research, participants must also produce corresponding action responses (e.g., key presses) upon detecting target stimuli. Recent studies have discovered that action responses alone can directly enhance memory for task-irrelevant background information, a phenomenon termed Action-Induced Memory Enhancement (AIME; Yebra et al., 2019). Using a Go-NoGo task paradigm, this study required participants to view a series of grayscale images (presented at approximately 4 s per item) during encoding while executing either a key press (Go response) or no response (NoGo response) based on pre-instructions regarding the color of the image border (blue or yellow). An unexpected recognition test was administered after one hour (or one day). Results showed that images accompanied by Go responses were better remembered than those accompanied by NoGo responses. The study further investigated the mechanism underlying AIME using functional magnetic resonance imaging (fMRI) and pupil diameter measurements (an indirect indicator of LC activity), explaining that AIME arises because brain regions critical for memory formation—the medial temporal lobe (MTL) and locus coeruleus (LC)—contain action-related neuronal responses. Consequently, action responses alone can directly increase neuronal activity in and connectivity between the LC and MTL, causing large amounts of norepinephrine (NE) released by the LC to act directly on memory circuits in the MTL (i.e., the hippocampus and surrounding cortex), thereby enhancing encoding of action-unrelated background information.

The discovery of AIME appears to offer an alternative explanation for ABE generation: might ABE stem from action-induced memory enhancement triggered by target action responses rather than from target decision-making? Previous studies have replaced key press responses with implicit mental counting responses during target detection and still observed stable ABE (Swallow & Jiang, 2012, 2014b, 2019), seemingly ruling out a role for action responses in ABE generation. However, according to the theory of event coding, counting responses, because they involve mental updating, are also encoded as action codes in event files and thus constitute a type of non-explicit action (Hommel, 2004; Makovski et al., 2013). Moreover, Swallow et al. (2019) observed pupil diameter increases when participants mentally counted target stimuli. Increased pupil diameter signifies activation of LC activity, and research on rhesus monkeys has found that LC+ neuron activity (i.e., neurons in the locus coeruleus and nearby subcoeruleus nucleus) is only activated during action-related "Go" responses (Kalwani et al., 2014). Therefore, counting responses to targets still constitute a "Go" response, and as long as target decision-making is accompanied by a "Go" response, the potential contribution of action-induced memory enhancement to ABE cannot be excluded.

The key to clarifying the source of ABE generation lies in separating target decision-making from Go responses. The experimental design of Makovski et al. (2013) provides valuable insights for this purpose. During encoding, they presented participants with three types of stimuli: male faces, female faces, and natural scenes. Participants were instructed to press a key as quickly as possible (Go response) when any picture appeared and memorize it, but to cancel the key press (NoGo response) when a pre-specified target picture (e.g., male face) appeared, memorizing only the picture. Results showed that target pictures requiring NoGo responses were better remembered than those requiring Go responses, indicating that target decision-making produced superior memory facilitation compared to action responses. However, unlike ABE research, which investigates "the effect of target detection tasks on memory for unrelated tasks," Makovski et al.' s study used detection targets that were the memory stimuli themselves rather than stimuli unrelated to the memory items (e.g., squares). Different detection stimulus configurations (relevant vs. irrelevant) produce different effects: phenomena observed when detecting relevant stimuli (Doallo et al., 2012) may not necessarily occur when detecting irrelevant stimuli (Inoue & Sato, 2017). Consequently, Makovski et al.' s findings cannot be directly applied to explain ABE, though their experimental design offers valuable reference for investigating the relationship between ABE and action responses.

Therefore, the present study adopts Makovski et al.'s (2013) experimental design within the ABE paradigm by establishing a NoGo target detection condition to separate target decision-making from action responses, aiming to further investigate the mechanism underlying ABE generation.

Building upon Mulligan et al.' s (2014) ABE paradigm, this study modified the detection task in two ways to create a NoGo target detection condition. First, we revised the instructions and participants' response requirements: participants were instructed to press a key as quickly as possible (Go distractor response) whenever a colored circle appeared below a word (distractor circle), but to withhold the key press (NoGo target response) when a pre-specified target circle (e.g., red circle) appeared. According to the dual-task interaction model, a "target" is defined as an item that changes the planned activity (Swallow & Jiang, 2013). Therefore, when instructions create a Go response tendency for all detection circles, the circle requiring a NoGo response (which requires changing the planned activity) becomes the target. Second, without changing the target-to-distractor ratio (1:4), we increased the variety of distractor circle colors (e.g., yellow, blue, green, purple) to be mixed with one target color circle (e.g., red), with each color circle presented at 20% probability. This prevented participants from reversing the instructions, as according to cognitive processing economy principles, participants tend to treat the less frequent stimulus as the target. For convenience, we refer to words presented with target circles as "target words" and those presented with distractor circles as "distractor words."

Additionally, to enable effective comparison, we established a classic Go target detection condition as a baseline, in which participants responded to target circles with a key press (Go target response) and ignored distractor circles (NoGo distractor response). All other settings remained identical to the NoGo target detection condition. This design allows for both within-condition and cross-condition comparisons, providing more evidence for explaining ABE. We hypothesized that if ABE primarily stems from target decision facilitation, both conditions (NoGo target detection and Go target detection) should show differences between target and distractor words—that is, both should exhibit ABE. Furthermore, memory performance under NoGo target responses should be better than under NoGo distractor responses, producing cross-condition ABE. Conversely, if ABE primarily stems from action-induced memory enhancement, NoGo target responses should confer no memory advantage, meaning no ABE would appear within the NoGo target detection condition (relative to Go distractor words) or across conditions (relative to NoGo distractor words). Additionally, memory performance under Go target or distractor responses should be significantly better than under NoGo target or distractor responses, demonstrating cross-condition action enhancement effects.

Experiment 1

2.1.1 Participants

Using G*Power 3.1 and based on previous ABE research (Mulligan et al., 2014; Mulligan & Spataro, 2015), we calculated the required sample size (Faul et al., 2007). With an average effect size of $f = 0.48$ (equivalent to $p^2 = 0.19$), at least 11 participants were needed to achieve a statistical power of 0.95 ($1 - \beta$) in repeated-measures ANOVA. Considering the standard for approximately normal distribution ($n \geq 30$), we recruited 35 university students through campus advertisements. All participants were right-handed, had normal or corrected-to-normal vision, and no red-green color blindness. Valid data inclusion criteria required detection accuracy above 0.4 and recognition performance within three standard deviations of the mean. Two participants were excluded—one due to a procedural error (completing the learning task twice) and another due to NoGo target detection accuracy below 0.4—resulting in 33 participants whose data were included in the final analysis (10 male), with a mean age of 19.42 ± 0.43 years. Participants read an informed consent form before the experiment and received compensation upon completion.

