

Effects of Target Number and Motion Frame Rotation Angle on Multiple Object Tracking Performance in Individuals with Different Field Cognitive Styles: Postprint

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Abstract

By manipulating the number of targets and the abrupt rotation angle of the motion reference frame, this study investigated the performance of participants with different field cognitive styles in a multiple object tracking task. The results revealed: (1) Under conditions of low task difficulty (stable motion reference frame, target numbers of 3 and 4) and medium task difficulty (motion reference frame abruptly rotated 20° to the right, target number of 4), field-independent participants demonstrated significantly superior multiple object tracking performance compared to field-dependent participants. Under high task difficulty conditions (stable motion reference frame, target number of 5, and motion reference frame abruptly rotated 40° to the right, target number of 4), no significant difference was observed between the two groups. This indicates that the tracking performance of participants with different field cognitive styles is influenced by task difficulty; (2) As the number of targets increased from 3 to 5, the increased tracking load resulted in a significant decline in participants' tracking performance; (3) Compared with a stable motion reference frame, abrupt rightward rotations of 20° and 40° both significantly impaired participants' tracking performance. Changes in rotation angle disrupted scene continuity, thereby affecting tracking performance.

Full Text

The Effects of Target Number and Abrupt Reference Frame Rotation on Multiple Object Tracking Performance in Individuals with Different Field Cognitive Styles

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Abstract

This study investigated how target number and abrupt rotation of the motion reference frame affect multiple object tracking (MOT) performance in individuals with different field-dependent-independent cognitive styles. The results revealed three key findings: (1) Field-independent participants demonstrated significantly better MOT performance than field-dependent participants under low-difficulty conditions (stable reference frame with 3 or 4 targets) and medium-difficulty conditions (reference frame abruptly rotated 20° rightward with 4 targets). However, no significant differences emerged between the two groups under high-difficulty conditions (stable reference frame with 5 targets or reference frame abruptly rotated 40° rightward with 4 targets), indicating that tracking performance differences between cognitive styles are moderated by task difficulty. (2) As target number increased from 3 to 5, the heightened tracking load significantly impaired tracking accuracy. (3) Compared with a stable reference frame, abrupt rightward rotations of 20° and 40° significantly degraded tracking performance, suggesting that rotation angle changes disrupted scene continuity and consequently affected tracking ability.

Keywords: Multiple Object Tracking; field dependence-independence; motion reference frame; rotation angle

Classification Code: B842

Traditional visual attention research has primarily examined visual information processing for single objects within stable motion reference frames. However, in daily life, people frequently encounter dynamic scenes with changing viewpoints and must maintain attention on multiple moving objects under unstable reference frame conditions. For example, pedestrians must attend to vehicles and other pedestrians while walking; soccer viewers must track multiple players during camera angle switches; action game players must monitor teammates and opponents in unstable visual perspectives; and virtual reality users experience immersive environments while visually navigating. The Multiple Object Tracking (MOT) paradigm developed by Pylyshyn and Storm (1988) is commonly used to study sustained visual attention processing in dynamic contexts. In this classic paradigm, the motion reference frame remains stable throughout the task. More recently, researchers have begun investigating factors and cognitive mechanisms underlying MOT performance in unstable reference frame scenarios to simulate real-world visual attention phenomena during perspective changes (Liu et al., 2005; Seiffert, 2005; Huff, Jahn, & Schwan, 2009; Huff, Papenmeier, Jahn, & Hesse, 2010; Jahn, Papenmeier, Meyerhoff, & Huff, 2012; Brockhoff et al., 2016).

1.1 Multiple Object Tracking Research

The classic MOT paradigm consists of three phases: cueing, tracking, and response. During the cueing phase, 8-10 identical objects (e.g., plus signs, circles, letters) appear on screen, with a subset designated as targets via flashing borders while the remainder serve as distractors. The flashing typically lasts 2-5 seconds before disappearing. In the tracking phase, all objects move randomly for 5-15 seconds while participants track the cued targets. After motion ceases, the response phase requires participants to identify the previously marked targets using a mouse or to judge whether highlighted objects were targets. Research indicates that participants can typically track 4-5 targets simultaneously with accuracy above 85% when target and distractor numbers are equivalent, though accuracy declines as target number increases (Pylyshyn, 2001; Pylyshyn, 2003).

