Effects of Attention and Memory Representations on Change Blindness in Traffic Scene Image Transitions

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Abstract

Change blindness constitutes one of the primary causes of driver error in traffic contexts, posing a severe threat to public safety. This study employed a motion-direction transient induction method for change blindness to systematically investigate, through three experiments, the influence of attention and memory representation on change blindness during turning maneuvers in traffic scene images. Experiment 1 manipulated scene motion speed, motion path, and change type, where motion speed might affect change detection by exacerbating attentional resource competition during the turning instant; the results revealed that rapid motion significantly aggravated change blindness only under turning conditions, with no significant effect under straight-line conditions. Experiment 2 controlled motion speed while manipulating motion duration (prechange), motion path, and change type, where the presentation duration of the original scene might influence change detection by increasing memory representation precision; the findings indicated that longer memory representation encoding time could alleviate change blindness within a limited scope. Experiment 3 controlled both motion speed and motion duration, manipulating motion path and change type under varying levels of scene expectation, establishing prior expectations through the probability distribution of route turning directions; the results demonstrated that individuals exhibited superior detection performance for target changes under high-expectation conditions. Conclusion: Change blindness during turning in traffic scenes results from the combined effects of attentional resource competition and the limitations of memory representation, while expectation may endogenously modulate attentional allocation and the effective construction of memory representation, thereby influencing the occurrence of change blindness. The research findings support and extend the attention-representation theory of change blindness.

Full Text

The Effects of Attention and Memory Representations on Change Blindness During Global Motion Direction Transients in Traffic-Scene Images

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Abstract

Change blindness is a primary cause of human-factor errors among traffic drivers and poses a serious threat to public safety. This study employed a motion-direction-transient paradigm to induce change blindness and systematically investigated the effects of attention and memory representations on change blindness during turning maneuvers in traffic-scene images through three experiments. Experiment 1 manipulated scene movement speed, trajectory, and change type, hypothesizing that faster speeds would exacerbate change detection failures by intensifying attentional resource competition during turning. The results revealed that fast motion significantly aggravated change blindness only under turning conditions, with no significant effect during straight-line motion. Experiment 2 controlled movement speed while manipulating pre-change movement duration, trajectory, and change type, testing whether longer encoding time for memory representations would enhance change detection. The findings showed that extended memory representation encoding time could mitigate change blindness within a limited range. Experiment 3 controlled both movement speed and duration while manipulating trajectory and change type under varying expectancy levels, establishing prior expectations through the probability distribution of turning directions. Participants demonstrated superior detection performance for target changes under high-expectancy conditions. The conclusion is that change blindness during traffic-scene turning arises from the joint action of attentional resource competition and memory representation limitations, while expectation may endogenously modulate attention allocation and the effective construction of memory representations, thereby influencing change blindness occurrence. These findings support and extend the attention-representation theory of change blindness.

Keywords: change blindness, visual search, motion-induced blindness, attention, memory representation
Classification Number: B842

1 Introduction

Change blindness refers to the phenomenon where observers fail to detect changes in visual scenes when brief interruptions or disturbances occur (Rensink, 2018; Simons, 2011). This phenomenon creates severe public safety risks in dynamic, complex traffic-driving scenarios (Beanland et al., 2017; Zhao et al., 2014). Research indicates that approximately 9%–12% of serious injury collisions can be attributed to drivers' failure to detect changes in traffic scenes (Beanland et al., 2013). Consequently, understanding and effectively preventing change blindness in traffic contexts has become a critical research priority.

1.1 The Attention-Representation Theoretical Framework

Simons and Rensink' s (2005) attention-representation theory posits that change blindness primarily stems from attentional failures and insufficient memory representations (Henderson & Hollingworth, 2003; Rensink, 2002; Simons & Levin, 1997). The attentional failure perspective emphasizes that change detection depends on active attentional resource allocation; changes in unattended regions often go unnoticed even when salient, whereas scene objects receiving prioritized attention are more likely to be encoded and compared. For instance, Rensink et al. (1997) developed the flicker paradigm, which alternates original and modified images with a blank screen interval, demonstrating that lack of focused attention is a key cause of change blindness. The memory representation perspective argues that change blindness arises from inadequate encoding (sparse information, incomplete structure, or complete absence) and retrieval/comparison failures. Hollingworth (2003) further proposed, through eye-tracking research, that visual attentional orienting integrates local information over time to gradually form more detailed scene representations that support subtle visual judgments, and these representations can be accurately retrieved even after attention shifts.

However, these theories exhibit clear limitations when explaining change detection in complex, dynamic contexts such as traffic driving. First, most existing research relies on static visual masking techniques and fails to adequately examine change detection processes under natural observation conditions with full visual fields (Beanland et al., 2017; Galpin et al., 2009). Second, visual masking itself may disrupt the continuity of attention allocation and memory representation, and previous studies often focused on manipulating variables tied to a single mechanism, making it difficult to systematically investigate the combined roles of attention and memory representations in complex traffic scenes within a unified framework (Bonneh et al., 2001; Wu & Flombaum, 2024).

1.2 Research on Traffic-Scene Change Blindness Using Motion-Direction Transients

This study employs sudden changes in motion direction to induce change blindness in traffic scenes. Research demonstrates that effective visuospatial attention and memory representations are crucial for processing target features (You

& Song, 2009; You et al., 2008). Therefore, it is necessary to systematically examine how attention and memory representations jointly influence change detection during traffic-scene turning under conditions without masking interference. Yao et al. (2019) provide an innovative experimental method for this purpose. They found that when the global motion direction of a grating array changed abruptly, the simultaneous instantaneous rotation of a target grating could effectively induce change blindness without relying on any external visual mask. Eye-tracking data further confirmed that this phenomenon was not caused by saccadic interference during the motion direction change but rather resulted from attentional distraction (Henderson & Hollingworth, 2003). This study defines the transient visual signal induced by abrupt motion direction changes that can cause change blindness as "motion-direction transients" (transients refer to stimuli that introduce instantaneous neural activity, typically manifesting as brief, suddenly changing visual signals). Compared to traditional masking paradigms, this method offers two advantages: First, it introduces a visual transient endogenous to the task scene through global motion direction changes, eliminating the need for additional interference, visual occlusion, or momentary interruption, thereby inducing change blindness within a continuous, full visual field. Second, it avoids active interference from external masks on attention and memory representations, providing more ideal experimental conditions for independently manipulating and evaluating their respective roles in change detection.

