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# Remote temporal camouflage: Contextual flicker disrupts perceived visual temporal order

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ABSTRACT

Correctly perceiving the temporal order of events is essential to many tasks. Despite this, the factors constraining our ability to make timing judgments remain largely unspecified. Here we present a new phenomenon demonstrating that perceived timing of visual events may be profoundly impaired by the mere presence of irrelevant events elsewhere in the visual field. Human observers saw two abrupt luminance events presented across a range of onset asynchronies. Temporal order judgment (TOJ) just noticeable differences (JNDs) provided a behavioural index of temporal precision. When target events were presented in isolation or in static distractor environments temporal resolution was very precise (JNDs ~20 ms). However, when surrounded by dynamic distractor events, performance deteriorated more than a factor of four. This contextual effect we refer to as *Remote Temporal Camouflage* (RTC) operates across large spatial and temporal distances and possesses a unique spatial distribution conforming to neither the predictions of attentional capture by transient events, nor by stimulus dependencies associated with other contextual phenomena such as surround suppression, crowding, object-substitution masking or motion-induced blindness. We propose that RTC is a consequence of motion-related masking whereby irrelevant motion signals evoked by dynamic distractors interfere with TOJ-relevant target-related apparent motion. Consistent with this we also show that dynamic visual distractors do not interfere with audio-visual TOJs. Not only is RTC the most spatially extensive contextual effect ever reported, it offers vision science a new technique with which to investigate temporal order performance, free of motion-related sensory contributions.



## 1. Introduction

Compared to auditory and somatosensory systems, the human visual system affords poor temporal resolution (Moore, 2012; Yau et al., 2009). Psychophysical thresholds demonstrate an upper perceptual limit of 50 Hz (20 ms per cycle) for the detection of luminance flicker and first order motion (de Lange, 1958; Holcombe, 2009). For other visual tasks, such as temporal phase discrimination and object tracking, temporal resolution is even worse (4–10 Hz) (Aghdaee & Cavanagh, 2007; Maruya, Holcombe, & Nishisa, 2013). It has been suggested that these differences may result from the differences in the attentional demands of each set of tasks (Holcombe, 2009). However, other factors may be involved. For example, it is well known that the mere presence of visual stimuli at spatially remote locations can influence both neural and psychophysical response to local attributes such as luminance, contrast, chromaticity, orientation, spatial configuration and direction of motion (Cass & Alais, 2006b; Kooi et al., 1994; Moore, 2012; Petrov & McKee, 2006; Polat & Sagi, 1993; Saarela & Herzog, 2008; Tadin et al., 2003; Wenderoth & Johnstone, 1988; Yau et al., 2009). Little is known, however, about the role that long-range contextual information might play in judgments of visual timing.

In our experiments subjects were instructed to perform temporal order judgments (TOJs). Two luminance events were presented across a range of stimulus onset asynchronies (SOAs) on the horizontal meridian 8 degrees left and right of fixation under three contextual conditions: (i) *Targets alone*: in which target elements were presented without distractor elements; (ii) *Static context*: whereby targets were each surrounded by ten black or white distractor disks (see Fig. 1a) whose luminance was constant throughout the trial; and (iii) *Dynamic context*: where the luminance of a randomly determined number of distractor disks modulated abruptly at a randomly allocated moment ⩾50 ms prior to the first target event and following the second target event (see Fig. 1).

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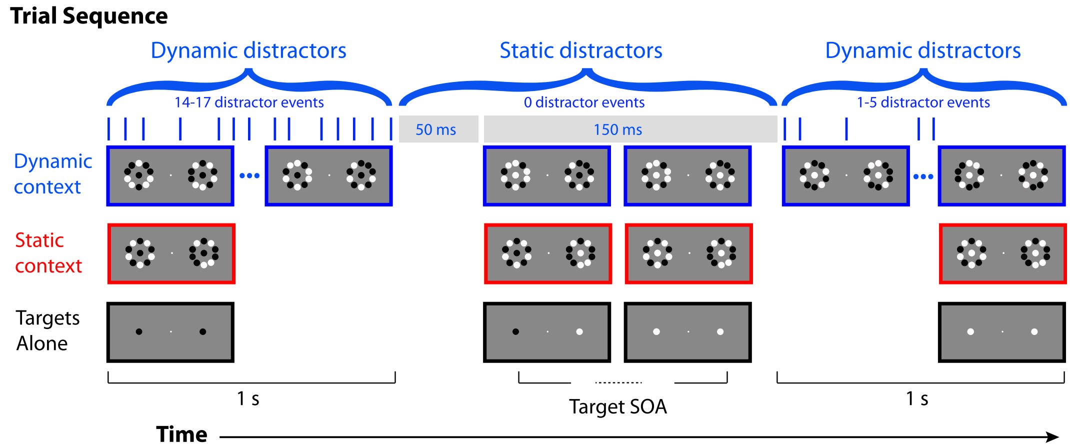


**Fig. 1.** Example trial sequence representing each of the three contextual conditions: *Dynamic context* (blue); *Static context* (red); *Targets alone* (black). Note that in the Dynamic context distractor elements remained unchanged at least 50 ms prior to, and 150 ms following the onset of the first target event. The interval between subsequent dynamic distractor events (prior to or following the target events) was either 50, 100 or 150 ms, chosen randomly following each distractor event.

