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EFFECTS OF ACOUSTIC STARTLE STIMULI ON INTERCEPTIVE ACTION

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Abstract—In reaction time (RT) tasks, presentation of a startling acoustic stimulus (SAS) together with a visual imperative stimulus can dramatically reduce RT while leaving response execution unchanged. It has been suggested that a prepared motor response program is triggered early by the SAS but is not otherwise affected. Movements aimed at intercepting moving targets are usually considered to be similarly governed by a prepared program. This program is triggered when visual stimulus information about the time to arrival of the moving target reaches a specific criterion. We investigated whether a SAS could also trigger such a movement. Human experimental participants were trained to hit moving targets with movements of a specific duration. This permitted an estimate of when movement would begin (expected onset time). Startling and sub-startle threshold acoustic probe stimuli were delivered unexpectedly among control trials: 65, 85, 115 and 135 ms prior to expected onset (10:1 ratio of control to probe trials). Results showed that startling probe stimuli at 85 and 115 ms produced early response onsets but not those at 65 or 135 ms. Sub-threshold stimuli at 115 and 135 ms also produced early onsets. Startle probes led to an increased vigor in the response, but sub-threshold probes had no detectable effects. These data can be explained by a simple model in which preparatory, response-related activation builds up in the circuits responsible for generating motor commands in anticipation of the GO command. If early triggering by the acoustic probes is the mechanism underlying the findings, then the data support the hypothesis that rapid interceptions are governed by a motor program. © 2006 Published by Elsevier Ltd on behalf of IBRO.

Key words: human, motor control, movement, startle, interception, timing.

In simple reaction time (RT) tasks, participants make a brief response as fast as possible following presentation of an imperative stimulus (IS). Standard models of these tasks have the structure shown in Fig. 1A (Luce, 1986); when the IS is detected, a GO command is issued that triggers a response program (Fig. 1B shows the temporal sequence of events). Recent work has shown that presenting a startling auditory stimulus (SAS) at the same time as a visual IS in a RT task can dramatically reduce RT while leaving a ballistic response relatively unaffected (Valls-Solé et al., 1999). This suggests that the SAS triggers the response program early without otherwise altering it (Carlsen et al., 2004; Valls-Solé et al., 1999). To explain RT reduction, Valls-Solé et al. (1999) proposed that activity evoked by a SAS travels to the program circuits via a subcortical pathway that is faster than the visual pathway.

If startle stimuli trigger motor programs as proposed, then they may be able to trigger movements in other, non-RT tasks. A candidate is intercepting a fast moving target, which appears to involve triggering by specific stimulus events (Lacquaniti and Maioli, 1989; Merchant et al., 2004). Interceptions of this sort are made when playing tennis strokes and hitting baseballs and are executed with brief movements that often last less than 250 ms from initiation to contact (Watts and Bahill, 1990). The short movement time (MT) and high velocity of these actions suggest that they are ballistic and controlled by a program (Schmidt, 1988; Tyldesley and Whiting, 1975). The program determines the time it will take to move from the start location to the interception location (the MT). Triggering of the program must be timed very precisely—often well within ±10 ms—if a successful contact is to be made (Regan, 1992; Watts and Bahill, 1990). The right moment to trigger the program depends upon the MT: at the moment the movement starts, the time the target will take to reach the interception location—its time-to-contact (TTC)—must be the same as the MT. Triggering at the right moment can be achieved by issuing a GO command when visual information about the target's TTC is determined to have reached a criterion value matched to the MT (Lacquaniti et al., 1993; Tresilian, 2005). Fig. 1C shows the structure of the program model; panel D shows the temporal sequence of events that occur during an interception. The model's structure is similar to that of the RT model (Fig. 1A) suggesting that a SAS may be able to trigger an interceptive action in the same way as it triggers a RT response. If so, the program model predicts that the results will be similar to those from RT experiments: kinematic and electromyographic (EMG) measures in responses triggered early by startle stimuli will be indistinguishable from those in responses triggered normally. Since the MT is predicted to be unaffected in early triggered responses, the effector is predicted to arrive at the interception location early, producing an early temporal error (TE).

An alternative to the program model is the prospective control model in which sensory input is directly transformed into motor commands (Lee et al., 1983; Peper

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Abbreviations: AD, anterior deltoid; CTL, control; EMG, electromyography/electromyographic; IRED, infrared light emitting diode; IS, imperative stimulus; MO, movement onset; MT, movement time; OOc, orbicularis oculi; RT, reaction time; SAS, startling auditory stimulus; SCM, sternocleidomastoid; TE, temporal error; t_s, target strike time; TTC, time to contact.