Previous MOT studies have primarily examined visual attention mechanisms under stable reference frame conditions, revealing that tracking performance is influenced by object motion speed (Tombu & Seiffert, 2011), target number (Pylyshyn & Storm, 1988; Yantis, 1992), task difficulty (Wei, Liu, Zhang, & Zhao, 2013), and spatial symmetry (Wang, Zhang, Li, & Lyu, 2016). More recent work has investigated MOT performance under changing reference frames, though findings remain controversial. Liu et al. (2005) examined MOT in 3D stereoscopic scenes and found that tracking accuracy was unaffected by reference frame velocity during continuous translation, scaling, and rotation combinations, with performance influenced only by object motion speed. In contrast, Seiffert (2005) demonstrated that altering the overall visual presentation of targets during tracking reduced mean accuracy from 86% to 62%. Abrupt reference frame rotations of 20° or 30° during tracking also significantly impaired performance (Huff et al., 2009). Subsequent research by Huff et al. (2010) showed that continuity of object and scene motion is critical for visual tracking, with participants performing worse under abrupt versus gradual smooth rotations, possibly because abrupt rotations eliminate continuous scene change information. Brockhoff et al. (2016) investigated developmental aspects of tracking ability in 3D environments across five age groups (first, third, fifth, seventh graders, and adults), finding that abrupt scene rotation affected all groups. While these studies used pictorial depth cues to examine reference frame changes in 3D space, few have explored individual differences in cognitive style as a factor in unstable reference frame MOT tasks.

1.2 Field Cognitive Style and Related Cognitive Function Research

Cognitive style refers to personalized and consistent preferences in organizing and processing information, reflecting individual characteristics in perception, memory, and thinking (Messick, 1984). Early scholars categorized cognitive styles along various dimensions, including field dependence-independence, reflectiveness-impulsivity, and converging-diverging (Kagan, 1966; Witkin,

Moore, Goodenough, & Cox, 1977; Bergum & Cooper, 1977). More recent work has integrated these into two primary dimensions: wholist-analytic and verbal-imagery (Riding & Cheema, 1991), with field dependence-independence, reflectiveness-impulsivity, and converging-diverging all falling under the wholist-analytic dimension. Research using this framework has been conducted both domestically and internationally (Liang & Zhang, 2012; Riding & Rayner, 1998; Zhou, Zhou, Li, & Zhang, 2015; Nitzantamar, Kramarski, & Vakil, 2016).

This study adopts the field dependence-independence cognitive style framework proposed by Witkin et al. (1977), the most widely used classification system, which distinguishes between field-independent (FI) and field-dependent (FD) individuals. The “field” represents the surrounding environment, with different cognitive styles showing varying degrees of dependence on environmental cues. Field-independent individuals tend to rely on internal bodily references during information processing and are less susceptible to environmental influences, whereas field-dependent individuals rely more heavily on external environmental cues. These processing differences align with characteristic patterns in thinking and perception, demonstrating cross-task consistency in measures such as the Rod and Frame Test (RFT), Body-adjustment Test, Rotating Room Test, and Embedded Figures Test (EFT). As a relatively stable trait, field cognitive style has garnered extensive attention, with research expanding from vertical perception to complex cognitive domains including memory, thinking, and problem-solving.

Beyond personality differences, field cognitive style is closely linked to cognitive functions. Field-independent participants outperform field-dependent participants in figural reasoning (Wang & Ou, 2004) and mental rotation tasks (Li, Zhang, Wu, & Mei, 2016; Zhao & You, 2007). ERP research has shown that field-dependent participants exhibit larger negative slow-wave amplitudes in central and right brain regions during visuospatial tasks, suggesting greater cognitive resource allocation compared to field-independent participants (Yue, Li, & Bai, 2012). Eye-tracking research on road scene observation revealed that field-independent participants fixated on regions of interest more quickly and made more fixations within these areas than field-dependent participants, though average fixation numbers did not differ between groups (Zheng & Shi, 2015). These findings indicate significant differences in visual cognitive processing between cognitive styles, likely because field-independent individuals tend to overcome or restructure field organization, perceiving field information as objects independent from the background and thus performing better, while field-dependent individuals tend to rely on given environmental information, perceiving objects and field as an integrated whole and being more susceptible to environmental influences.