1.2.1 Change Types in Traffic Scenes This study uses low-altitude aerial traffic-scene images from a top-down perspective as experimental materials, which avoids visual occlusion and scale distortion issues present in driving perspectives while maintaining global spatial distribution, semantic integrity, and ecological validity (Kondyli et al., 2023; Kvasova et al., 2024), enabling precise manipulation of change targets and locations. The study focuses on three typical changes in traffic scenes: disappearance, appearance, and location shifts (Murphy & Andalis, 2013; Türkan et al., 2016). Previous research indicates that different change types involve distinct attentional and representational mechanisms: appearance changes typically possess stronger bottom-up attentional capture advantages than disappearance changes (Donaldson & Yamamoto, 2016); disappearance changes lack significant behavioral urgency signals and may rely more heavily on continuous monitoring of task context and retrieval-based comparison (Brockmole & Henderson, 2005; Cole & Kuhn, 2010); location shifts may simultaneously engage spatial attention and visual working memory and generate larger visual scene change magnitudes (Martens, 2011; Murphy & Andalis, 2013). Based on this analysis, we anticipate that in the current traffic-scene turning task, appearance changes will be least affected by attentional resource competition, disappearance changes will show the most significant performance impairment, and location shifts—while demonstrating overall optimal performance—will still experience some interference.

Building on this analysis of change types, this study designed three experiments to systematically investigate the effects of attention and memory representations on change blindness during traffic-scene turning, focusing on three core variables: movement speed (attentional resource competition), movement time (memory representation encoding precision), and expectancy level (endogenous expectancy modulation).

1.2.2 The Effect of Movement Speed on Turning-Related Blindness: The Role of Attention Based on the attention-representation theory of change blindness, attentional resource allocation and competition are considered key causes of missed changes (Simons & Rensink, 2005; Rensink, 2002). Experiment 1 therefore introduced movement speed as an experimental variable to manipulate attentional resource demands (Milders et al., 2004; Tombu & Seiffert, 2008). When turning signals and target change detection signals overlap temporally, intense attentional resource competition may arise. This mechanism receives theoretical support from the attentional blink phenomenon (Raymond et al., 1992) and the two-stage processing model (Chun & Potter, 1995), which demonstrate that two target stimuli presented in close temporal proximity compete for limited attentional resources, causing processing inhibition for temporally adjacent targets—the essence of sequential allocation conflict for cognitive resources along the temporal dimension. Critically, movement speed may modulate this temporal attentional resource competition. Tombu and Seiffert (2008) found in a multiple-object tracking task that increasing target movement speed intensified attentional resource competition with a temporally overlapping pitch discrimination task, leading to decreased performance on the subsequent task.

However, existing research has not clarified the mechanism through which movement speed influences change blindness: Does it directly consume attentional resources to interfere with change detection, or does it exert indirect effects through interaction with features such as motion direction? This constitutes the first research question of this study. We hypothesize that increased movement speed may intensify attentional resource competition during the turning instant, thereby significantly exacerbating change blindness.

1.2.3 The Effect of Movement Time on Turning-Related Blindness: The Role of Memory Representations The attention-representation perspective posits that insufficient representation or comparison failure is also an important factor causing change blindness (Simons & Rensink, 2005). In Experiment 1, different movement speed conditions resulted in varying presentation durations for traffic scenes, with fast motion potentially compressing the time window available for memory representation encoding and thereby weakening representation quality. Experiment 2 therefore introduced movement time as a key variable to manipulate memory representation precision while controlling movement speed. Although longer visual processing time may enhance memory representation precision and completeness to improve change detection performance (Bays et al., 2009; Gao et al., 2013; Martens, 2011), this possibility has not been systematically examined within continuous, full-field experimental paradigms. Wright et al. (2024) recently attempted to investigate the role of memory representations in multiple-feature change detection tasks, but their use of the flicker paradigm may have introduced additional interference, causing information loss or representation instability in the visual field and making it difficult to clearly reveal the contribution of memory representations.

Notably, memory representations of pre-change information play an important role in change detection (Nishiyama & Kawaguchi, 2014). Therefore, this study proposes a second research question: Under conditions of controlled movement speed, will extending pre-change scene movement time mitigate change blindness by enhancing memory representation encoding quality? We hypothesize that longer visual processing time may improve change detection performance by enhancing the precision of memory representation encoding for scene information, thereby reducing change blindness.

1.2.4 The Effect of Expectancy on Turning-Related Blindness: The Role of Endogenous Expectations

Experiments 1 and 2 respectively examined the roles of exogenous attentional interference and memory representations in traffic-scene change blindness. However, visual detection processes in dynamic scenes are often simultaneously influenced by both exogenous (stimulus-driven) and endogenous (goal-driven) attention. On one hand, moving objects in scenes can automatically capture visual attention (Abrams & Christ, 2003); on the other hand, observers may develop prior expectations about scene change patterns through implicit learning (Zuanazzi & Noppeney, 2020), prioritizing attentional resources toward high-probability change regions or events (Roth et al., 2024; Steelman et al., 2013) and promoting the formation of more stable and precise memory representations (Awh & Vogel, 2008; Cohen-Dallal et al., 2023) to optimize visual search efficiency in a top-down manner.

Thus, this study proposes a third research question: In traffic-scene turning tasks, can endogenous expectancy regulate exogenous motion signal-induced attentional interference and improve change detection performance by modulating attentional resource allocation and optimizing memory representations? We hypothesize that when individuals form probabilistic expectations about turning directions based on scene regularities, they may endogenously prioritize attentional resources toward high-probability directions and enhance memory representation encoding precision, thereby significantly improving change detection performance.

1.3 Research Framework

Based on these three research questions, this study adopts the attention-representation theory of change blindness (Simons & Rensink, 2005) as its theoretical framework and employs the motion-direction-transient method to induce change blindness (Yao et al., 2019). Using top-down perspective traffic-scene images as experimental materials, we applied three types of changes to scene elements: disappearance, appearance, and location shifts. The study designed two movement trajectory conditions (turning vs. straight motion), introducing instantaneous target changes at the moment of turning or at the midpoint of straight motion, aiming to systematically examine the effects of attention and memory representations on change blindness during traffic-scene turning while avoiding the confounding effects of traditional masking. The study comprised three experiments: Experiment 1 manipulated scene movement speed, trajectory, and change type, focusing on whether movement speed affects change detection performance by intensifying attentional resource competition during turning; Experiment 2 controlled movement speed while manipulating pre-change movement time, trajectory, and change type to investigate whether longer original scene presentation duration mitigates change blindness by enhancing memory representation encoding quality; and Experiment 3 controlled both movement speed and time while manipulating trajectory and change type under varying expectancy levels, establishing prior expectations through designing probabilistic "+" -shaped random turning paths (Yao, 2013) to explore the modulatory effect of endogenous expectancy on turning-related blindness.