If judgments of temporal order are unaffected by contextual factors, then we should observe no variation in performance precision across our three contextual conditions. Alternatively, if temporal judgments are subject to contextual constraints similar to those associated with other visual dimensions (e.g. colour, brightness, orientation, direction of motion), then we expect to observe impaired performance precision under *dynamic* contextual conditions relative to contextual conditions without temporal change (*targets alone* and *static* contexts).

## 2. General methods

### 2.1. Observers

Six human observers (two females, four males) with ages ranging from 23 to 48 participated in all experiments after giving informed written consent. Four were naïve to the purposes of the experiment and were paid for their participation. The other two were the authors. All had normal or corrected to normal vision. Experiments were approved by the University of Western Sydney's Human Research Ethics committee and were conducted in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans.

### 2.2. Apparatus and stimuli

Stimuli were created using E-Prime running on a desktop PC. Stimuli were presented on an LCD monitor (Viewsonic VX2265wm; 1024 × 768 pixels, 85 Hz). Viewing distance was approximately 57 cm. In all experiments the screen's background luminance was held constant at 32 cd/m$^2$.

### 2.3. Procedure

Each trial began with a single white circular fixation point (diameter = 0.2°, 62 cd/m$^2$) presented at the centre of the screen for one second. Two black target disks (diameter = 1.5° of visual angle, 2 cd/m$^2$) appeared 8° to the left and to the right of fixation. Three general contextual conditions were used across experiments: *targets alone*; *static* and *dynamic contexts* (Fig. 1). In the *dynamic context*, each target disk was surrounded by a set of ten 'distractor' disks (diameter = 1.5°), each set equidistantly located on an imaginary circle (radius = 3°) centered on each target element. Each distractor disk was randomly assigned to be either black (2 cd/m$^2$) or white (62 cd/m$^2$) at the beginning of each trial. The display then changed a total of 21 times. The initial set of changes involved a randomly determined number of distractor disk(s) (1–5 out of the possible 20) abruptly changing luminance polarity (from black to white or vice versa), with each change separated in time by a randomly determined interval (50, 100 or 150 ms). These changes continued until a randomly determined number of events had occurred (14–17). Subsequently, after 50 ms the luminance of one of the two target disks changed abruptly to white (62 cd/m$^2$), and then, after a randomly determined SOA (−94, −62, −30, −14, 14, 30, 62 or 94 ms) was followed by an equivalent luminance change in the other target. Negative SOAs indicate that the left target changed first, whereas positive SOAs indicate that the right target changed first. Then, 150 ms from the onset of the first target, the remaining (2–5) display changes (21 total changes – (2 target display changes + number of distractor changes prior the target events)) were again distractor changes. Similar to the previous distractor changes, a randomly determined number (1–5) of distractor disk(s) were assigned to potentially undergo an abrupt change in luminance polarity (from black to white or reversed) with each change separated by 50, 100 or 150 ms. In the *static* contextual condition the luminance of the distractors remained constant before disappearing at the conclusion of the trial. In the *targets alone* condition, there were no distractors present. Aside from the distractor changes the timing of the *static* and *targets alone* conditions were identical to the *dynamic condition*. Following a key press response, the display became black, and the next trial was initiated after a 300 ms inter-trial time. Each SOA was presented 16 times in each contextual condition (112 trials in total per condition per subject).

The subjects' task was to identify whether the left or right target event occurred first, by pressing the Z-key or M-key, respectively.

### 2.4. Results

Temporal resolution was indexed by just noticeable differences (JNDs) for judgments of temporal order. JNDs were obtained by fitting cumulative Gaussian functions separately to each subject's data using a Levenberg-Marquardt maximum likelihood fitting procedure and multiplying the standard deviation of each fit by 0.675. A within-subjects ANOVA on JNDs reveals a significant effect of context $F_{(2,5)} = 10.8$, $p = .003$) (see Fig. 2b). Whilst adding static distractor disks had no effect on thresholds relative to the *targets alone* condition (two-tailed t-tests; $t_5 = 0.393$, $p = .711$), introducing flicker to this context significantly increased thresholds