In summary, previous MOT research has primarily examined how factors such as object speed, size, number, and identity features affect tracking performance under stable reference frames. Few studies have investigated the relationship between field cognitive style and MOT performance under both stable and chang-

ing reference frames from an individual differences perspective. Such research could enhance our understanding of how different cognitive style individuals perform in multi-target visual tracking tasks with stable and changing reference frames, offering theoretical and practical significance for understanding the role of reference frames in complex dynamic scene processing. Howard (1982) noted that during information processing, people use objects, background environments, or themselves as reference points to transform dispersed input into relatively stable and detailed representations. Field cognitive style can be used to examine whether information processing is influenced by background context (Jonassen & Grabowski, 1993). Field-independent individuals tend to use themselves as reference points, processing field objects as independent, separate perceptual objects unaffected by external information, making it easier to separate objects from the environment. In contrast, field-dependent individuals tend to use external information as reference points, processing perceptual objects holistically and uniformly, making object-background separation more difficult (Witkin et al., 1977; Witkin & Goodenough, 1981; Pithers, 2002; Evans, Richardson, & Waring, 2013). Classic MOT examines information processing in dynamic contexts, using a stable motion reference frame and multiple discrete, identical objects, some designated as targets and others as distractors, requiring participants to continuously track targets among distractors. Do the habitualized and preferential information processing approaches of different cognitive style individuals affect MOT performance? How does target number variation influence different cognitive style participants? How does reference frame rotation during tracking affect performance? These questions require further investigation.

Based on this background, the present study combined the classic MOT paradigm with abrupt reference frame rotation to examine performance differences between field-independent and field-dependent participants. Drawing on previous research and the characteristics of field cognitive style and MOT paradigms, we hypothesized: (1) MOT performance would be influenced by cognitive style, target number, and abrupt reference frame rotation angle; (2) Field-independent participants would more easily separate targets from distractors and the reference frame, showing superior tracking performance compared to field-dependent participants; (3) Increases in target number and abrupt rotation angle would significantly affect MOT performance.

Two experiments were designed to address these questions and hypotheses. Experiment 1 varied target number using the classic MOT paradigm to investigate performance differences between cognitive style groups. Experiment 2 fixed target number at 4 and varied abrupt reference frame rotation angle to further examine how sudden reference frame changes affect tracking performance in different cognitive style individuals. This research simulates real-world perspective changes on visual attention tracking, extending the classic MOT paradigm and offering theoretical and practical value for understanding multi-target tracking abilities across cognitive styles and the impact of reference frame rotation.

Experiment 1

Experiment 1 examined how different cognitive style participants performed across varying target numbers in the classic MOT task and potential performance differences.

2.1 Participants

Seventy-one undergraduate students majoring in science at a 985 university in Beijing were randomly recruited (29 males, 42 females; mean age = 19.96 ± 2.15 years). Embedded Figures Test (EFT) scores were rank-ordered, with participants scoring in the top 27% (15 points) classified as the field-independent group and those in the bottom 27% (11 points) as the field-dependent group. Forty-two participants ultimately completed Experiment 1 (20 males, 22 females; mean age = 19.81 ± 1.93 years), comprising 19 field-independent participants (8 males, 11 females) and 23 field-dependent participants (12 males, 11 females). All participants had normal or corrected-to-normal vision and normal color perception, and received compensation upon completion.

2.2 Experimental Design

A 2 (cognitive style: field-independent vs. field-dependent) \times 3 (target number: 3, 4, 5) mixed factorial design was employed, with tracking accuracy as the dependent variable. Stimuli consisted of black solid circles, with a constant total of 10 objects. Three conditions were created with target numbers of 3, 4, and 5, corresponding to distractor numbers of 7, 6, and 5, respectively.