In summary, this study hypothesizes that: (1) Increased movement speed may differentially affect change detection performance across change types by intensifying attentional resource competition during traffic-scene image turning, whereas increased speed during straight motion will not significantly exacerbate change blindness; (2) Extended original scene presentation time may mitigate change blindness by effectively increasing scene memory representation encoding precision; and (3) Individuals form spatial turning expectations based on the probability distribution of traffic-scene image turning directions, which may top-down modulate attentional resource allocation and promote effective construction of memory representations, thereby improving change detection performance.

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2 Experiment 1: The Influence of Movement Speed

Experiment 1 set traffic scenes to two movement speeds (fast/slow) along two trajectories (turning vs. straight motion) with three change types (disappearance, appearance, location shift), aiming to test whether movement speed differentially affects change detection performance across change types by intensifying attentional resource competition during turning (Hypothesis 1).

2.1 Method

2.1.1 Participants Sample size was calculated using G*Power 3.1 software, with an expected statistical power of 0.95, medium effect size of 0.25, and alpha level of 0.05, yielding a required sample size of 18 participants (Faul et al., 2007). Experiment 1 recruited 40 university student participants (17 male, 42.50%)

with a mean age of 20.18 ± 1.72 years. All participants were right-handed, had normal or corrected-to-normal vision, no color blindness or weakness, and had not participated in similar experiments previously. All participants signed informed consent before the experiment and received modest compensation afterward. All experiments in this study were approved by the Ethics Committee of the School of Psychology at Shaanxi Normal University (Approval No: HR2024-09-03).

2.1.2 Materials Aerial urban traffic and maritime traffic scene images from a top-down perspective were used as experimental materials. Image complexity scores were predicted using the ICNet deep learning-based complexity prediction model proposed by Feng et al. (2022), which estimates image complexity heatmaps and outperforms traditional hand-crafted features and machine learning methods while achieving high correspondence with human perception. Twenty-four images with normally distributed complexity scores were selected as experimental stimuli (see [Figure 1: see original paper]). Using Photoshop CS 6.0, images were proportionally resized to 480px × 270px to match common drone display resolutions. Vehicles, ships, or pedestrians in the images were manipulated to create three change types: disappearance, appearance, and location shift (see [Figure 2: see original paper]). Target positions were determined by dividing images into 2 rows and 4 columns, with target change areas controlled within 62px × 62px (Yao et al., 2019) and balanced across quadrants and central/peripheral distributions (Galpin et al., 2009). Stimuli were presented on a 24-inch monitor with 1920 × 1080 pixel resolution and 60 Hz refresh rate. Participants were seated approximately 55–60 cm from the screen in a bright, quiet environment free from irrelevant noise interference.

[Figure 1: see original paper] shows sample traffic scene complexity visualization results (input images on the left, predicted complexity heatmaps on the right, with ICNet-predicted complexity scores below each image). [Figure 2: see original paper] illustrates the three change types in traffic scenes (post-change images divided into 8 regions corresponding to numeric keypad keys 1–8).

2.1.3 Design A 2 (movement speed: fast, slow) × 2 (movement trajectory: turning, straight) × 3 (change type: disappearance, appearance, location shift) within-subjects design was employed. Fast motion speed was 19.14°/s, while slow motion was 13.92°/s. Dependent variables were change detection accuracy and reaction time.

2.1.4 Procedure The experimental program was developed using the Psychopy package. The experiment consisted of practice and formal experimental phases. After entering the laboratory, participants completed informed consent forms and received instructions: They were required to perform a change detection task where different speeds of moving images would be presented on screen, with instantaneous changes occurring at the turning moment or straight-motion midpoint. Participants needed to maintain gaze tracking of the moving images and respond by pressing the key corresponding to the number of the changed region. After fully understanding the instructions, participants completed a practice block of 12 trials before proceeding to the formal experiment. The practice task followed the same procedure as the formal experiment.

The trial procedure was as follows: First, a fixation cross "+" appeared on the left side of the screen for 500 ms to indicate where the image would appear. After 500 ms, the traffic scene image appeared and began moving after 200 ms. In the turning condition, images moved from the left side of the screen toward the center at either fast (19.14°/s) or slow (13.92°/s) speed for approximately 21.34°, then immediately turned 90° downward and continued moving for about 6.34°, with an instantaneous change occurring at the turning moment. In the straight condition, images moved only along the horizontal axis, first moving rightward for about 10.67° with an instantaneous change occurring at the screen' s midline, then continuing the same distance (see [Figure 3: see original paper]). When the image reached the path endpoint, it disappeared. After a 100 ms blank screen, the post-change image appeared at the center of the screen, divided into 8 numbered regions corresponding to numeric keypad keys 1–8. Participants pressed the key corresponding to the number of the changed region; if they missed the change, they were instructed to make their best guess. If no response was made within 5 s, the trial advanced automatically (see [Figure 4: see original paper]). The formal experiment comprised 2 blocks with 288 trials total, with trials randomly presented within each block. Participants could rest for 2 minutes after completing each block. Total experiment duration was approximately 0.5 hours.

[Figure 3: see original paper] shows the movement trajectories for turning and straight conditions in Experiment 1 (note: the scene changes instantaneously when the image reaches the marked position; the same applies below). [Figure 4: see original paper] illustrates the experimental trial sequence.

2.2 Results and Analysis

2.2.1 Accuracy A repeated-measures ANOVA on change detection accuracy revealed significant main effects of movement speed, $F(1, 39) = 25.96$, $p < 0.001$, ^{2}p = 0.40, with lower accuracy for fast motion ($M = 0.59$) than slow motion ($M = 0.63$); movement trajectory, $F(1, 39) = 814.84$, $p < 0.001$, ^{2}p = 0.95, with lower accuracy for turning ($M = 0.41$) than straight motion ($M = 0.81$); and change type, $F(2, 78) = 10.90$, $p = 0.001$, ^{2}p = 0.22, with lower accuracy for disappearance ($M = 0.58$) and appearance ($M = 0.60$) than location shifts ($M = 0.67$), while disappearance and appearance did not differ significantly. Bayesian repeated-measures ANOVA provided extremely strong evidence for main effects of movement speed (BF_{incl} = 278.595), trajectory (BF_{incl} = 6.649$×$10^+24), and change type (BF_{incl} = 389.219).

