Cognition 121 (2011) 73–82

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Continuous visual cues trigger automatic spatial target updating in dynamic scenes

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ARTICLE INFO

Article history:
Received 25 January 2011
Revised 26 May 2011
Accepted 2 June 2011
Available online 2 July 2011

Keywords:
Spatial updating
Multiple object tracking
Dynamic attention

ABSTRACT

Dynamic tasks often require fast adaptations to new viewpoints. It has been shown that automatic spatial updating is triggered by proprioceptive motion cues. Here, we demonstrate that purely visual cues are sufficient to trigger automatic updating. In five experiments, we examined spatial updating in a dynamic attention task in which participants had to track three objects across scene rotations that occurred while the objects were temporarily invisible. The objects moved on a floor plane acting as a reference frame and unpredictably either were relocated when reference frame rotations occurred or remained in place. Although participants were aware of this dissociation they were unable to ignore continuous visual cues about scene rotations (Experiments 1a and 1b). This even held when common rotations of floor plane and objects were less likely than a dissociated rotation (Experiments 2a and 2b). However, identifying only the spatial reference direction was not sufficient to trigger updating (Experiment 3). Thus we conclude that automatic spatial target updating occurs with pure visual information.

1. Introduction

In dynamic tasks such as navigating in inner-city traffic, playing or watching team sports, it is often required to keep track of several moving objects simultaneously. Besides object motion, the observer's viewpoint on such a scene often changes as well due to self-motion. Compensating for self-motion and viewpoint changes while keeping track of object locations is commonly referred to as spatial updating (see Berthoz, Israël, Georges-François, Grasso, & Tsuzuku, 1995) and has most often been studied with static object configurations. Several studies showed that spatial updating based on proprioceptive information about self-motion is an automatic process that cannot be suppressed (e.g., Farrell & Robertson, 1998). However, there is at least one experiment suggesting that it is possible to ignore body rotations of 180° (see Waller, Montello, Richardson, & Hegarty, 2002). While driving, proprioceptive information about self-motion is reduced and is usually absent while watching TV. However, continuous visual information about the frame of reference is available. In the present experiments, we tested whether spatial updating is automatic when proprioceptive information is absent and when only visual information about viewpoint changes is available. We use the term *spatial updating* exclusively to refer to changes of the object representation elicited by changes of the reference frame. For the purpose of this paper, we define automatic updating as a process that reflexively maintains object positions in relation to their environment (reference frame). In our experiments, we tested whether participants can ignore non-predictive visual cues suggesting updating when they are instructed to do so and whether processing of visual cues is independent of presentation probabilities. As outlined by previous

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doi:10.1016/j.cognition.2011.06.001

research (Jonides, 1981) these mechanisms namely resistance to suppression and independence of expectations reflect two major characteristics of automatic information processing.

Spatial updating based on proprioceptive information was repeatedly investigated by Wang and Simons (1999; see also Simons & Wang, 1998; Wang et al., 2006). In their experiments, they presented an array of static objects on a circular table. The table was occluded by a large screen containing two small windows separated by 40° (calculated from the center of the table). The participants' task was change recognition: the experimenter displaced one of the objects and the participants had to indicate the displaced object. When participants viewed the table through the same window before and after the displacement, rotating the table between views clearly disrupted change recognition performance compared to presenting the same view on the table. When participants walked to the second window, however, presenting the same view by rotating the table yielded lower performance than presenting the novel view (table not rotated). Thus, although participants were presented with the same retinal projection when they walked to the second window and the table was rotated with them, automatic spatial updating impaired change recognition performance. This impairment occurred although the participants were fully aware of the table rotation that was indicated by a continuously moving handle attached to the table and protruding through the screen occluding the table. Observing the moving handle did not trigger spatial updating of the invisible object configuration. This observation is in line with several other studies suggesting that visual cues are insufficient to trigger spatial updating (e. g., Klatzky, Loomis, Beall, Chance, & Golledge, 1998; Riecke, 2008; Ruddle & Lessels, 2006). As we will show, this is not true for visual information in general. On the contrary, visual information can trigger automatic spatial updating even when proprioceptive information is absent.

Recent research on dynamic attention revealed a spatial updating effect triggered by continuous visual information alone (Huff, Meyerhoff, Papenmeier, & Jahn, 2010). These experiments used the multiple object tracking paradigm (MOT; Pylyshyn & Storm, 1988) measuring the number of successfully tracked objects as dependent variable (Halleman, 2005). In a typical MOT experiment, participants are presented with a display of moving objects and have to keep track of a set of moving targets among identically looking moving distracters. Thus, they have to keep track of target locations. Huff et al. (2010) studied MOT with 3D scenes (3D model projected onto 2D screen) in which objects moved on a floor plane. Rotations of the floor plane that indicated a changed view occurred while the moving objects were temporarily invisible. The empty floor plane as a reference frame either rotated continuously or abruptly. The invisible objects rotated with the floor plane. Tracking performance was clearly superior with continuous compared with abrupt rotations. Because objects were invisible during rotations, it seems as if participants were able to update object positions based on continuous visual information about the rotating reference frame. The studied reference frame rotations resemble those of Wang and Simons (1999), Simons and Wang (1998) with three important differences: First, the traditional spatial updating studies measured change recognition with static layouts while the MOT studies measured tracking capacities in dynamic scenes. Second, while the traditional spatial updating studies postulated the need of proprioceptive cues the multiple object tracking studies provided visual cues alone. Third, in their change recognition experiments, self-motion and presented viewpoints were dissociated from each other. In other words, proprioceptive cues were non-predictive with respect to the presented view. Therefore processing of proprioceptive cues was useless and indeed detrimental. Such invalid associations between two sources of information have proven to be an excellent approach to investigate automatic information processing. For instance, invalid spatial cues cannot be ignored in signal detection tasks (Jonides, 1981; Müller & Rabbitt, 1989; see also Posner & Cohen, 1984), and conflicting color words cannot be ignored in color naming (Stroop, 1935).

In order to test whether spatial updating based on continuous visual information in MOT is automatic, in the present experiments, we dissociate rotations of the reference frame from target locations. Thus, the rotation of the reference frame is no longer a valid source of information for updating the locations of temporarily invisible objects. If spatial updating based on visual information in MOT was automatic, invalid visual information of viewpoint changes (i.e., a visible reference frame rotating unpredictably dissociated from temporarily invisible objects) should impair tracking performance even if object locations in the retinal projection do not change. We present five MOT experiments demonstrating that spatial updating in MOT occurs automatically counter instruction and when participants are motivated to suppress updating. Furthermore, we present evidence that presenting only the spatial reference direction is insufficient to trigger automatic spatial target updating.

2. Experiment 1a

In the present paper we argue that purely visual cues are sufficient to trigger automatic target updating during multiple object tracking. Whereas it has been demonstrated that human observers can take advantage of continuous scene rotations to improve tracking performance (Huff et al., 2010; see also Liu et al., 2005) it is unclear whether this updating occurs automatically as typically observed for spatial updating based on proprioceptive cues (e.g., Farrell & Robertson, 1998). In Experiments 1a and 1b we dissociated rotations of a floor plane from rotations of the set of moving objects. Thus, floor plane rotations were non-predictive for object positions. We tested whether participants can follow instructions to ignore these non-predictive floor plane rotations. In other words, we tested whether the processing of floor plane rotations is impossible or at least difficult to suppress, which is a key feature of automatic information processing (Jonides, 1981). If target updating following continuous scene rotations in MOT is an automatic process, participants should be unable to suppress floor plane rotations independent of their instruc-