2.3 Apparatus and Materials

The experiment was conducted on an i5 3.2 GHz desktop computer with a 22-inch monitor. Screen resolution was set to 1680 \times 1050 pixels (approximately 0.028 cm per pixel) with a 60 Hz vertical refresh rate. The program was written in Visual Basic 6.0.

The stimulus presentation area was an 800 \times 600 pixel white-bordered frame [RGB (255, 255, 255)] at the center of the screen (approximately 22° horizontal and 17° vertical viewing angle), with a 2-pixel border width against a gray background [RGB (128, 128, 128)]. Moving objects were black solid circles [RGB (0, 0, 0)] with a diameter of 30 pixels. A white cross fixation point remained at the center of the tracking area. All objects were randomly positioned initially, with inter-object distances exceeding the object diameter and object-border distances at least twice the object diameter. Objects bounced off each other and the border upon collision, preventing occlusion during the experiment.

2.3.2 Cognitive Style Assessment The Embedded Figures Test (EFT), revised by Beijing Normal University in 1981, was used to classify cognitive style. The test has a reliability of 0.90 and correlates 0.49 with the Rod and Frame

Test, demonstrating high reliability and validity and widespread application in domestic cognitive style research. The test contains 29 items divided into three sections: 9 items in Section 1 (not scored), and 10 items each in Sections 2 and 3 (scored). Higher scores indicate greater field independence, while lower scores indicate greater field dependence.

2.4 Procedure

Participants completed the group-administered Embedded Figures Test, with each section lasting 3 minutes 30 seconds. Scores were rank-ordered, and participants scoring in the top 27% (15 points) and bottom 27% (11 points) were selected as field-independent and field-dependent groups, respectively, for the tracking experiment.

The viewing distance was approximately 57 cm. The tracking procedure is illustrated in Figure 1 [Figure 1: see original paper]. Participants pressed the spacebar to begin each trial. All objects appeared stationary on screen, with 3, 4, or 5 black circles designated as targets by flashing red borders for 2 seconds. After the borders disappeared, all objects moved randomly at $10^\circ/\text{s}$ for 6 seconds, during which participants tracked the targets. When motion ceased, participants used the mouse to select the targets, then pressed the spacebar for the next trial. Target number conditions were administered in three blocks with counterbalanced order across participants. Each block contained 20 trials, for a total of 60 trials. Six practice trials preceded each block. The entire experiment lasted approximately 30 minutes. The program automatically recorded tracking accuracy as (number of correctly selected targets / total target number) \times 100%.

Because the number of correctly selected targets differs from the actual number of tracked targets due to guessing probability, which varies with target number, we converted selected targets to actual tracked targets using Formula (1), where k represents the corrected number of actually tracked targets, P represents the number of correctly selected targets, t represents target number, and a represents total response options (targets + distractors) (Horowitz et al., 2007).

$$k = \frac{tP}{a - P + 1}$$

SPSS 19.0 was used for subsequent statistical analyses on corrected tracking accuracy: (actual tracked targets / total targets) \times 100%.

2.5 Results

2.5.1 Participant Grouping Validity

Forty-two valid participants completed Experiment 1 (19 field-independent, 23 field-dependent). Field-independent participants' EFT scores ($M = 16.26$, $SD = 1.41$) were significantly higher than field-dependent participants' scores ($M = 9.48$, $SD = 1.70$), with a mean difference of 6.79 points, confirming effective group classification: $t(40)$

= 13.88, $p < 0.001$, Cohen's $d = 4.41$. Gender differences in cognitive style were not significant: $t(40) = -0.24$, $p = 0.812$, Cohen's $d = 0.08$.

2.5.2 Effects of Target Number on MOT Across Cognitive Styles

Tracking accuracy for both cognitive style groups across target numbers is shown in Figure 2 [Figure 2: see original paper]. A 2 (cognitive style: field-independent vs. field-dependent) \times 3 (target number: 3, 4, 5) repeated measures ANOVA on tracking accuracy revealed significant main effects for cognitive style, $F(1, 40) = 6.90$, $p < 0.05$, $\eta^2 = 0.147$, with field-independent participants ($M = 0.70$, $SD = 0.12$) outperforming field-dependent participants ($M = 0.60$, $SD = 0.12$). The target number main effect was also significant, $F(2, 80) = 54.22$, $p < 0.001$, $\eta^2 = 0.575$. Post-hoc tests showed that tracking accuracy for 3 targets was significantly higher than for 4 or 5 targets, and accuracy for 4 targets was significantly higher than for 5 targets (3 vs. 4: $MD = 0.09$, $p < 0.001$; 3 vs. 5: $MD = 0.23$, $p < 0.001$; 4 vs. 5: $MD = 0.14$, $p < 0.001$). The cognitive style \times target number interaction was not significant, $F(2, 80) = 0.74$, $p = 0.480$, $\eta^2 = 0.018$.

