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Short communication

Smooth pursuit under stimulus–response uncertainty

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Abstract

Simple reaction times (RTs) are typically faster than choice reaction times and increase with uncertainty according to Hick's law. Here we show that smooth pursuit eye movement RTs show no effect of SR uncertainty while joystick tracking shows a step change between SRT and CRT, but no significant increases beyond two choices. The results suggest there is a benefit to pre-programming joystick tracking but not for smooth pursuit eye movements (SPEMs).

Theme: Sensory systems
Topic: Visual psychophysics and behavior

Keywords: Smooth pursuit; Hick's law; Stimulus–response uncertainty

Over 50 years ago, Hick [4] described the logarithmic relation between stimulus–response (S–R) uncertainty and reaction times (RTs): $RT = a + b\log_2(N)$, where a is simple RT, b is the slope of the increase, and N is the number of S–R alternatives. Hick's law holds for many tasks although exceptions are known [1,7,8,11]. In view of the recent finding that prosaccades show no increase between simple and choice RTs [7], and evidence that the superior colliculus plays an important role in generating both saccades and smooth pursuit eye movements (SPEMs) [3,5,9,10,12–14], we extended these observations of S–R uncertainty to SPEMs. The present experiment compares the effects of S–R uncertainty on two different response systems: SPEM and manual tracking of the same stimuli using a joystick.

1. Ocular tracking

Four subjects participated (1 male, mean age = 28.75 years). Two subjects (MB, KK) are authors. All procedures for both experiments were approved by the Dartmouth Committee for the Protection of Human Subjects. Subjects were informed of any potential risks and signed consent forms prior to experimentation.

Eye position was calibrated and monitored using the search coil technique using the same procedures as employed by Kveraga et al [7]. Subjects sat in a completely darkened room. Stimuli were displayed on a 15-in. LCD computer monitor (Micro Touch, 3M, USA) at a viewing distance of 57 cm. The onset of SPEMs was established using an eye velocity criterion of $1.5°\ s^{-1}$ which was equivalent to 25% of the stimulus velocity. This criterion placed SPEM onset prior to the first saccade.

Experimental sessions began with verbal instructions to the subject to visually track the moving target as quickly and accurately as possible. The instructions were repeated in text on the monitor. Fig. 1 illustrates the time course of events during a trial. The number of possible directions of motion was fixed within blocks of 16 trials and changed randomly between blocks. There were four levels of direction uncertainty (one, two, four or eight possible trajectories) which were indicated prior to each trial using arrows 1° of visual angle in length. The direction of motion on each trial was randomly selected from this set of possible motion trajectories. The pursuit target moved at a velocity of $6°\ s^{-1}$ for 1000 ms.

Following each block of trials the Ss were given a rest period. An experimental session consisted of 12 blocks of

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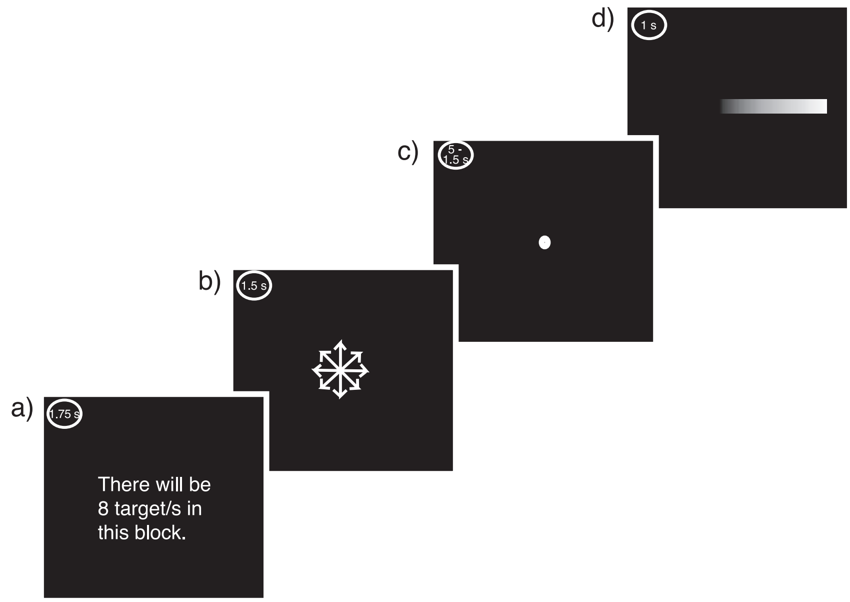

Fig. 1. Trial sequence. (a) Block instructions were presented prior to each 16 trial block for 1.75 s. (b) Arrow arrays of the possible trajectory directions were displayed for 1.5 s prior to each trial. (c) A variable fixation period with a fixation point 0.1° of visual angle lasting between 0.5 and 1.5 s replaced the arrows. (d) Target motion in the direction of one arrow lasting 1 s at a rate of 6o s^{-1} followed.