2.1.2 Materials and Apparatus

Memory materials were selected from the "Table 2 (2): Top 8,000 Most Frequent Words" in the *Modern Chinese Frequency Dictionary* (1986), focusing on neutral two-character nouns. We cross-referenced the National Language Commission Modern Chinese Corpus (www.cncorpus.zhonghuayuwen.org) to ensure currency, then removed two-character words with frequencies exceeding three standard deviations above the mean, yielding 256 keywords for the experiment (average word frequency: 1.31% ± 1.18%). These 256 keywords were randomly divided into two sets for the Go target detection and NoGo target detection conditions. The two word sets were matched on frequency (M = 1.31% ± 1.20% vs. M = 1.31% ± 1.18%), valence (M = 5.08 ± 0.31 vs. M = 5.08 ± 0.33), arousal (M = 4.95 ± 0.25 vs. M = 4.95 ± 0.27), and stroke count (M = 15.73 ± 3.59 vs. M = 15.71 ± 3.43), with $t(127)s < 0.90$, $ps > 0.40$. In each detection condition, the 128 keywords were randomly divided into two subsets: one presented during the learning phase (half with target circles as target words, half with distractor circles as distractor words) and the other serving as new words mixed with old words during the test phase. Additionally, 256 high-frequency two-character words were selected as filler words during the learning phase (average frequency: 0.60% ± 0.50%), and 36 words served as practice items for both learning and test phases (average frequency: 0.30% ± 0.20%), with half used in the Go target detection condition and half in the NoGo target detection condition. All words appeared in white on a black screen, size 60 font, subtending a visual angle of 1.03° × 2.15°.

Detection stimuli were colored circles with a diameter of 1 cm (visual angle: 0.72°), including five colors: red (RGB: 255, 0, 0), yellow (RGB: 255, 255, 0), blue (RGB: 0, 0, 255), green (RGB: 0, 255, 0), and purple (RGB: 255, 0, 255).

The experimental program was created using Presentation software and run on a Dell computer with a 15-inch CRT monitor at 1280 × 1024 resolution. Participants were tested individually in a soundproof room, seated approximately 80 cm from the display.

2.1.3 Design and Procedure

The experiment employed a 2 (target detection type: Go vs. NoGo) × 2 (attention type: target vs. distractor) within-subjects design. All participants completed both Go target detection and NoGo target detection conditions. To prevent fatigue, participants were required to rest for at least three minutes between conditions, with the option to continue when ready. The order of conditions was counterbalanced across participants.

Each condition comprised a learning phase, a distraction phase, and a test phase. During the learning phase, two-character words and colored circles were presented simultaneously at the center of a black screen. Words appeared in white, size 60 font, subtending 1.03° × 2.15°, with circles positioned 1 cm below the words, subtending 0.72°. Stimuli were organized into 32 blocks of five items each: one target word with a target circle, one distractor word with a distractor circle, and three filler words with distractor circles. Each circle color (red, yellow, blue, green, purple) appeared with 20% probability. The target circle was designated as red for half the participants and green for the other half to control for color preference (Aslam, 2006); all other colors served as distractor circles. Within each block, the target word always appeared in the third position, while distractor and filler words were arranged pseudorandomly in the remaining four positions. Additionally, 0–2 filler words were presented randomly between blocks. Participants were instructed to silently read and memorize the words while performing Go or NoGo target detection tasks on the circles. In the Go target detection task, participants pressed the spacebar with their dominant hand immediately upon seeing a target circle (e.g., red circle) but made no response to other-colored circles (distractor circles). In the NoGo target detection task, participants pressed the spacebar for all circles (distractor circles) but withheld their response when a target circle (e.g., red circle) appeared. Each word and its detection circle were presented simultaneously for 100 ms, after which the circle disappeared while the word remained for an additional 400 ms, followed by a 500 ms inter-stimulus interval (ISI) blank screen (see Figure 1 for the learning phase flowchart).

Immediately after the learning phase, participants performed a distraction calculation task (20 two-digit addition/subtraction problems), followed by the recognition test.

During the recognition phase, the 128 keywords were presented sequentially and randomly at the center of the screen: 64 old words from the learning phase (32 target words and 32 distractor words) and 64 new words. Participants were instructed to judge each word as old or new as quickly and accurately as possible (press F for new, J for old). Each word remained on screen until a response was made, with an inter-trial interval of 1400 ± 200 ms.

Figure 1. Flowchart of the learning phase.

2.2.1 Target Detection Task

We analyzed participants' detection performance across the two target detection conditions. In the Go target detection condition, the correct detection rate for targets (i.e., number of correct key presses / total target trials) was 99.24% (SE = 0.30%). In the NoGo target detection condition, the correct detection rate for targets (i.e., number of successful no-response trials / total target trials) was 76.89% (SE = 2.80%). Shapiro-Wilk tests indicated that detection accuracy was non-normally distributed ($Ws < 0.80$, $ps < 0.05$), so we used Wilcoxon signed-rank tests to compare performance between conditions. Results showed that target detection accuracy was lower in the NoGo condition than in the Go condition, $Z = -5.02$, $p < 0.001$. This pattern mirrors findings from Makovski et al. (2013), who reported 79.3% correct detection for NoGo target stimuli in their Experiment 4. Additionally, correct rejection rates for distractors remained high in both conditions: 99.15% (SE = 0.80%) in the Go target detection condition and 97.44% (SE = 0.60%) in the NoGo target detection condition. These results confirm that participants followed task instructions correctly during encoding.

2.2.2 Recognition Task

Old-word recognition rates and new-word false alarm rates for both detection conditions are presented in Table 1. Since our primary interest concerned the impact of successful target detection on word memory, old-word recognition rates were calculated as the percentage of successfully detected keywords that were later correctly recognized (i.e., old-word recognition rate = number of correctly recognized keywords from successfully detected trials / total number of successfully detected trials).

Table 1. Old-word recognition rates and new-word false alarm rates in Experiment 1.

Target Detection Type	Old-word Recognition Rate	False Alarm Rate
Go target detection	0.62 (0.02)	0.36 (0.02)
NoGo target detection	0.61 (0.03)	0.39 (0.03)

Note: Values in parentheses are standard errors (SE).

Given that false alarm rates might influence results, we calculated corrected recognition rates by subtracting false alarm rates from old-word recognition rates. The corrected recognition rates for old words are shown in Figure 1, and subsequent analyses were based on these corrected scores.