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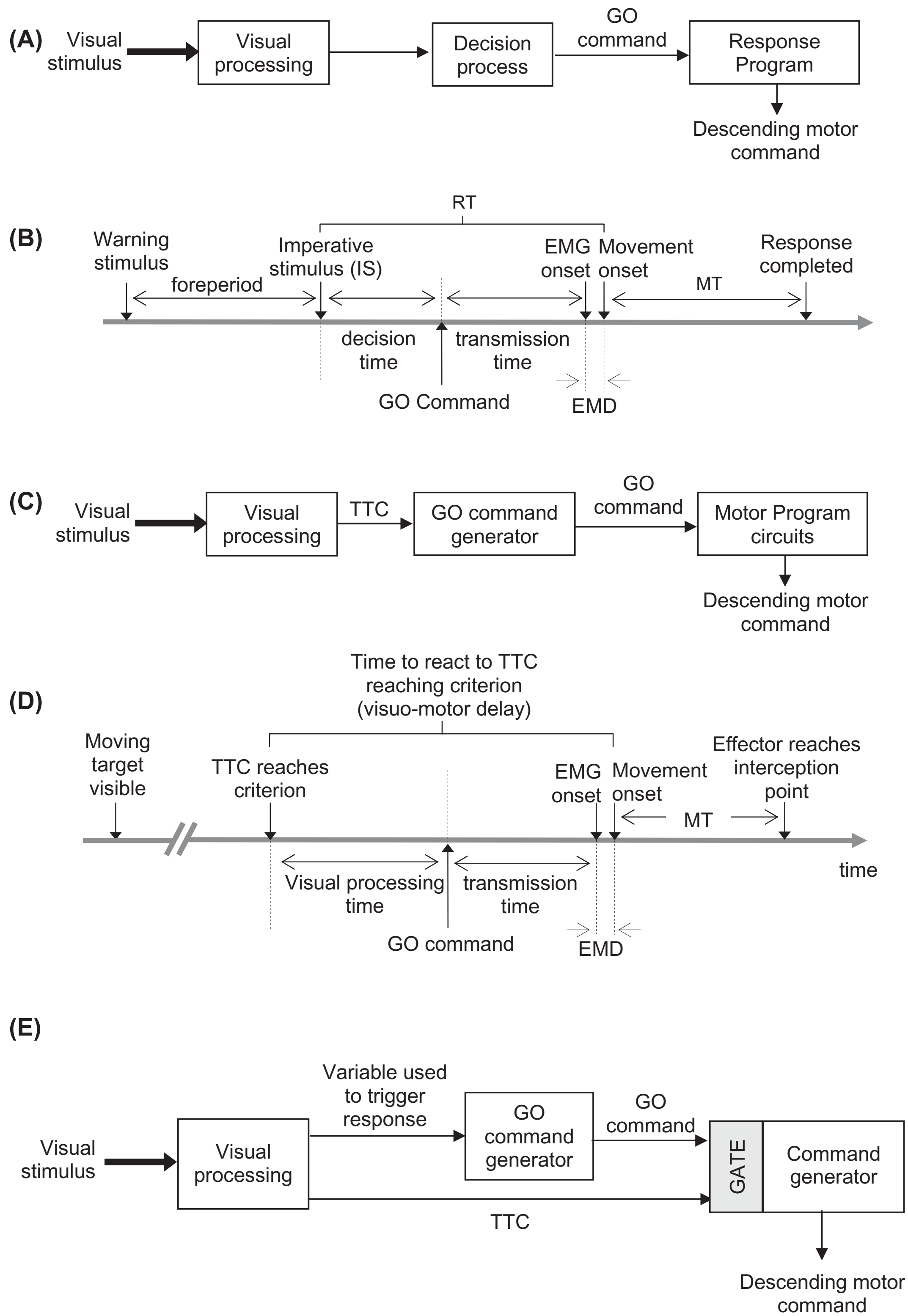

Fig. 1. (A) Functional block diagram of the standard model of RT tasks. (B) Sequence of events in a simple RT experiment: a warning stimulus is presented first, followed by the IS. The GO command that triggers the response program is issued once the decision that the IS has been presented is made (EMD=electromechanical delay). (C) Block diagram of the program model of interception. Visual processing mechanisms extract time to contact (TTC) information from the stimulus and pass it to the GO command generator which outputs a command to the motor program circuits when TTC reaches the preset criterion. (D) Sequence of events in the program model. When the TTC of the moving target reaches criterion (a stimulus event) some time is needed to process the information and send a GO command to the motor program (the visual processing and transmission time). (F) Simple block diagram of the basic structure of the prospective model. The GO signal is shown as a trigger signal that opens a gate allowing the perceptual TTC input signal to flow into the command generator. A variety of implementations of the model are possible (Dessing et al., 2002), but the basic idea is as shown.