16 trials each (three replications of each uncertainty condition, 192 trials/session). Subjects participated in five experimental sessions. Stimuli were presented using True Basic software (TrueBasic, New Hampshire, USA). The stimulus presentation software set a bit on the parallel port that was synchronized with the vertical retrace at the beginning of each motion sequence. Eye position was digitized at 1000 Hz and analyzed off-line using Labview 6i software (National Instruments, USA). The eye traces were visually inspected and a trial was excluded if the subject did not

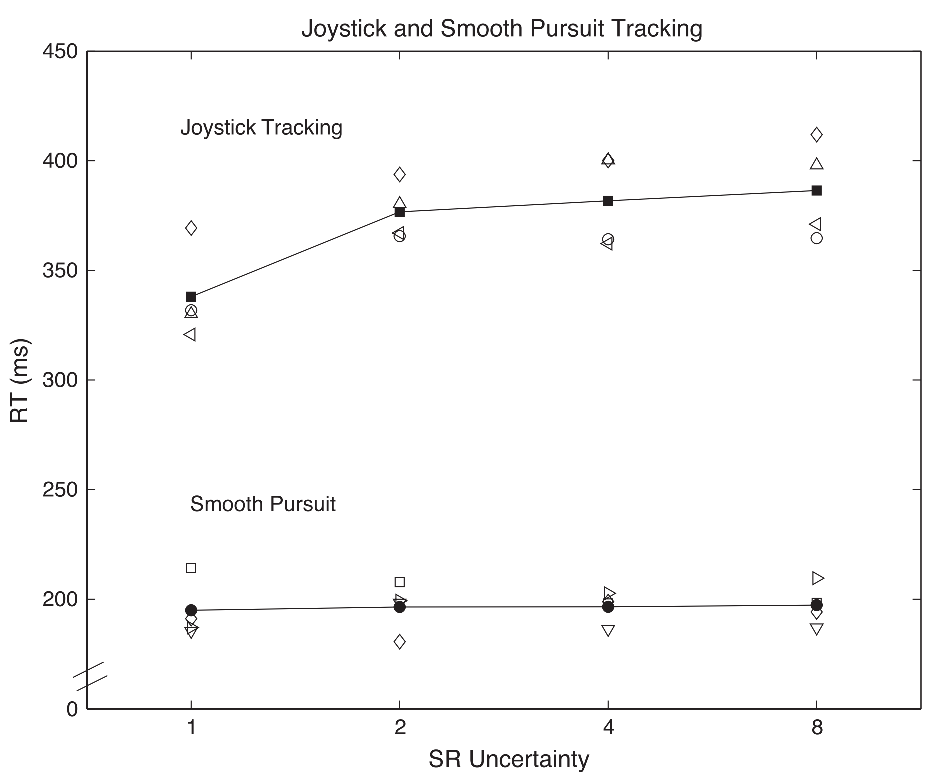

Fig. 2. Results of joystick and smooth pursuit tracking experiments with overall means (filled symbols) and individual subject means (empty symbols).

engage in smooth pursuit or if anticipatory pursuit was evident. Five percent of trials were excluded (3647 trials analyzed from a total of 3840 trials).

2. Manual tracking

Four Ss (1 male, mean age = 30 years). Subjects MB, KK are authors. The stimulus conditions were the same, but a second monitor was optically superimposed via a half-silvered mirror. The second monitor (a 17-in. fast phosphor vector graphics monitor (Hewlett-Packard) was used to provide the observers with visual feedback of the joystick movements. The joystick was comfortably positioned at hip level.

Subjects were instructed to track the moving target visually and with the joystick as quickly and accurately as possible. Visual tracking data were not collected. Joystick tracking data were digitized at 1000 Hz using Labview software. Off-line analysis was performed with Matlab software (The Mathworks, Massachusetts). Less than 3% of trials were excluded due to subjects not tracking the target or technical difficulties (3319 trials analyzed from a total of 3408 trials). The statistical results we describe below all had a statistical power of 0.95 or higher.

The design of the experiment was intended to insure that the SPEMs observed are controlled by visual input. As such, anticipatory smooth pursuit was almost never observed, presumably because of the temporal and directional uncertainties for motion onsets. The SPEM latencies were analyzed using repeated measures analysis of variance with no significant differences between the four levels of S–R uncertainty ($F(3,9)=0.72$, $p=0.97$). All subjects demonstrated the same pattern of results and the group means for each level of response uncertainty never differed by more than 2 ms (Fig. 2). The standard errors of the group means are less than 6 ms. These results demonstrate that uncertainty of motion direction does not influence the latency of SPEM.

The joystick tracking results did not follow either the Hick's law pattern seen in anti-saccades and manual key presses [7] or the zero-slope line pattern of prosaccades and smooth pursuit. The repeated measures analysis of variance was significant ($F(3,9)=24.86$, $p<0.001$). Simple RT showed the fastest RTs while the two, four and eight choice response conditions were significantly slower, as determined by post hoc least squares methods pairwise comparisons. The choice RT values [2,4,6] were not significantly different (Fig. 2).

Smooth pursuit eye movements show no effect of S–R uncertainty. Like saccades, SPEM motor programs appear to be automatically accessed by their eliciting stimuli. Manual tracking does not conform to Hick's law either, but does show a significant cost of choice motor programming over simple RTs. The resulting step function suggests that when the direction of target motion is known in advance, the tracking movements can be pre-programmed resulting in a reduction in RT. Subjects appear to pay a flat rate for making a choice regardless of how many S–R choices are available. We conclude that in the one target condition, a single activated motor plan is sufficient for task performance and accounts for rapid simple RTs. In the choice conditions, motor programming appears to require a time-consuming selection process. However, unlike many other types of manual responses [1,7], there is no additional cost in RT incurred beyond 2 response alternatives.

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