Shapiro-Wilk tests revealed that corrected old-word recognition rates were normally distributed ($Ws > 0.9$, $ps > 0.5$). To examine within-condition ABE, we conducted a 2 (target detection type: NoGo vs. Go) × 2 (attention type: target word vs. distractor word) repeated-measures ANOVA on corrected recognition rates. Results showed a significant main effect of attention type, $F(1,32) = 56.39$, $p < 0.001$, $p^2 = 0.64$, 95% CI [0.40, 0.75], with better recognition for target words than distractor words. The main effect of detection type was also significant, $F(1,32) = 5.08$, $p = 0.03$, $p^2 = 0.14$, 95% CI [0.00, 0.35], with better recognition under Go target detection than NoGo target detection. The interaction between attention type and detection type was not significant [$F(1,32) = 0.02$, $p = 0.877$]. Thus, both target detection conditions produced significant within-condition ABE, with no significant difference in ABE magnitude between conditions [Go target detection: 11.70%, NoGo target detection: 12.10%, $t(32) = -0.16$, $p = 0.877$].

To further isolate the influence of action responses on ABE, we compared NoGo target words from the NoGo condition with NoGo distractor words from the Go condition. Results showed that NoGo target words were recognized significantly better than NoGo distractor words, $t(32) = 2.60$, $p = 0.010$, $d = 0.45$, 95% CI = [0.09, 0.81], demonstrating cross-condition ABE. This ABE magnitude (7.22%) did not differ from that in the Go target detection condition (11.71%) [$t(32) = 1.74$, $p = 0.090$] but was significantly smaller than that in the NoGo target detection condition (12.08%) [$t(32) = 2.15$, $p = 0.04$, $d = 0.37$, 95% CI =

[0.02, 0.72]]. Further analysis revealed that NoGo distractor words were better remembered than Go distractor words, $t(32) = 2.26$, $p = 0.03$, $d = 0.39$, 95% CI = [0.04, 0.74], while Go target words did not differ significantly from NoGo target words [$t(32) = -1.74$, $p = 0.090$].

Figure 2. Comparison of corrected old-word recognition rates across conditions in Experiment 1.
Note: Error bars represent standard errors; $p < 0.05$, $\mathbf{p < 0.01}$, *$p < 0.001$.*

2.3 Discussion

The results from both detection conditions clearly demonstrate the ABE phenomenon, indicating that target detection produces ABE regardless of whether it requires an action response. Additionally, NoGo target words showed better recognition than NoGo distractor words, exhibiting cross-condition ABE. Since neither NoGo target words nor NoGo distractor words were accompanied by action responses, this finding further demonstrates that ABE generation does not require action responses to target stimuli; target decision-making alone can produce facilitative effects.

Experiment 1 also revealed an interesting pattern: recognition performance did not differ between Go target words and NoGo target words, but Go distractor words were significantly poorer than NoGo distractor words. These results suggest that under target detection tasks, action responses not only fail to facilitate encoding of target words but may further inhibit encoding of distractor words, leading to poorer recognition. This finding directly contradicts Yebra et al. (2019). In their study, the ratio of action to non-action signals was 1:1, whereas in our Experiment 1' s NoGo target detection condition, the ratio of action signals (Go distractors) to non-action signals (NoGo targets) was 5:1. Research has shown that frequently presented signals typically attract weaker attention (Theeuwes, 1992, 2010). Could the poorer recognition of Go distractor words in the NoGo target detection condition result from frequent action responses causing participants to perform the action task with lower attentional levels, thereby producing greater inhibition of distractor words?

Therefore, Experiment 2 manipulated the target-to-distractor ratio to 1:1 to exclude confounding effects arising from differential action-to-non-action ratios. Based on Yebra et al. (2019), we predicted that when target and distractor presentation frequencies are equal, Go actions should produce memory enhancement for background information (distractor words). Would this action-induced memory enhancement for distractor words weaken or even offset the attentional boost effect on target words produced by target detection, causing ABE to disappear under NoGo target detection conditions? This question was addressed in Experiment 2.

Experiment 2

3.1.1 Participants

Participant selection criteria matched Experiment 1. Thirty-six university students were newly recruited, with one excluded due to old-word recognition rates falling more than three standard deviations below the mean, yielding 35 valid datasets. To standardize sample sizes across experiments for more reliable comparisons, we randomly selected 33 participants' data using SPSS (15 male), with a mean age of 19.79 ± 0.43 years. All participants were right-handed, had normal or corrected-to-normal vision, and no red-green color blindness.

3.1.2 Materials and Procedure

We used the same 256 keywords and 256 filler words from Experiment 1. The allocation of 256 keywords across experimental conditions was identical to Experiment 1. To ensure a 1:1 target-to-distractor ratio during the learning phase detection task, half of the 256 filler words were presented with target circles and half with distractor circles. Only keywords (target and distractor words) were tested during the recognition phase. All other aspects remained consistent with Experiment 1.

3.2.1 Target Detection Task

In the Go target detection condition, target detection accuracy was 98.77% (SE = 0.90%). In the NoGo target detection condition, target detection accuracy was 92.61% (SE = 2.00%), significantly lower than in the Go condition, $Z = -3.80$ (as detection rates were non-normally distributed, $Ws < 0.80$, $ps < 0.05$, Wilcoxon signed-rank test), $p < 0.001$. Additionally, distractor correct rejection rates remained high in both conditions: 97.06% (SE = 0.81%) in the Go condition and 96.88% (SE = 1.00%) in the NoGo condition, confirming that participants performed the detection tasks as instructed.

3.2.2 Recognition Task

Old-word recognition rates and new-word false alarm rates for both detection conditions are shown in Table 2. Consistent with Experiment 1, primary analyses focused on corrected old-word recognition rates (see Figure 3).

Table 2. Old-word recognition rates and new-word false alarm rates in Experiment 2.

Target Detection Type	Old-word Recognition Rate	False Alarm Rate
Go target detection	0.55 (0.03)	0.39 (0.03)
NoGo target detection	0.51 (0.02)	0.34 (0.02)

Note: Values in parentheses are standard errors (SE).