The interaction between movement speed and trajectory was significant (see [Figure 5: see original paper]A), $F(1, 39) = 13.16$, $p = 0.001$, ^{2}p = 0.25. Simple effects analysis showed that during turning motion, accuracy was significantly lower for fast motion ($M = 0.38$) than slow motion ($M = 0.44$), $F(1, 39) = 28.76$, $p < 0.001$, ^{2}p = 0.42; during straight motion, movement speed did not significantly affect accuracy, $F(1, 39) = 2.50$, $p = 0.122$, ^{2}p = 0.06.

The trajectory × change type interaction was significant, $F(2, 78) = 4.35$, $p = 0.025$, ^{2}p = 0.10. Simple effects analysis revealed that during turning motion, accuracy increased significantly across disappearance ($M = 0.36$), appearance ($M = 0.40$), and location shifts ($M = 0.48$), $F(2, 78) = 21.77$, $p < 0.001$, ^{2}p = 0.36; during straight motion, change type did not significantly affect accuracy, $F(2, 78) = 2.86$, $p = 0.091$, ^{2}p = 0.07.

The speed × change type interaction was significant, $F(2, 78) = 4.52$, $p = 0.014$, ^{2}p = 0.10. Simple effects analysis showed that during fast motion, accuracy increased significantly across disappearance ($M = 0.55$), appearance ($M = 0.59$), and location shifts ($M = 0.64$), $F(2, 78) = 9.21$, $p = 0.001$, ^{2}p = 0.19; during slow motion, disappearance ($M = 0.60$) and appearance ($M = 0.60$) showed significantly lower accuracy than location shifts ($M = 0.69$), with no difference between disappearance and appearance, $F(2, 78) = 10.47$, $p = 0.001$, ^{2}p = 0.21.

The three-way interaction between speed, trajectory, and change type was significant (see [Figure 5: see original paper]B), $F(2, 78) = 5.25$, $p = 0.007$, ^{2}p = 0.12. Further analysis of two-way interactions at different speed levels showed that during fast motion, the trajectory × change type interaction was significant, $F(2, 78) = 10.03$, $p < 0.001$, ^{2}p = 0.20, whereas during slow motion it was not, $F(2, 78) = 1.42$, $p = 0.249$, ^{2}p = 0.04. Simple main effects under fast motion showed that during turning, accuracy increased significantly across disappearance ($M = 0.31$), appearance ($M = 0.40$), and location shifts ($M = 0.45$), $F(2, 78) = 20.01$, $p < 0.001$, ^{2}p = 0.34; during straight motion, change type did not significantly affect accuracy, $F(2, 78) = 1.87$, $p = 0.173$, ^{2}p = 0.05.

[Figure 5: see original paper]A shows boxplot-violin plots of accuracy across movement speeds for different trajectories. [Figure 5: see original paper]B depicts the effects of movement speed and change type on accuracy for turning and straight conditions. Note: $p < 0.05$, **p* < 0.01,** $p < 0.001$; the same applies below.

2.2.2 Reaction Time A repeated-measures ANOVA on reaction times for correct detections revealed significant main effects of trajectory, $F(1, 39) = 49.20$, $p < 0.001$, ^{2}p = 0.56, with longer RTs for turning ($M = 1615.31$ ms) than straight motion ($M = 1407.78$ ms); and change type, $F(2, 78) = 13.03$, $p < 0.001$, ^{2}p = 0.25, with longer RTs for disappearance ($M = 1578.21$ ms) than appearance ($M = 1485.46$ ms) and location shifts ($M = 1470.97$ ms), while appearance and location shifts did not differ. The main effect of movement speed was not significant, $F(1, 39) = 1.92$, $p = 0.174$, ^{2}p = 0.05.

The trajectory × change type interaction was significant, $F(2, 78) = 4.56$, $p = 0.020$, ^{2}p = 0.11. Simple effects analysis showed that during turning motion, RTs were significantly longer for disappearance ($M = 1711.80$ ms) than appearance ($M = 1592.97$ ms) and location shifts ($M = 1541.16$ ms), with no difference between appearance and location shifts, $F(2, 78) = 10.17$, $p = 0.001$, ^{2}p $= 0.21$; during straight motion, RTs were significantly longer for disappearance ($M = 1444.61$ ms) than appearance ($M = 1377.96$ ms) and marginally longer than location shifts ($M = 1400.78$ ms), with no difference between appearance and location shifts, $F(2, 78) = 5.40$, $p = 0.006$, ^{2}p $= 0.12$.

The speed × trajectory interaction was not significant (see [Figure 6: see original paper]A), $F(1, 39) = 0.003$, $p = 0.960$, ^{2}p $= 0.00$. The speed × change type interaction was also not significant, $F(2, 78) = 0.08$, $p = 0.926$, ^{2}p $= 0.002$, indicating that movement speed did not significantly affect RTs across trajectories and change types. The three-way interaction was not significant (see [Figure 6: see original paper]B), $F(2, 78) = 0.18$, $p = 0.838$, ^{2}p $= 0.01$.

[Figure 6: see original paper]A shows boxplot-violin plots of RTs across movement speeds for different trajectories. [Figure 6: see original paper]B depicts the effects of movement speed and change type on RTs for turning and straight conditions.

2.3 Discussion

Experiment 1 results show that movement speed exacerbated change blindness, with significantly lower change detection accuracy under fast motion compared to slow motion, though RT differences were not significant. The main effect of trajectory was significant, with turning motion showing both lower accuracy and longer RTs than straight motion, demonstrating that motion-direction transients can effectively induce change blindness (Yao et al., 2019). Notably, disappearance changes showed the lowest accuracy and longest RTs, appearance changes were intermediate, and location shifts demonstrated optimal overall performance, confirming our predictions.

Furthermore, for accuracy, under fast motion, the turning condition showed significant differences across change types whereas the straight condition did not; this pattern did not emerge under slow motion. Specifically, during fast turning motion, accuracy increased significantly from disappearance to appearance to location shifts, while RTs showed a decreasing trend. This indicates that disappearance changes are most vulnerable to interference, and that movement speed as a visual transient signal intensifies attentional resource competition during turning motion, differentially affecting change detection performance across change types. These results support Hypothesis 1.

However, different movement speeds in Experiment 1 resulted in varying original scene presentation durations, with slow motion potentially enhancing memory representation precision and stability (Bays et al., 2009; Gao et al., 2013). Therefore, Experiment 2 was designed to investigate the influence of memory representations on turning-related blindness.

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3 Experiment 2: The Influence of Movement Time

Experiment 2 controlled movement speed and set traffic scenes to two movement durations (long/short) along two trajectories (turning vs. straight motion) with three change types (disappearance, appearance, location shift), aiming to examine whether longer original scene presentation duration mitigates change blindness by enhancing memory representation encoding precision (Hypothesis 2).