2.5.3 Effects of Cognitive Style on MOT

Independent samples t -tests examined group differences across target numbers. Field-independent participants significantly outperformed field-dependent participants with 3 targets, $t(40) = 2.10$, $p < 0.05$, Cohen's $d = 0.67$, and with 4 targets, $t(36.72) = 3.01$, $p < 0.01$, Cohen's $d = 0.91$. No significant difference emerged with 5 targets, $t(40) = 1.60$, $p = 0.118$, Cohen's $d = 0.51$.

2.6 Discussion

Experiment 1 used the classic MOT paradigm to examine performance differences between cognitive style groups across target numbers. Results showed that field-independent participants achieved significantly higher overall tracking accuracy than field-dependent participants. Specifically, field-independent participants outperformed field-dependent participants under low-load (3 targets) and medium-load (4 targets) conditions, but not under high-load (5 targets) conditions. This indicates that performance differences between cognitive style groups are moderated by task difficulty, with significant differences emerging under low-to-medium difficulty but disappearing under high difficulty.

Furthermore, target number significantly affected all participants' tracking performance. With constant total objects, increasing targets from 3 to 4 to 5 elevated tracking load and task difficulty, significantly reducing accuracy—consistent with previous findings (Bai, Lyu, Wei, Zhou, & Zhang, 2015; Alvarez & Franconeri, 2007; Pylyshyn & Storm, 1988). The target number manipulation effectively revealed performance differences between cognitive style groups in the classic MOT task, representing a key finding of this research.

Experiment 2

Experiment 1 demonstrated that cognitive style affects classic MOT performance with a stable reference frame, with field-independent participants showing superior performance. Experiment 2 built upon these findings by fixing target number at 4 and examining performance in a more complex context—when the reference frame undergoes abrupt rotation during tracking.

3.1 Participants

Sixty-nine undergraduate science majors at a 985 university in Beijing were recruited (33 males, 36 females; mean age = 21.58 ± 2.39 years). Using the same EFT classification criteria as Experiment 1 (top 27% 15 points as field-independent; bottom 27% 11 points as field-dependent), 38 participants completed Experiment 2 (16 males, 22 females; mean age = 21.18 ± 2.49 years), including 19 field-independent participants (8 males, 11 females) and 19 field-dependent participants (8 males, 11 females). All had normal or corrected-to-normal vision and normal color perception, and received compensation.

3.2 Experimental Design

A 2 (cognitive style: field-independent vs. field-dependent) \times 3 (abrupt rotation angle: 0° , 20° , 40°) mixed factorial design was employed, with tracking accuracy as the dependent variable. Stimuli were black solid circles with a constant total of 10 objects and a fixed target number of 4 (corresponding to 6 distractors). Three reference frame rotation conditions were created: 0° (stable, no rotation), rightward (clockwise) abrupt rotation of 20° , and rightward abrupt rotation of 40° .

3.3 Apparatus and Materials

The apparatus and materials were identical to Experiment 1, with the exception that the reference frame underwent abrupt rightward rotation (0° , 20° , or 40°) during the experiment, after which objects continued random motion.

3.4 Procedure

Participants first completed the group EFT, with those scoring 15 points and 11 points classified as field-independent and field-dependent groups, respectively, for Experiment 2.

The procedure differed from Experiment 1 in that after 6 seconds of random object motion, the reference frame abruptly rotated rightward (0° , 20° , or 40°). Participants were required to continue tracking after rotation. After another 6 seconds of random motion, participants selected targets with the mouse and pressed the spacebar for the next trial.