Shapiro-Wilk tests confirmed that corrected recognition rates were normally distributed (Ws > 0.90, ps > 0.20). A 2 (target detection type: NoGo vs. Go) × 2 (attention type: target word vs. distractor word) repeated-measures ANOVA revealed a significant main effect of detection type, $F(1,32) = 6.59$, $p = 0.015$, $p^2 = 0.17$, 95% CI [0.01, 0.38]. The main effect of attention type was not significant [$F(1,32) = 3.04$, $p = 0.090$], but the interaction between attention type and detection type was significant, $F(1,32) = 6.81$, $p = 0.010$, $p^2 = 0.18$, 95% CI [0.01, 0.39]. Simple effects analysis showed that in the Go target detection condition, corrected recognition rates for target words were significantly better than for distractor words, $F(1,32) = 8.97$, $p = 0.005$, $p^2 = 0.22$, 95% CI [0.02, 0.43], demonstrating ABE. However, in the NoGo target detection condition, no significant difference existed between target and distractor words [$F(1,32) = 0.16$, $p = 0.690$], indicating no ABE. Additionally, Go distractor words were recognized significantly better than NoGo distractor words, $F(1,32) = 14.41$, $p = 0.001$, $p^2 = 0.31$, 95% CI [0.07, 0.51], while Go target words did not differ significantly from NoGo target words [$F(1,32) = 0.06$, $p = 0.820$].

To examine whether NoGo target detection could produce cross-condition ABE, we conducted a paired-samples t-test comparing NoGo target words from the NoGo condition with NoGo distractor words from the Go condition. Results showed that NoGo target words were recognized significantly better than NoGo distractor words, $t(32) = 3.13$, $p = 0.004$, $d = 0.45$, 95% CI = [0.09, 0.81], demonstrating cross-condition ABE. This ABE magnitude (7.54%) did not differ from that in the Go target detection condition (6.97%) [$t(32) = 0.23$, $p = 0.820$] or from the cross-condition ABE magnitude in Experiment 1 (7.22%) [$t(64) = 0.09$, $p = 0.930$].

Figure 3. Comparison of corrected old-word recognition rates across conditions in Experiment 2.
Note: Error bars represent standard errors; $p < 0.05$, **p < 0.01,** *p < 0.001.*

3.3 Discussion

Unlike Experiment 1, when the target-to-distractor ratio was 1:1, no within-condition ABE was observed under NoGo target detection. However, cross-condition ABE for NoGo target detection emerged: NoGo target words still showed memory advantages compared to Go distractor words from the Go condition. The magnitude of this effect (7.54%) was similar to the within-condition ABE in the Go target detection condition (6.97%) and to the cross-condition ABE in Experiment 1 (7.22%), indicating that the facilitative effect of target decision-making on background information is relatively stable and unaffected by target-to-distractor ratio. This pattern is consistent with previous findings (see also Swallow & Jiang, 2012).

Another result differing from Experiment 1 was that Go distractor words were recognized significantly better than NoGo distractor words, demonstrating an action enhancement effect similar to Yebra et al. (2019). Since Go target words and NoGo target words did not differ in recognition performance, the absence of ABE under NoGo target detection in Experiment 2 appears to stem from action responses producing a facilitative effect on distractor words comparable to the attentional boost effect on target words, thereby eliminating the difference in recognition rates between them. When target detection and action enhancement effects act on the same background information, their effects seem to become redundant. Redundancy between target detection and other memory enhancement effects has been observed in other studies (Meng et al., 2018; Spataro et al., 2015). This also explains why, in both Experiments 1 and 2, the cross-condition ABE under NoGo target detection was equivalent in magnitude to the within-condition ABE under Go target detection.

The results of Experiment 2 indicate that the memory enhancement effect of action responses on background information is influenced by action response frequency. When the ratio of action to non-action signals is 1:1, action responses produce memory enhancement for background information (distractor words) similar to the attentional boost effect on target words, resulting in the disappearance of ABE under NoGo target detection. However, this disappearance could also arise from participants reversing the instructions, treating the Go distractor key-press task as the target. Research has shown that under otherwise equal conditions (e.g., presentation frequency), people tend to treat "no response/no key press"as the default behavior and "action response"as the target behavior that changes the default. For example, when male and female faces are presented at a 1:1 ratio, participants may reverse instructions to "press key for male faces" when instructed to "withhold response for female faces" (Makovski et al., 2013). Previous research has successfully avoided participants treating key presses as target behavior by changing the action-to-non-action stimulus ratio to 2:1 (Makovski et al., 2013). Therefore, Experiment 3 changed the Go distractor to NoGo target ratio to 2:1 to exclude confounds from instruction reversal and to further examine whether different action response frequencies modulate action-induced memory enhancement, providing additional evidence to explain the roles of target detection and action responses in ABE.

Experiment 3

4.1.1 Participants

Participant selection criteria matched Experiment 1. Thirty-six university students were newly recruited. To enhance reliability of cross-experiment comparisons, we randomly selected 33 participants' data using SPSS (14 male), with a mean age of 19.33 ± 0.34 years. All participants were right-handed, had normal or corrected-to-normal vision, and no red-green color blindness.

4.1.2 Materials and Procedure

Materials and procedures were similar to Experiment 2, with one modification: during the learning phase, 64 filler words were presented with target circles and

192 with distractor circles, achieving a 1:2 target-to-distractor ratio.

4.2.1 Target Detection Task

In the Go target detection condition, target detection accuracy was 98.96% (SE = 0.40%). In the NoGo target detection condition, target detection accuracy was 79.83% (SE = 2.00%), significantly lower than in the Go condition, Z = -5.02 (as detection rates were non-normally distributed, $Ws < 0.93$, $ps < 0.05$, Wilcoxon signed-rank test), $p < 0.001$, indicating greater difficulty in the NoGo target detection task. Distractor correct rejection rates remained high in both conditions: 98.30% (SE = 0.40%) in the Go condition and 98.30% (SE = 0.60%) in the NoGo condition, confirming that participants performed the detection tasks as instructed.

4.2.2 Recognition Task

Old-word recognition rates and new-word false alarm rates were calculated as in Experiments 1 and 2 (see Table 3). Primary analyses focused on corrected old-word recognition rates (see Figure 4).

Table 3. Old-word recognition rates and new-word false alarm rates in Experiment 3.

Target Detection Type	Old-word Recognition Rate	False Alarm Rate
Go target detection	0.56 (0.03)	0.33 (0.03)
NoGo target detection	0.53 (0.03)	0.33 (0.02)

Note: Values in parentheses are standard errors (SE).

Shapiro-Wilk tests confirmed that recognition performance was normally distributed ($Ws > 0.90$, $ps > 0.20$). A 2 (target detection type: NoGo vs. Go) × 2 (attention type: target vs. distractor) repeated-measures ANOVA on corrected recognition rates revealed a significant main effect of attention type, $F(1,32) = 18.05$, $p < 0.001$, $p^2 = 0.36$, 95% CI [0.11, 0.55]. The main effect of detection type was not significant [$F(1,32) = 0.43$, $p = 0.520$], and the interaction between attention type and detection type was not significant [$F(1,32) = 1.37$, $p = 0.250$]. Thus, ABE was stable in both detection conditions, with target detection producing better memory than distractor rejection, and no significant difference in ABE magnitude between conditions [Go target detection: 9.00%, NoGo target detection: 5.19%, $t(32) = 1.17$, $p = 0.250$].