3.1 Method

3.1.1 Participants Sample size calculation using G*Power 3.1 (power = 0.95, medium effect size = 0.25, $\alpha = 0.05$) yielded a required sample of 18 participants. Experiment 2 recruited 30 university students (14 male, 46.67%) with a mean age of 19.90 ± 2.34 years. None had participated in Experiment 1.

3.1.2 Materials Identical to Experiment 1.

3.1.3 Design A 2 (movement time: long, short) × 2 (trajectory: turning, straight) × 3 (change type: disappearance, appearance, location shift) within-subjects design was used. Movement speed was controlled at 19.14°/s. The vertical movement distance was identical to Experiment 1, while horizontal distances were calculated based on the time differences from Experiment 1' s speed conditions multiplied by the fast speed. The long movement time horizontal distance was calculated as 19.14°/s × 21.3345° / 13.92°/s 29.33°. Independent variables were movement time (pre-change), trajectory, and change type, with long movement time covering approximately 29.33° horizontally and short movement time covering about 21.34°. Dependent variables were change detection accuracy and RT.

3.1.4 Procedure The procedure was largely identical to Experiment 1. Instructions informed participants that images would maintain consistent speed, that instantaneous changes would occur at turning moments or straight-motion midpoints, but that pre-change movement times would vary across trials. Participants were required to maintain gaze tracking and respond to changed regions.

All images in Experiment 2 moved at 19.14°/s. In the turning condition, images moved from the left side toward the center for approximately 29.33° (long) or 21.34° (short), then immediately turned 90° downward and continued for about 6.34°, with an instantaneous change at the turning moment (see [Figure 7: see original paper]). In the straight condition, images moved horizontally rightward for about 14.67° (long) or 10.67° (short) with an instantaneous change at the screen' s midline, then continued the same distance. The formal experiment comprised 2 blocks with 288 trials total, randomly presented within blocks. Participants could rest for 2 minutes after each block. Total duration was approximately 0.5 hours.

[Figure 7: see original paper] shows the movement trajectories for short and long movement times in Experiment 2' s turning condition.

3.2 Results and Analysis

3.2.1 Accuracy A repeated-measures ANOVA revealed significant main effects of movement time, $F(1, 29) = 4.36$, $p = 0.046$, ^{2}p = 0.13, with higher accuracy for long ($M = 0.58$) than short ($M = 0.57$) movement times; trajectory, $F(1, 29) = 802.48$, $p < 0.001$, ^{2}p = 0.97, with lower accuracy for turning ($M = 0.35$) than straight motion ($M = 0.80$); and change type, $F(2, 58) = 49.48$, $p < 0.001$, ^{2}p = 0.63, with accuracy increasing significantly from disappearance ($M = 0.52$) to appearance ($M = 0.57$) to location shifts ($M = 0.63$). Bayesian repeated-measures ANOVA provided extremely strong evidence for main effects of trajectory (BF_{incl} = 6.899$×10^{+}19)*andchangetype*(BF_{incl} = 2.587×$10^+10), but weak evidence against a movement time effect (BF_{incl} = 0.704).

The trajectory × change type interaction was significant, $F(2, 58) = 3.93$, $p = 0.025$, ^{2}p = 0.12. Simple effects analysis showed that during turning motion, disappearance ($M = 0.28$) had significantly lower accuracy than appearance ($M = 0.37$) and location shifts ($M = 0.40$), with no difference between appearance and location shifts, $F(2, 58) = 23.39$, $p < 0.001$, ^{2}p = 0.45; during straight motion, disappearance ($M = 0.76$) and appearance ($M = 0.78$) had significantly lower accuracy than location shifts ($M = 0.86$), with no difference between disappearance and appearance, $F(2, 58) = 28.40$, $p < 0.001$, ^{2}p = 0.50.

The movement time × trajectory interaction was not significant (see [Figure 8: see original paper]A), $F(1, 29) = 1.61$, $p = 0.215$, ^{2}p = 0.05. The movement time × change type interaction was not significant, $F(2, 58) = 0.10$, $p = 0.902$, ^{2}p = 0.004. However, the three-way interaction was significant (see [Figure 8: see original paper]B), $F(2, 58) = 3.28$, $p = 0.045$, ^{2}p = 0.10. Analysis of two-way interactions at different movement time levels showed that both long and short movement time conditions produced significant trajectory × change type interactions: long time, $F(2, 58) = 3.35$, $p = 0.042$, ^{2}p = 0.10; short time, $F(2, 58) = 4.06$, $p = 0.022$, ^{2}p = 0.12. Simple main effects under long movement time showed that during turning, disappearance ($M = 0.31$) had lower accuracy than appearance ($M = 0.38$) and location shifts ($M = 0.40$), with no difference between appearance and location shifts, $F(2, 58) = 11.16$, $p < 0.001$, ^{2}p = 0.28; during straight motion, disappearance ($M = 0.75$) and appearance ($M = 0.78$) had lower accuracy than location shifts ($M = 0.88$), with no difference between disappearance and appearance, $F(2, 58) = 27.37$, $p < 0.001$, ^{2}p = 0.49. Under short movement time, during turning, accuracy increased significantly from disappearance ($M = 0.26$) to appearance ($M = 0.35$) to location shifts ($M = 0.40$), $F(2, 58) = 19.32$, $p < 0.001$, ^{2}p = 0.40; during straight motion, disappearance ($M = 0.76$) and appearance ($M = 0.78$)

had lower accuracy than location shifts (M = 0.85), with no difference between disappearance and appearance, F(2, 58) = 12.99, $p < 0.001$, ^{2}p = 0.31.

[Figure 8: see original paper]A shows boxplot-violin plots of accuracy across movement times for different trajectories. [Figure 8: see original paper]B depicts the effects of movement time and change type on accuracy for turning and straight conditions.

3.2.2 Reaction Time A repeated-measures ANOVA on correct RTs revealed significant main effects of movement time, F(1, 29) = 8.09, p = 0.008, ^{2}p = 0.22, with longer RTs for long (M = 1642.98 ms) than short (M = 1583.94 ms) movement times; and trajectory, F(1, 29) = 80.97, $p < 0.001$, ^{2}p = 0.74, with longer RTs for turning (M = 1770.13 ms) than straight motion (M = 1456.79 ms). The main effect of change type was not significant, F(2, 58) = 1.51, p = 0.233, ^{2}p = 0.05.