Three rotation angle conditions (0°, 20°, 40°) were administered in three blocks of 20 trials each (60 total trials), with counterbalanced order across participants. Six practice trials preceded each block. The experiment lasted approximately 30 minutes. The procedure is illustrated in Figure 3 [Figure 3: see original paper].

3.5 Results

3.5.1 Participant Grouping Validity Thirty-eight valid participants completed Experiment 2 (19 field-independent, 19 field-dependent). Field-independent participants' EFT scores ($M = 16.58$, $SD = 1.35$) were significantly higher than field-dependent participants' scores ($M = 9.16$, $SD = 1.30$), with a mean difference of 7.42 points, confirming effective group classification: $t(36) = 17.27$, $p < 0.001$, Cohen's $d = 5.76$. Gender differences in cognitive style were not significant: $t(36) = 0.09$, $p = 0.929$, Cohen's $d = 0.03$.

3.5.2 Effects of Rotation Angle on MOT Across Cognitive Styles Tracking accuracy for both groups across rotation angles is shown in Figure 4 [Figure 4: see original paper]. A 2 (cognitive style: field-independent vs. field-dependent) \times 3 (rotation angle: 0°, 20°, 40°) repeated measures ANOVA revealed significant main effects for cognitive style, $F(1, 36) = 5.10$, $p < 0.05$, $\eta^2 = 0.124$, with field-independent participants ($M = 0.63$, $SD = 0.07$) outperforming field-dependent participants ($M = 0.57$, $SD = 0.07$). The rotation angle main effect was significant, $F(2, 72) = 89.13$, $p < 0.001$, $\eta^2 = 0.712$, and the rotation angle \times cognitive style interaction was significant, $F(2, 72) = 4.056$, $p < 0.05$, $\eta^2 = 0.101$.

Further analysis showed that field-independent participants significantly outperformed field-dependent participants at 0° rotation ($MD = 0.08$, $p < 0.05$) and 20° rotation ($MD = 0.07$, $p < 0.05$), but not at 40° rotation ($MD = 0.01$, $p = 0.566$).

For field-independent participants, tracking accuracy differed significantly between all rotation angle pairs (0° vs. 20°: $MD = 0.06$, $p < 0.01$; 20° vs. 40°: $MD = 0.14$, $p < 0.001$; 0° vs. 40°: $MD = 0.20$, $p < 0.001$). Similarly, for field-dependent participants, all rotation angle pairs differed significantly (0° vs. 20°: $MD = 0.06$, $p < 0.01$; 20° vs. 40°: $MD = 0.08$, $p < 0.001$; 0° vs. 40°: $MD = 0.14$, $p < 0.001$).

3.6 Discussion

Experiment 2 examined performance of both cognitive style groups under abrupt reference frame rotation conditions (0°, 20°, 40° rightward rotation). Results showed differential performance across conditions: as rotation angle increased, both groups' tracking accuracy significantly declined. Field-independent participants significantly outperformed field-dependent participants under 0° and 20° rotation conditions, but not under 40° rotation. These findings indicate that group differences are moderated by task difficulty, with significant differences

emerging under low-to-medium difficulty (0° and 20° rotation) but disappearing under high difficulty (40° rotation).

4.1 Effects of Field Cognitive Style on Multiple Object Tracking

Combined results from Experiments 1 and 2 demonstrate significant differences between cognitive style groups in both classic MOT and reference frame rotation MOT tasks. Field-independent participants achieved higher accuracy than field-dependent participants across both tasks, though this advantage was moderated by task difficulty. Under low-difficulty conditions (stable reference frame with 3 or 4 targets) and medium-difficulty conditions (reference frame abruptly rotated 20° with 4 targets), field-independent participants showed clear advantages. However, under high-difficulty conditions (stable reference frame with 5 targets or reference frame abruptly rotated 40° with 4 targets), the field-independent advantage diminished and group differences became nonsignificant.