To examine cross-condition ABE under NoGo target detection, we conducted a paired-samples t-test comparing NoGo target words with Go distractor words. Results showed that NoGo target words were recognized significantly better than Go distractor words, $t(32) = 2.38$, $p = 0.030$, $d = 0.42$, 95% CI = [0.06, 0.77], demonstrating cross-condition ABE. This effect magnitude (5.83%) did not differ significantly from that in the NoGo target detection condition [t(32) = -0.24, p = 0.810] or the Go target detection condition [t(32) = 1.33, p = 0.190]. Experiment 3 also found no difference between NoGo distractor words and Go distractor words [t(32) = 0.24, p = 0.810].

Figure 4. Comparison of corrected old-word recognition rates across conditions in Experiment 3.
Note: Error bars represent standard errors; $p < 0.05$, $\mathbf{p < 0.01}$, $p < 0.001$.

4.3 Discussion

Experiment 3 set the target-to-distractor ratio at 1:2 and found significant ABE in both Go and NoGo target detection conditions, as well as cross-condition ABE under NoGo target detection. Specifically, NoGo target words showed memory advantages over Go distractor words, reflecting target decision-induced facilitation that was equivalent in magnitude to within-condition ABE effects. This again demonstrates that the facilitative effect of target decision-making on background information is relatively stable and unaffected by target-to-distractor ratio.

Unlike Experiments 1 and 2, when the target-to-distractor ratio was 1:2, Experiment 3 found no difference in recognition performance between Go distractor words and NoGo distractor words—neither the inhibitory effect observed in Experiment 1 nor the facilitative effect found in Experiment 2. This indicates that action response frequency modulates action-induced memory enhancement. Although Experiment 2' s design already increased distractor color variety to minimize instruction reversal, and the finding that NoGo target detection produced similar cross-condition ABE across Experiments 1, 2, and 3 [F(2,101) = 0.13, p = 0.880] indirectly suggests this possibility was minimal, previous research has demonstrated that a 2:1 action-to-non-action ratio effectively prevents participants from treating key presses as target behavior (Makovski et al., 2013). To ensure more rigorous conclusions, we conducted a supplementary experiment based on Experiment 2 that further reduced the likelihood of instruction reversal through experimental design while maintaining a 1:1 target-to-distractor ratio. The supplementary experiment replicated Experiment 2' s results, rejecting the instruction reversal hypothesis proposed in Experiment 2' s discussion. Therefore, the results from all three experiments further support our hypothesis that the facilitative effect of action responses on background information is influenced by action response frequency.

4.4 Analysis of Action Response Frequency Effects on ABE

Comparing results across the three experiments, we found that action response frequency primarily exerted different effects on distractor words. Under high action response frequency, action responses produced inhibitory effects on distractor words (Experiment 1). As action response frequency decreased, this inhibitory effect gradually disappeared (Experiment 3). When action and non-action response frequencies were equivalent, action responses produced facilitative effects on distractor words (Experiment 2). Based on these findings, we hypothesize that action-induced memory enhancement exhibits a linear relationship with action response frequency, which can be expressed as: $y = ax + b$ ($x > 0$), where x represents action response frequency and y represents the difference in recognition performance between Go distractor words and NoGo distractor words, indicating the magnitude of action-induced memory enhancement. Substituting data from Experiments 1 and 2 yielded a = -0.41 ± 0.09, 95% CI [-0.59, -0.22] and b = 0.29 ± 0.06, 95% CI [0.16, 0.41].

To further test this relationship' s reliability, we solved for x when y = 0, obtaining x = 0.66 ± 0.06, 95% CI [0.54, 0.77], corresponding to a frequency of 2/3 (0.67). This matches Experiment 3' s design, and since Experiment 3 found neither facilitative nor inhibitory effects (y = 0), action response frequency of 2/3 appears to be a critical balance point between facilitative and inhibitory effects. When action response frequency exceeds 2/3, frequent action responses gradually produce inhibitory effects on background information encoding; conversely, when frequency is lower than 2/3, action responses gradually produce facilitative effects.

When target detection and action responses simultaneously affect background information—that is, under classic Go target detection conditions—does action response frequency influence the facilitative effect of target detection on background information? Comparing across the three experiments, we found that Go target word recognition performance decreased as target proportion increased, $F(2,96) = 3.55$, $p = 0.033$, $p^2 = 0.07$, 95% CI [0.00, 0.17], whereas NoGo target word performance was unaffected by proportion [$F(2,96) = 1.29$, $p = 0.280$]. This indicates that while target decision-making alone produces stable facilitation, target detection accompanied by action responses is still modulated by action response frequency. Since Go target word response frequencies in all three studies were below 2/3 (see Table 4), according to our proposed "formula," action responses should produce facilitative effects on target words at these frequencies. This facilitative effect would be redundant with the boost from target detection, explaining why Go target word recognition was equivalent to NoGo target word performance across all three experiments. This also accounts for recent findings that ABE under Go target detection conditions is affected by target-to-distractor ratio: in these studies, target presentation frequency equals action response frequency. For example, Au and Cheung (2020) found that higher target presentation frequency produced smaller ABE, and Lin (2019) found that ABE disappeared when target presentation frequency was 4/5, with NoGo distractor words actually showing better memory than Go target words. Substituting this action frequency into our formula yields $y < 0$, indicating that action responses produce inhibitory effects on target words at this frequency. Thus, these phenomena may not reflect effects of target proportion on target detection but rather result from action response frequency increasing inhibitory effects on target words, reducing or even eliminating the difference between target and distractor conditions.

Table 4. Corrected old-word recognition rates and action response frequencies across Experiments 1-3.

Condition	Go Target Words	NoGo Distractor Words	Action Response Frequency
Exp 1	0.26 (0.02)	0.14 (0.02)	0.83
Exp 2	0.16 (0.02)	0.23 (0.02)	0.50
Exp 3	0.22 (0.03)	0.10 (0.02)	0.67

Note: Values in parentheses are standard errors (SE).