The movement time × trajectory interaction was not significant (see [Figure 9: see original paper]A), F(1, 29) = 0.91, p = 0.349, ^{2}p = 0.03. The trajectory × change type interaction was not significant, F(1, 29) = 2.03, p = 0.156, ^{2}p = 0.07. The movement time × change type interaction was not significant, F(2, 58) = 2.14, p = 0.140, ^{2}p = 0.07. The three-way interaction was not significant (see [Figure 9: see original paper]B), F(2, 58) = 2.24, p = 0.130, ^{2}p = 0.07.

[Figure 9: see original paper]A shows boxplot-violin plots of RTs across movement times for different trajectories. [Figure 9: see original paper]B depicts the effects of movement time and change type on RTs for turning and straight conditions.

3.3 Discussion

Experiment 2 results show that longer movement time conditions produced significantly higher change detection accuracy than short movement time conditions, albeit with longer RTs, indicating that extended visual processing time helps mitigate change blindness but at the cost of additional time. Based on Hollingworth' s (2003) view that memory array presentation duration is closely related to visual information encoding completeness and memory representation precision (Bays et al., 2009; Gao et al., 2013), these results generally support Hypothesis 2: extending original scene movement time can improve change detection performance by enhancing memory representation encoding precision.

Disappearance, appearance, and location shift changes showed sequentially increasing accuracy with no significant RT differences, again confirming differential processing mechanisms across change types. Notably, although ANOVA showed significant differences in accuracy across movement time conditions, the numerical differences were small. Bayesian repeated-measures ANOVA further provided weak evidence against a movement time main effect, suggesting that while memory representations influence change detection, their contribution is relatively limited. Additionally, accuracy results showed that in the turning condition under fast motion, disappearance changes showed significantly improved accuracy under long movement time, whereas other change types did not show this effect.

Given that Experiments 1 and 2 examined the roles of attention and memory representations respectively, and both may be influenced by prior experience and expectancy (Roth et al., 2024), Experiment 3 was designed to investigate the influence of expectancy level on turning-related blindness.

4 Experiment 3: The Influence of Expectancy

Experiment 3 controlled movement speed and time, setting traffic scenes to three trajectories (high-expectancy turning, low-expectancy turning, straight motion) with three change types (disappearance, appearance, location shift), aiming to examine whether individuals can endogenously modulate attentional resource allocation and optimize memory representation quality based on prior expectations to improve change detection performance (Hypothesis 3).

4.1 Method

4.1.1 Participants Sample size calculation using G*Power 3.1 (power = 0.95, medium effect size = 0.25, $\alpha = 0.05$) yielded a required sample of 22 participants. Experiment 3 recruited 36 university students (18 male, 50%) with a mean age of 19.64 ± 2.34 years. These participants only took part in Experiment 3.

4.1.2 Materials Identical to Experiment 1.

4.1.3 Design A 3 (trajectory: high-expectancy turning, low-expectancy turning, straight motion) × 3 (change type: disappearance, appearance, location shift) within-subjects design was employed. Movement speed and duration were controlled at 19.14°/s, with vertical movement distance identical to Experiment 1. Independent variables were trajectory under different expectancy levels and change type. Images moved along "+"-shaped trajectories, with high-expectancy turning conditions having 70.83% of trials turn downward (or upward) and low-expectancy turning conditions having 29.17% turn downward (or upward); the straight condition involved only horizontal motion. Dependent variables were change detection accuracy and RT.

4.1.4 Procedure The procedure was largely identical to Experiment 1. Instructions informed participants that images would maintain consistent speed and that when approaching the screen' s midline, three movement trajectories were possible: upward turn, downward turn, or continued straight motion. Changes occurred instantaneously at turning moments or straight-motion midpoints. Participants were required to maintain gaze tracking and respond to changed regions. Participants familiarized themselves with the turning probability patterns through practice trials before beginning the formal experiment. The practice block contained 45 training trials. All images moved at 19.14°/s. In turning conditions, images moved from the left side toward the center for approximately 10.67°, then high/low-expectancy conditions turned upward or downward with different probability distributions, continuing for about 6.34° with an instantaneous change at the turning moment; straight condition images moved horizontally rightward for 10.67° with an instantaneous change at the midline, then continued the same distance (see [Figure 10: see original paper]). The formal experiment comprised 2 blocks with 432 trials total, with straight condition trials evenly distributed across blocks. Participants could rest for 5 minutes after each block. Total duration was approximately 1 hour.

[Figure 10: see original paper] illustrates the movement trajectories for Experiment 3.

4.2 Results and Analysis

4.2.1 Accuracy A repeated-measures ANOVA revealed significant main effects of trajectory, $F(2, 70) = 698.37$, $p < 0.001$, ^{2}p = 0.95, with accuracy increasing significantly from low-expectancy turning ($M = 0.37$) to high-expectancy turning ($M = 0.39$) to straight motion ($M = 0.81$) (see [Figure 11: see original paper]A); and change type, $F(2, 70) = 64.24$, $p < 0.001$, ^{2}p = 0.65, with accuracy increasing significantly from disappearance ($M = 0.44$) to appearance ($M = 0.54$) to location shifts ($M = 0.59$). Bayesian repeated-measures ANOVA provided extremely strong evidence for main effects of trajectory (BF_{incl} = 2.025\$×$10^{+}43)andchangetype(BF_{incl}$ = 1.408×\$10^+13).

The trajectory × change type interaction was significant (see [Figure 11: see original paper]B), $F(4, 140) = 16.86$, $p < 0.001$, ^{2}p = 0.33. Simple effects analysis showed that during low-expectancy turning, disappearance ($M = 0.25$) had significantly lower accuracy than appearance ($M = 0.44$) and location shifts ($M = 0.42$), with no difference between appearance and location shifts, $F(2, 70) = 39.92$, $p < 0.001$, ^{2}p = 0.53; during high-expectancy turning, accuracy increased significantly across disappearance ($M = 0.30$), appearance ($M = 0.38$), and location shifts ($M = 0.49$), $F(2, 70) = 67.16$, $p < 0.001$, ^{2}p = 0.66; during straight motion, disappearance ($M = 0.77$) and appearance ($M = 0.80$) had significantly lower accuracy than location shifts ($M = 0.86$), with no difference between disappearance and appearance, $F(2, 70) = 13.56$, $p < 0.001$, ^{2}p = 0.28.

[Figure 11: see original paper]A shows boxplot-violin plots of accuracy across trajectories. [Figure 11: see original paper]B depicts the effects of trajectory and change type on accuracy.