In Experiment 1, field-independent participants showed superior overall tracking accuracy, with both groups' performance declining significantly as target number increased. This indicates that increased target number raised task difficulty and significantly affected tracking performance, consistent with previous research (Alvarez & Franconeri, 2007; Pylyshyn & Storm, 1988). Under low-load (3 targets) and medium-load (4 targets) conditions, field-independent participants outperformed field-dependent participants, but not under high-load (5 targets) conditions. Miyake, Witkin, and Emerson (2001) found that field-independent participants tend to use internal cues and separate information from background, while field-dependent participants are more influenced by external cues and have difficulty separating information from background. In the classic MOT task, participants must track targets among identical distractors. Under low-to-medium load conditions, field-independent participants' superior performance likely reflects their tendency to process targets and distractors as independent, separate objects, easily identifying targets without distractor interference. Field-dependent participants, conversely, tend to perceive targets and distractors as an integrated whole, making them more susceptible to distractor interference and resulting in lower accuracy. Under high-load conditions (5 targets), the increased task difficulty may have prevented field-independent participants from maintaining their advantage in separating targets from distractors, eliminating group differences and demonstrating that the field-independent advantage is task-difficulty dependent.

Experiment 2 fixed target number at 4 and examined performance under more complex background conditions: stable reference frame, abrupt 20° rotation, and abrupt 40° rotation. Results replicated Experiment 1, showing field-independent participants outperformed field-dependent participants in the stable reference frame condition. Additionally, field-independent participants maintained superior performance under 20° rotation. This advantage may stem from cognitive style characteristics: Li et al. (2016) found that cognitive style groups differed

in orientation and navigation tasks, possibly because field-independent participants use self-references while field-dependent participants use environmental references, leading to different environmental information perception, acquisition, and processing. Extensive research indicates that field-independent individuals tend to deconstruct and reconstruct field organization, flexibly extracting information, whereas field-dependent individuals rely on the holistic structure of presented information (Witkin, Oltman, Raskin, & Karp, 1971; Witkin et al., 1977; Zhang, 2004; Boccia, Piccardi, Pizzamiglio, & Guariglia, 2016). In Experiment 2, under low-difficulty conditions (stable reference frame and 20° rotation), field-independent participants likely used self-references, processing targets, distractors, and reference frame as independent objects and analyzing each target's spatial position. This approach enabled higher selective attention, greater search flexibility, more elemental information decomposition, and better filtering of task-irrelevant information, facilitating target separation from distractors and the rotating reference frame for more effective tracking (Witkin et al., 1977; Pithers, 2002; Jia, Zhang, & Li, 2014). Field-dependent participants, in contrast, tended toward holistic processing, representing targets, distractors, and reference frame as an integrated whole, making them more susceptible to background changes and less able to inhibit irrelevant information (Song & Han, 2007), resulting in lower performance. However, under high-difficulty conditions (stable reference frame with 5 targets or 40° rotation with 4 targets), both groups' performance was significantly impaired, eliminating the field-independent advantage, likely because limited attentional resources prevented field-independent participants from simultaneously tracking targets and inhibiting distractors and reference frame changes. Nevertheless, field-independent participants' accuracy remained higher than field-dependent participants even under high difficulty. These results indicate that field-independent participants show better MOT performance overall, but this advantage is moderated by task difficulty.

4.2 Effects of Target Number and Rotation Angle on Multiple Object Tracking

Experiment 1 demonstrated that target number significantly affected tracking performance. Previous research has shown that participants can maintain continuous tracking of moving targets among identical distractors (Pylyshyn & Storm, 1988). Our Experiment 1 results, consistent with prior findings (Alvarez & Franconeri, 2007; Hu, Lyu, Zhang, & Wei, 2018; Wei et al., 2013), showed that tracking performance declined significantly as target number increased from 3 to 5 under stable reference frame conditions. Increased target number elevated tracking load and task difficulty, significantly reducing accuracy, demonstrating that target number manipulation effectively influences tracking performance.

Experiment 2 found that rotation angle significantly affected tracking performance, consistent with Huff et al. (2009). Compared with the stable reference frame condition, abrupt rightward rotations of 20° and 40° significantly impaired tracking performance. Under stable conditions, participants could track targets

continuously, but abrupt reference frame rotation disrupted scene continuity, preventing real-time target location updating and impairing tracking outcomes. These results indicate that both target number variation and abrupt reference frame rotation significantly influence MOT performance.