Based on this analysis, we propose that ABE generation does not solely originate from target decision facilitation, regardless of whether target detection requires action responses. Instead, ABE represents the result of dynamic trade-offs between target decision facilitation and action-induced memory enhancement. We term this the "dynamic trade-off model" of ABE. However, the first three experiments primarily demonstrated effects of action response frequency on Go distractor words; direct evidence for how action response frequency and target decision-making jointly affect Go target words and consequently influence ABE remains limited. While we believe Lin' s (2019) finding that ABE disappears at a target presentation frequency of 4/5 (i.e., target-to-distractor ratio of 4:1) provides strong support, that author attributed the effect to novelty effects from low-frequency NoGo distractors on background information. Therefore, Experiment 4 added blank words (words presented without detection stimuli) equivalent in proportion to distractors, further controlling action response frequency so that Go target action response frequency was 2/3 (relative to NoGo distractors and NoGo blanks). Based on our derived formula and the dynamic trade-off model, since Go target action response frequency does not exceed the 2/3 critical point, no inhibitory effect should occur, and ABE should be observable despite the 4:1 target-to-distractor ratio. Experiment 4 also included a NoGo target detection condition with equivalent action presentation frequency (NoGo target: Go distractor: NoGo blank = 1:4:1) as a control to further examine whether action response frequency modulation of ABE could be replicated, providing additional evidence for the dynamic trade-off model.

Experiment 4

5.1.1 Participants

Participant selection criteria matched Experiment 1. To maintain consistent sample sizes with previous studies, 33 university students were newly recruited and included in the analysis (8 male), with a mean age of 19.27 ± 0.25 years. All participants were right-handed, had normal or corrected-to-normal vision, and no red-green color blindness.

5.1.2 Materials and Apparatus

Based on the vocabulary from Experiment 1 and following the same selection criteria, we added 128 new keywords for a total of 384 keywords, randomly divided into two sets for Go and NoGo target detection conditions. The two keyword sets were matched on frequency (M = 1.17% ± 1.08% vs. M = 1.16% ± 1.05%), valence (M = 5.07 ± 0.34 vs. M = 5.12 ± 0.36), arousal (M = 4.80 ± 0.32 vs. M = 4.84 ± 0.36), and stroke count (M = 15.73 ± 4.45 vs. M = 15.79 ± 4.18), with t(191)s < 0.9, ps > 0.1. All other aspects remained consistent with Experiment 1.

5.1.3 Design and Procedure

Similar to Experiment 1, with the addition of blank words (words presented without detection stimuli). Experiment 4 used a 2 (target detection type: Go vs. NoGo) × 3 (attention type: target vs. distractor vs. blank) within-subjects design. During each condition' s learning phase, 32 target words, 32 distractor words, 32 blank words, and 96 filler words were presented in random order. To ensure an action frequency of 2/3 in each condition, filler words in the Go target detection condition were all presented with target circles (target-to-distractor ratio of 4:1), while filler words in the NoGo target detection condition were all presented with distractor circles (target-to-distractor ratio of 1:4). Practice phase detection stimulus ratios matched the formal phase.

5.2.1 Target Detection Task

In the Go target detection condition, target detection accuracy was 99.34% (SE = 0.30%). In the NoGo target detection condition, target detection accuracy was 76.14% (SE = 2.00%), significantly lower than in the Go condition, Z = -5.02 (as detection rates were non-normally distributed, Ws < 0.93, ps < 0.05, Wilcoxon signed-rank test), p < 0.001, indicating greater difficulty in the NoGo target detection task. Distractor correct rejection rates remained high: 86.17% (SE = 2.00%) in the Go condition and 98.86% (SE = 0.30%) in the NoGo condition, confirming that participants performed the detection tasks as instructed.

5.2.2 Recognition Task

Old-word recognition rates and new-word false alarm rates were calculated as in previous experiments (see Table 5). Primary analyses focused on corrected old-word recognition rates (see Figure 5).

Table 5. Old-word recognition rates and new-word false alarm rates in Experiment 4.

Target Detection Type	Old-word Recognition Rate	False Alarm Rate
Go target detection	0.60 (0.03)	0.39 (0.03)
NoGo target detection	0.54 (0.03)	0.36 (0.03)

Note: Values in parentheses are standard errors (SE).

Shapiro-Wilk tests confirmed that recognition performance was normally distributed (Ws > 0.90, ps > 0.10). To examine whether both target detection conditions produced ABE, we conducted a 2 (target detection type: Go vs. NoGo) × 3 (attention type: target vs. distractor vs. blank) repeated-measures ANOVA on corrected recognition rates. Results showed a significant main effect of attention type, $F(1,32) = 12.73$, $p < 0.001$, $p^2 = 0.29$, 95% CI [0.05, 0.49]. Post-hoc comparisons revealed that target words were recognized significantly better than both distractor words ($p < 0.001$) and blank words ($p = 0.003$), while distractor words did not differ significantly from blank words ($p = 0.353$). The main effect of detection type was not significant [$F(1,32) = 1.13$, $p = 0.296$], and the interaction between attention type and detection type was not significant [$F(1,32) = 0.22$, $p = 0.803$]. Thus, both target detection conditions produced significant within-condition ABE, with no difference in magnitude between conditions [Go target detection: 8.45%, NoGo target detection: 12.10%, $t(32) = 0.73$, $p = 0.355$].

To examine cross-condition ABE under NoGo target detection, we conducted a paired-samples t-test comparing NoGo target words with Go distractor words. Results showed that NoGo target words were recognized significantly better than Go distractor words, $t(32) = 2.31$, $p = 0.028$, $d = 0.40$, 95% CI = [0.04, 0.75], demonstrating cross-condition ABE. This effect magnitude (5.69%) did not differ significantly from that in the NoGo target detection condition [$t(32) = 0.68$, $p = 0.504$] or the Go target detection condition [$t(32) = -1.00$, $p = 0.323$]. Additionally, Experiment 4 found no difference between NoGo distractor words and Go distractor words [$t(32) = 0.70$, $p = 0.486$] or between NoGo target words and Go target words [$t(32) = 1.02$, $p = 0.317$].

Figure 5. Comparison of corrected old-word recognition rates across conditions in Experiment 4.
Note: Error bars represent standard errors; $p < 0.05$, **$p < 0.01$,** *$p < 0.001$.*

5.3 Discussion

Experiment 4 added blank words, resulting in a Go target word action response frequency of 2/3. Despite maintaining the 4:1 target-to-distractor ratio used in Lin (2019), the results differed completely: ABE was observed under Go target detection, confirming our dynamic trade-off model hypothesis. According to this model, although action responses and target detection co-occur under Go target detection, the Go target action response frequency did not exceed the critical threshold (2/3), thus no inhibitory effect emerged to influence ABE generation. Additionally, Go target words and NoGo target words did not differ in recognition performance, supporting the explanation that action responses and target detection produce redundant facilitative effects on background information under these conditions.