4.2.2 Reaction Time A repeated-measures ANOVA on correct RTs revealed significant main effects of trajectory, $F(2, 70) = 40.23$, $p < 0.001$, ^{2}p = 0.54, with significantly longer RTs for low-expectancy turning ($M = 1625.59$ ms) and high-expectancy turning (M = 1575.96 ms) than straight motion (M = 1337.38 ms), and a marginally significant trend for longer RTs in low- than high-expectancy turning (see [Figure 12: see original paper]A); and change type, $F(2, 70) = 24.94$, $p < 0.001$, ^{2}p = 0.42, with longer RTs for disappearance (M = 1631.92 ms) than appearance (M = 1451.90 ms) and location shifts (M = 1455.11 ms), with no difference between appearance and location shifts.

The trajectory × change type interaction was significant (see [Figure 12: see original paper]B), $F(4, 140) = 6.03$, $p = 0.003$, ^{2}p = 0.15. Simple effects analysis showed that during low-expectancy turning, disappearance (M = 1810.50 ms) had significantly longer RTs than appearance (M = 1543.68 ms) and location shifts (M = 1522.59 ms), with no difference between appearance and location shifts, $F(2, 70) = 9.89$, $p = 0.001$, ^{2}p = 0.22; during high-expectancy turning, disappearance (M = 1727.16 ms) had significantly longer RTs than appearance (M = 1510.86 ms) and location shifts (M = 1489.87 ms), with no difference between appearance and location shifts, $F(2, 70) = 35.06$, $p < 0.001$, ^{2}p = 0.50; during straight motion, appearance (M = 1301.16 ms) had significantly shorter RTs than disappearance (M = 1358.10 ms) and location shifts (M = 1352.88 ms), with no difference between disappearance and location shifts, $F(2, 70) = 5.00$, $p = 0.009$, ^{2}p = 0.13.

[Figure 12: see original paper]A shows boxplot-violin plots of RTs across trajectories. [Figure 12: see original paper]B depicts the effects of trajectory and change type on RTs.

4.3 Discussion

Experiment 3 results show that the high-expectancy turning condition produced significantly higher change detection accuracy and shorter RTs than the low-expectancy condition. Since Experiment 3 controlled image movement speed and duration, eliminating confounds from exogenous transient intensity and encoding time, the observed performance differences likely stem primarily from endogenous expectancy modulation, generally supporting Hypothesis 3. Additionally, disappearance changes again showed the lowest accuracy and longest RTs, demonstrating more pronounced change blindness than appearance and location shift changes.

More importantly, compared to the low-expectancy turning condition, the high-expectancy condition showed significantly improved accuracy for disappearance and location shift changes, but the opposite pattern for appearance changes. This suggests that expectancy modulation of change detection in moving images may depend on specific task contexts. Appearance changes, which possess bottom-up attentional capture advantages (Brockmole & Henderson, 2005; Donaldson & Yamamoto, 2016), may have their processing efficiency inhibited to some degree by strong, sustained endogenous attentional biasing toward expected directions in the high-expectancy condition (Theeuwes, 2010; Yantis & Jonides, 1984)—a dynamic competition between endogenous expectancy guidance and exogenous attentional capture. In contrast, under low-expectancy conditions with weaker endogenous guidance, observers rely more on immediate stimulus-driven processing, allowing appearance changes' attentional capture advantage to exert greater effectiveness.

5 General Discussion

This study employed the motion-direction-transient method to induce change blindness, using top-down traffic-scene images with disappearance, appearance, and location shift changes as materials. Participants performed change detection under different movement speed (Experiment 1), movement time (Experiment 2), and expectancy level (Experiment 3) conditions. Three experiments investigated how attention and memory representations affect change blindness during traffic-scene turning. Experiment 1 manipulated image speed during turning/straight motion, introducing instantaneous target changes at turning moments or straight-motion midpoints. Experiment 2 extended pre-change horizontal movement distance to manipulate movement duration. Experiment 3 used probability distributions of multiple random turning paths to manipulate expectancy levels.

The findings reveal that motion-direction changes mask target changes more effectively than continuous motion alone; increased movement speed impairs change detection by intensifying attentional resource competition during turning; extended movement time (i.e., increased encoding duration) mitigates change blindness through limited effects on memory representation precision; and heightened expectancy levels may dynamically optimize the modulatory effects of endogenous expectations on attention allocation and memory representation construction, further improving target change detection efficiency.

5.1 Movement Speed During Turning Exacerbates Change Blindness: Attentional Resource Competition

This study first verified the interactive effect of movement speed and direction on change blindness. Results show that fast motion significantly exacerbated change blindness only under turning conditions, while performance remained stable across speeds during straight motion, supporting Hypothesis 1. This indicates that movement speed does not independently affect attention but must combine with instantaneous directional changes to influence change detection. In this study, the abrupt change in motion direction itself constitutes a distractor signal endogenous to the task scene that masks target changes (Rensink, 2002; Yao et al., 2019).

According to attentional blink mechanisms (Raymond et al., 1992) and the two-stage processing model (Chun & Potter, 1995), which reveal processing inhibition for temporally adjacent targets, increased movement speed acts as a "catalyst" that amplifies attentional conflict between temporally overlapping turning signals and target change detection signals, further enhancing attentional processing demands during turning and creating more intense attentional resource competition (Tombu & Seiffert, 2008), thereby significantly impairing change detection. This finding extends the attention-representation theory (Simons & Rensink, 2005) and deepens understanding of Tombu and Seiffert' s (2008) research—simply increasing movement speed (e.g., straight acceleration) alone is insufficient to support hypotheses about motion signal strength suppressing or capturing attention (Abrams & Christ, 2003; Suchow & Alvarez, 2011; Wallisch et al., 2023); its interference effect only emerges within specific task conflict contexts (e.g., motion direction changes).

Crucially, this attentional resource competition mechanism receives further support from Experiment 1' s change type results: no significant performance differences across change types emerged during straight motion, whereas significant differences appeared during turning motion. During turning, appearance changes were not significantly affected by movement speed, likely due to the visual system' s processing priority for new object onsets, which confers stronger attentional capture priority and RT advantages over disappearance changes (Donaldson & Yamamoto, 2016; Franconeri & Simons, 2003; Shen et al., 2010), making this change type most automated and able to "resist"such interference to some extent. Disappearance changes suffered the most severe performance impairment; under fast turning motion, their reliance on continuous task context monitoring and retrieval-based comparison mechanisms (Brockmole & Henderson, 2005; Cole & Kuhn, 2010; Van Pelt et al., 2025) may become less stable under more intense attentional resource competition, making them significantly susceptible to movement speed effects. Location shift changes maintained optimal performance across both speed conditions, but their accuracy still decreased significantly with speed increases. We speculate that although this change type may benefit from effective spatial position information storage in visual working memory or from the substantial visual scene change magnitude generated by position shifts (Martens, 2011; Murphy & Andalis, 2013; Türkan et al., 2016), its larger change magnitude may also reduce processing stability, making it vulnerable to attentional interference from movement speed and thus showing performance declines under fast motion.