4.3 Theoretical and Practical Implications

Previous research has focused primarily on MOT factors under stable reference frames. The present study extends classic MOT tasks by incorporating reference frame rotation to examine individual differences in tracking performance under unstable conditions. This research provides theoretical explanations for performance patterns across cognitive styles in MOT tasks and offers practical applications.

In daily life, people frequently encounter complex visual scenes with changing perspectives, motion, and complexity—such as attending to vehicles and pedestrians from different viewpoints while crossing streets, or tracking team and opponent positions from various angles in basketball or soccer. Our abrupt reference frame rotation paradigm simulates perspective changes in dynamic scenes through laboratory experiments, enhancing ecological validity and generalizability. Additionally, integrating MOT research with social-psychological factors and examining individual differences helps understand visual attention processing characteristics of different cognitive style individuals in reference frame-changing MOT tasks. From the perspective of both classic and reference frame-rotation MOT tasks, this study provides further evidence for explanations of cognitive style processing preferences, enriching cognitive style theory and offering empirical support for understanding the cognitive processing characteristics, advantages, and adaptive environments of different cognitive style individuals in real-world settings.

Examining MOT performance across cognitive styles can help individuals better understand their cognitive approaches, maximize their potential, and process visual information more flexibly and effectively in ecological contexts. In low-to-medium difficulty visual motion scenarios (e.g., crossing streets, driving, action games, watching sports, team sports), field-dependent individuals could learn from field-independent individuals' information processing preferences by using self-references rather than environmental references, treating dynamic scene information as independent objects to reduce irrelevant information interference and achieve effective attention and tracking. Virtual reality technology could be used to design visual dynamic scene tracking tasks or training simulations at varying difficulty levels to improve field-dependent individuals' tracking abilities. For cognitive skill-based occupational selection related to cognitive style and visual tracking performance (e.g., drivers, referees, surveillance operators, real-world and virtual navigation tasks), field-independent individuals could be selected for positions involving low-to-medium difficulty visual dynamic scenes to improve human-machine and visual environment interaction efficiency. When necessary, field-independent individuals could also be trained to enhance their

performance in high-difficulty visual scene tasks. For high-difficulty and complex dynamic visual scenes, future research could further manipulate tracking load (e.g., incremental target number changes) and reference frame difficulty (e.g., progressive rotation angle changes) to investigate specific performance patterns of different cognitive style individuals in high-difficulty tasks, providing evidence for selecting professionals with strong complex visual scene processing abilities.

This study examined MOT performance in 2D visual attention tracking tasks. Although planar MOT can investigate attention allocation and maintenance, it differs substantially from real-world visual information acquisition. Future research should employ 3D stereoscopic MOT tasks to better approximate everyday visual attention scenarios and combine virtual reality technology to enable natural interaction between different cognitive style individuals and environments, examining cognitive style effects on perception and thinking in more ecological contexts. Additionally, future studies could integrate eye-tracking, EEG, and fMRI technologies to investigate the cognitive and neural mechanisms underlying tracking performance in different cognitive style individuals, providing empirical evidence for understanding the cognitive and neural bases of field cognitive style.

Conclusions

1. In both classic MOT and reference frame-rotation MOT tasks, significant differences emerged between cognitive style groups, with performance differences moderated by task difficulty. Field-independent participants showed significantly better performance than field-dependent participants under low-difficulty conditions (stable reference frame with 3 or 4 targets) and medium-difficulty conditions (reference frame abruptly rotated 20° rightward with 4 targets). Under high-difficulty conditions (stable reference frame with 5 targets or reference frame abruptly rotated 40° rightward with 4 targets), the field-independent advantage was eliminated and group differences became nonsignificant.
2. Target number significantly affected tracking performance. As target number increased from 3 to 5, tracking accuracy declined significantly, likely because increased targets elevated cognitive load and impaired tracking performance.
3. Rotation angle significantly influenced MOT performance. Compared with a stable reference frame, abrupt rightward rotations of 20° and 40° significantly impaired tracking performance, possibly because larger rotation angles disrupted continuous scene change information, preventing real-time target location updating and reducing tracking accuracy.

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