Furthermore, ABE was also observed under NoGo target detection, where action responses and target detection affected different types of background information. Although the target-to-distractor ratio was 1:4, Go distractor words had an action response frequency of 2/3. According to our formula, this critical point represents the balance between facilitative and inhibitory action effects. Experiment 4' s observation of ABE under NoGo target detection, with no difference between Go distractor words and NoGo distractor words, replicates Experiment 3' s findings (target-to-distractor ratio of 1:2) and further validates this hypothesis. Moreover, consistent with all three previous experiments, Experiment 4 found stable cross-condition ABE under NoGo target detection: NoGo target words showed memory advantages over Go distractor words, with magnitude equivalent to within-condition ABE effects, again demonstrating that target decision-making facilitation is stable and unaffected by target-to-distractor ratio.

Additionally, by including blank words, Experiment 4 replicated Swallow and Jiang (2014b): target words were recognized better than baseline words (blank words), while distractor words did not differ from baseline, indicating that ABE does not arise from inhibitory effects of distractor rejection on background information. This pattern held across both action and non-action target detection conditions, indirectly validating our experimental design.

6 General Discussion

This study adapted Makovski et al.' s (2013) experimental paradigm to modify the ABE paradigm, creating NoGo target detection and Go target detection conditions to systematically investigate the roles and relationship of action responses and target detection in ABE generation through four experiments. Results showed that under the ABE paradigm, the attentional facilitation effect of target decision-making on background information is relatively stable, unaffected by whether target decision-making requires action responses or by target-to-distractor ratio. However, the memory enhancement effect of action responses on background information varies with action response frequency, and this modulation influences not only ABE under NoGo target detection but also ABE under classic Go target detection conditions.

6.1 The Attentional Facilitation Effect of Target Decision-Making Is Stably Present

Across all four experiments, ABE under Go target detection conditions was highly stable, and cross-condition ABE under NoGo target detection was also stable: NoGo target words were consistently recognized better than NoGo distractor words from the Go condition. Since cross-condition ABE is not confounded by action responses, it more purely validates that the attentional facilitation effect induced by target decision-making is reliable, stable, and not easily influenced by target-to-distractor ratio, consistent with previous research (Swallow & Jiang, 2012). Although Lin (2019) found that ABE disappeared at a 4:1 target-to-distractor ratio, Experiment 4 added blank words to reduce

Go target word action response frequency while maintaining the 4:1 ratio, and ABE was observed. This indicates that ABE disappearance in Lin (2019) did not reflect loss of target detection' s attentional facilitation but rather resulted from dynamic trade-offs between action response and target detection effects, which we elaborate in section 6.3.

Our findings further validate Swallow and Jiang' s dual-task interaction model, which posits that identifying a detection stimulus as a target triggers a transient time-based selective attention mechanism. This mechanism is accompanied by massive LC-NE release (also called phasic LC-NE activation), producing brief attentional enhancement that increases perceptual processing of concurrently presented background information (Swallow & Jiang, 2013; Meng & Lin, 2017). Research indicates that phasic LC-NE activation occurring 100–200 ms before target-related behavioral responses is remarkably similar for both easy and difficult targets (Aston-Jones & Cohen, 2005). We therefore hypothesize that target decision facilitation is unaffected by proportion changes because different ratios trigger similar phasic LC-NE activation, with NE release likely falling within a fixed approximate range.

6.2 Action Response Frequency Affects Action-Induced Memory Enhancement in a Linear Trend

This study created NoGo target detection conditions within the ABE paradigm, separating action responses from target detection to affect different background information types. Combined results from four experiments indicate that, compared to the stable facilitation from target detection, action-induced memory enhancement is highly susceptible to action response frequency. Based on analyses from the first three experiments, we proposed a linear relationship: $y = ax + b$ ($x > 0$), where x is action response frequency and y is the magnitude of action-induced memory enhancement (difference between Go and NoGo distractor words). Parameter estimates were $a = -0.41 \pm 0.09$, 95% CI [-0.59, -0.22] and $b = 0.29 \pm 0.06$, 95% CI [0.16, 0.41], with 2/3 identified as the balance point between facilitative and inhibitory effects.

This linear pattern may relate to differential norepinephrine (NE) arousal levels produced by different action frequencies. Building on Yebra et al.' s (2019) explanation of AIME, both MTL and LC contain action neurons, so actions modulate MTL activity and activate phasic LC activity, releasing NE that promotes memory formation by acting on MTL memory circuits (hippocampus and surrounding cortex). AIME is modulated by NE arousal level: participants showing higher tension/excitement during fMRI exhibited increased NE arousal that eliminated AIME. This aligns with the inverted-U relationship between NE arousal and cognitive performance (Yerkes-Dodson law; Diamond et al., 2007; Yerkes & Dodson, 1908), where moderate NE arousal benefits attention and memory but excessive levels impair them (Aston-Jones et al., 1999; Gold et al., 1977; Yebra et al., 2019). We hypothesize that action response frequency affects AIME through NE arousal level. When response frequency is below 2/3, participants experience lower tension/excitement and NE arousal; combined with NE from AIME, this yields moderate arousal and memory enhancement. When frequency exceeds 2/3, higher baseline tension/excitement produces high NE arousal that, when combined with AIME-related NE, reaches excessive levels that impair memory. This hypothesis requires further empirical support.

6.3 A New ABE Theory: The Dynamic Trade-Off Model of Target Decision and Action Effects

Under classic ABE paradigms, target detection and action responses have overlapping effects on background information. Our results demonstrate that action-induced memory enhancement varies with action response frequency, modulating not only NoGo target detection conditions but also classic Go target detection conditions. We therefore propose the "dynamic trade-off model" of ABE to supplement explanations of its generation mechanism.

This model posits that regardless of whether target detection requires action responses, ABE generation does not solely reflect target decision facilitation but rather results from dynamic trade-offs between target decision facilitation and action-induced memory enhancement. Trade-offs are primarily based on action response frequency' s modulation of action-induced memory enhancement, with approximately 2/3 action frequency serving as an optimal balance point. Specifically, under Go target detection, when target detection action response frequency is too high (exceeding 2/3), frequent action responses produce inhibitory effects on target words that weaken or offset target detection' s facilitative effects, reducing or eliminating ABE. Under NoGo target detection, action responses affect concurrently presented distractor words; frequent action responses (exceeding 2/3) produce inhibitory effects that increase the difference between target and distractor conditions, as evidenced by Experiment 1' s larger NoGo condition ABE (12.10%) compared to Experiment 3 (5.19%). Non-high action frequencies (below 2/3, such as 1/2) produce action-induced memory enhancement that makes distractor word recognition comparable to target words, reducing or eliminating ABE.