5.2 Movement Time During Turning Reduces Change Blindness: The Role of Memory Representations

Experiment 2 systematically manipulated pre-change movement time to investigate memory representation effects on traffic-scene change blindness. Results show that extending visual processing time for original scenes improved change detection accuracy. These findings generally support Hypothesis 2, suggesting that under controlled movement speed, longer visual processing time may enhance encoding completeness and memory representation precision (Bays et al., 2009; Gao et al., 2013; Martens, 2011), thereby mitigating change blindness to some extent.

However, it is noteworthy that although the movement time main effect was statistically significant, the actual numerical difference was small. Specifically, when turning condition (pre-change) movement time increased from approximately 1115 ms to 1532 ms, accuracy only improved from about 33.67% to 36.33%. Moreover, Bayesian repeated-measures ANOVA provided weak evidence against a movement time effect, suggesting its practical explanatory power is relatively limited, with low effect strength or high uncertainty. This result aligns with previous research. For example, Beck et al.' s (2007) eye-tracking study found that memory encoding failure could only explain a minimal proportion of change detection failures and was not the primary cause. Wood and Simons (2019) found that reducing unexpected object presentation time by 50%-70% only moderately affected noticing rates (5 s vs. 1.5 s difference = 12.7%), indicating that visual attention stabilizes after the initial rapid processing phase (first 1.5 s), with diminishing returns from extended presentation time. Based on these findings, we infer that in traffic-scene turning tasks, memory representation precision may be constrained by inherent system properties; when the representation system approaches its capacity threshold, performance gains from extended encoding time are relatively limited (Wood & Simons, 2019; Zhang & Luck, 2008).

Additionally, the significant RT increase provides another perspective for understanding memory representation mechanisms. Results show that while extended movement time improved accuracy, it was accompanied by longer RTs. A possible explanation is that more detailed and richer memory representations may expand the mental search space for visual search and feature comparison, requiring observers to perform more complex and time-consuming retrieval and comparison processes during change detection, thereby increasing RTs needed for detection and matching (Gilchrist & Cowan, 2014). Experiment 2' s findings provide important supplementary understanding for Experiment 1 results: the exacerbation of traffic-scene change blindness caused by fast motion may stem from two mechanisms: first, as Experiment 1 revealed, movement speed may intensify attentional resource competition during turning; second, fast motion compresses effective encoding time, potentially reducing memory representation quality.

5.3 Expectancy During Turning Reduces Change Blindness: Endogenous Expectancy Modulation

The low-expectancy turning group showed significantly greater change blindness than the high-expectancy group. When changes were more likely to occur in expected directions (high-expectancy condition), prepared individuals could more effectively process concurrent stimulus changes during turning moments, modulating attentional interference from exogenous motion signals and demonstrating higher change detection accuracy and shorter RTs. These results generally support Hypothesis 3. According to the change probability effect (Beck et al., 2007), we infer that individuals may form spatial expectations based on traffic-scene image turning direction probability distributions, top-down prioritizing attentional resources toward high-probability change regions (Roth et al., 2024; Steelman et al., 2013; Zuanazzi & Noppeney, 2020) and enhancing encoding priority and representation precision for target regions (Awh & Vogel, 2008; Cohen-Dallal et al., 2023), thereby improving change detection performance.

Analysis of different change types further reveals the complexity of expectancy effects. For disappearance and location shift changes, which lack processing priority and are more susceptible to exogenous interference enhancement (Experiment 1) and endogenous modulation weakening (Experiment 3), interestingly, appearance changes showed decreased accuracy in the high-expectancy turning condition, contrary to expectations. We speculate that because appearance changes possess bottom-up attentional capture advantages (Brockmole & Henderson, 2005; Donaldson & Yamamoto, 2016), the strong, sustained endogenous attentional biasing toward expected directions in the high-expectancy condition may have inhibited processing efficiency for new object onsets to some degree (Theeuwes, 2010; Yantis & Jonides, 1984)—a dynamic competition between endogenous expectancy guidance and exogenous attentional capture. In contrast, under low-expectancy conditions with weaker endogenous guidance, observers relied more on immediate stimulus-driven processing, allowing appearance changes' attentional capture advantage to exert greater effectiveness.

In summary, change blindness during traffic-scene turning results from the joint action of attentional resource competition and memory representation limitations, while expectancy levels may endogenously modulate attention allocation and effective memory representation construction to dynamically optimize change detection efficiency. These findings support and extend the attention-representation theory of change blindness (Simons & Rensink, 2005).

5.4 Limitations and Future Directions

Unlike previous change blindness studies that often involved visual interruptions or masking, this study used traffic-scene images to explore mechanisms underlying turning-signal-induced change blindness. However, several limitations remain. First, the target changes, viewing perspective, and experimental conditions differ from real driving situations, limiting direct application to traffic driving contexts. Future research could combine driving simulators with augmented reality technology to deepen understanding of turning-related blindness mechanisms in three-dimensional environments. Second, although Experiment 3 manipulated expectancy using event probability distributions following previous research (Berggren & Eimer, 2019), and participant feedback may have reflected potential implicit learning effects, no formal manipulation check was conducted to confirm that participants perceived the trial proportion differences. Future studies should include manipulation checks and systematic feedback surveys. Third, eye-tracking measures were not included to examine the influence of scene path segmentation, making this an exploratory study of turning-related blindness mechanisms in moving scenes. Future research should incorporate electrophysiological measures to more comprehensively reveal the mechanisms underlying change blindness during turning.

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6 Conclusion

This study employed the motion-direction-transient method using traffic-scene images with different change types to investigate how attention and memory representations affect change blindness during traffic-scene turning through three experiments. The main conclusions are: (1) Increased movement speed exacerbates change blindness, likely because fast motion intensifies attentional resource competition during turning, differentially affecting change detection performance across change types, but movement speed must interact with other basic visual feature changes to induce change blindness; (2) Extended movement time (i.e., increased encoding duration) can mitigate change blindness, with visual processing time affecting change detection by enhancing scene memory representation encoding precision, though this effect is limited; (3) Heightened expectancy levels reduce change blindness, as individuals' spatial expectations about turning directions may introduce response biases that endogenously modulate attentional pre-allocation and effective memory representation construction to improve change detection quality and efficiency.

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