The dynamic trade-off model effectively supplements explanations of action responses' role in ABE mechanisms, extending the ABE paradigm from Go target detection to NoGo target detection. However, many questions remain about ABE under Go target detection where target detection and action responses overlap. Although target decision facilitation and action-induced memory enhancement have different underlying mechanisms, both involve phasic LC activation as a basis. When target detection and action responses co-occur, do their effects become redundant or does one dominate? How do dynamic trade-offs across different response frequencies reflect in LC activity? Research shows that rhesus monkey LC+ neurons (LC and nearby noradrenergic subcoeruleus nucleus) exhibit phasic activation only during "Go" responses, not during "Stop" responses (Kalwani et al., 2014). Does this mean NoGo target detection ABE is not based on phasic LC activity but other mechanisms? However, Kalwani' s (2014) Go responses were not separated from target decision-making, leaving unclear whether phasic LC-NE activation is specific to Go responses or to target cognitive decisions. Future research should use pupillometry to measure pupil diameter increases (an indirect LC activity indicator) during NoGo target detection to clarify the cognitive-neural changes underlying trade-offs between action enhancement and target decision effects. Additionally, recent ERP studies show that Go target detection elicits larger P300 amplitudes and smaller N200 amplitudes than distractor conditions (Lin et al., 2020). P300 is typically associated with action responses, while N200 relates to action inhibition (Shitova et al., 2017; Johnstone et al., 2007). Does NoGo target detection, which lacks action and may involve response inhibition, produce similar patterns? How do trade-offs between action effects and target decision effects on target/distractor words manifest in neural mechanisms? Future ERP research is needed to clarify ABE generation mechanisms under different target detection conditions and refine the dynamic trade-off model.

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The Role of Action in the Attentional Boost Effect

Abstract

The attentional boost effect (ABE) represents a phenomenon in which, in some dual tasks, increasing attention to a brief target in a detection task can enhance memory for unrelated items that are presented at the same time (relative to distractor-paired items). The ABE was different from the dual-task interference phenomenon found in previous studies, and to explain the ABE, Swallow and Jiang (2013) proposed a dual-task interaction model. This model claimed that the ABE was mainly triggered by the decision that an item is a target, which can lead to the transient information by inducing a temporal selection but widespread perceptual enhancement of mechanism. However, the target detection tasks always coincide with Go responses that require action. One recent study found that action can enhance memory for unrelated items, which was called action-induced memory enhancement (AIME; Yebra et al., 2019). Therefore, it is unclear whether the ABE is induced by the action or the target decision. To address this question, in the present study, inspired by Makovski et al. (2013), the verbal paradigm of the ABE was modified (Mulligan et al., 2014) and designed with a NoGo-target detection condition (NoGo-targets vs. Go-distractors) to separate target items from action responses, and a traditional Go-target detection condition (Go-targets vs. NoGo-distractors) was used for comparison. If the ABE is mainly triggered by the target decision, then NoGo-target detection

could trigger the cross-conditional ABE (relative to NoGo-distractor items). In contrast, if the ABE is mainly triggered by the action, the NoGo-target items will not have any memory advantage.

The present study included four experiments, and 137 valid data points were collected, including 33 valid data points in Experiment 1, 35 valid data points in Experiment 2, 36 valid data points in Experiment 3, and 33 valid data points in Experiment 4. The only difference among the four experiments was that the ratio of target-to-distractor items was different during the dual-task encoding phase. In Experiment 1, the ratio of target-to-distractor items was the same as that in the classic ABE verbal paradigm (1:5) to explore the role of AIME in the ABE. In Experiments 2 and 3, the ratio of target-to-distractor items was set to 1:1 and 1:2 to explore the role of the AIME and target decision in the ABE with different action frequencies. In Experiment 4, blank words (words without detection stimuli) were added in the detection phase to separate the action frequency (2/3) from the target frequency (relative to distractors; Go-targets: 4/5; NoGo-targets: 1/5) and verify the dynamic trade-off model of the target decision and action reaction proposed in the present study. Each experiment contained two conditions, namely, NoGo-target detection and Go-target detection, and each condition consisted of two phases, namely, a dual-task encoding phase and a recognition phase. During the dual-task encoding phase, a series of memory stimuli (words) and detection stimuli (coloured circles presented, 1 cm below the words) were presented at the same time, and the participants were asked to simultaneously perform the memory and detection tasks.

During the recognition phase, only memory stimuli were presented, and the participants were required to judge the stimuli as old or new. The only difference between the NoGo-target condition and Go-target condition was reflected in the instructions for the detection task: in the Go-target condition, the participants were asked to press the space bar as quickly as possible when they saw the target circles (e.g., a red circle with Go-response) but did not need to respond when they saw other-coloured circles (i.e., distractor circles with NoGo-responses); in contrast, in the NoGo-target condition, the participants were required to press the space bar as quickly as possible for all circles (i.e., distractor circles with Go-responses) but withhold a button press for the target circle (e.g., a red circle with NoGo-response). the NoGo-target items were better remembered than the Go-distractor The results showed that NoGo-target detection enhanced memory performance for target items (relative to Go-distractor/NoGo-distractor items) in the four experiments. First, it was found items and NoGo-distractor items in Experiment 1 (1:5 ratio), and performance with the Go-distractor items was worse than that with the NoGo-distractor items, showing that the ABE was triggered by the target decision without an action response and that actions had inhibitory effects at high frequencies. Second, it was found that the NoGo-target items were better recognized than the NoGo-distractor items but not better than the Go-distractor items in Experiment 2 (1:1 ratio), and the AIME was found with the Go-distractor items, showing that the boosting effect from

the target decision on background information is robust, but the AIME affected the generation of the ABE items were better within the NoGo-target condition. Third, remembered than Go-distractor items and NoGo-distractor items in Experiment 3 (1:2 ratio), and there was no difference in memory performance between the Go-distractor items and the NoGo-distractor items, indicating that action frequency affected the generation of the ABE by adjusting the AIME. Finally, it was found that at 2/3 of the action frequency, both the Go-target detection with high target frequency and the NoGo-target detection with low target frequency triggered the ABE, and the memory performance was similar between the Go-distractor items and the NoGo-distractor items, indicating again that action frequency affected the generation of the ABE by adjusting the AIME, verifying the hypothesis of the dynamic trade-off model. it was found that NoGo-target Overall, the results of all four experiments found memory advantages with the NoGo-target items, but the generation of the ABE was affected by the frequency of action responses, indicating that the boosting effect from the target decision is robust in the ABE, and the action and the target decision work together in the generation of the ABE. Accordingly, we propose the dynamic trade-off model, arguing that the AIME at different frequencies dynamically trade-off against the boosting effect of target decisions and thus influence the ABE.

Keywords: attentional boost effect; action-induced memory enhancement; dual-task interaction model; Go-target detection; NoGo-target detection

Note: Figure translations are in progress. See original paper for figures.