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Strategies for stimulus selective stopping in the elderly

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ABSTRACT

This study consisted of two primary aims: (1) to determine if different age groups exhibited different strategies (based on their behavioral reaction time [RT] patterns) while performing a stop-signal task and (2) whether there were age-related differences in reactive and/or proactive control processes. Twenty-four younger adults (20–30 years) and 24 older adults (61–76 years) participated in this study. Participants performed a stop-signal task, which included a choice RT block, global stop-signal block, and stimulus-selective stop-signal block. Participants' strategies were classified using the Bayes factor to support or reject the null hypotheses at the individual level based on paired comparisons among the mean no-signal, signal-respond, and ignore RTs. We found that older adults used a similar pattern of strategies as younger adults in performing a stimulus-selective stop-signal task; most of them utilized either the Stop then Discriminate strategy or Discriminate then Stop strategy with dependency between go and stop processing. In addition, while older adults exhibited an impaired reactive control deficiency reflected on their increased stop-signal RTs in the stimulus-selective stop-signal task, they did not show an impaired proactive control process because their go trials' RT differences between the choice RT and stop-signal blocks did not differ significantly from those of young adults.

1. Introduction

Response inhibition refers to the ability to suppress an already-activated or on-going response when no longer required or when in danger; it is a crucial survival skill. Therefore, it is important to examine if this crucial behavior is maintained, deteriorated, or modified with age. A conventional laboratory approach to studying response inhibition is the stop-signal paradigm (Logan & Cowan, 1984). In the stop-signal paradigm, participants are typically presented with a stimulus requiring a speeded left- vs. right-hand response (choice). In some trials, a stop-signal is presented occasionally and unpredictably within a few hundred milliseconds (such as 150–600 ms) following the onset of a stimulus indicating that such a response should be withheld. The speed of stopping ("unobservable" latency of the stop process) in this paradigm refers to the stop-signal reaction time (SSRT), which is best determined by subtracting the stop-signal delay from the go reaction time (RT) at the dissection point (the median of the go RT distribution) in which the probabilities of inhibition and response are equal to 0.5 (Band, van der Molen, & Logan, 2003). This method of estimating the SSRT is primarily based on the assumption of the independent race model (Logan, 1981; Logan & Cowan, 1984).

According to the independent race model, the stop-signal paradigm can be modeled as a "horse race" between a go process that is triggered by a go stimulus and a stop process that is triggered by the presentation of the stop signal. Response inhibition is successful when the stop process finishes before the go process in a signal presence trial, and no response is emitted. When the go process finishes before the stop process, response inhibition is unsuccessful, and the response is incorrectly emitted. Using this concept, Logan (1981) suggested that the "unobservable" latency of the stop process (such as the SSRT) could be estimated. Based on this idea, most stop-signal studies focus mainly on the SSRT as an index of inhibitory control (also known as reactive control).

Although the vast majority of stop-signal studies described in the literature support the independent race model (Verbruggen & Logan, 2009a), research has also shown that the empirical data collected from some stop-signal scenarios such as selective stop-signal tasks (Bissett & Logan, 2014) or a complex version of selective stop-change paradigm[1] (Verbruggen & Logan, 2009a, 2015) might violate the predictions of the independent horse-race model to challenge the validity of

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[1] In a simple stop-change task, participants are instructed to stop an originally planned go response and then execute an alternative 'change' response whenever a signal occurs (Verbruggen & Logan, 2009a, 2015); whereas in a selective stop-change task, participants are further required to discriminate whether to stop and change the planned go response if one of the signals occurs (valid signal) or to execute the planned go response if the other signal occurs (invalid signal). A complex version of the selective stop-change refers to the condition when the stop-signal rules change frequently (known as varied-mapping condition in Verbruggen & Logan, 2015). In simple stop-change tasks, the independence assumption is not violated. Yet in selective stop-change tasks, the dependence assumption is violated especially when the rules change frequently.

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the conventional SSRT estimation in some cases. The selective stopping paradigm (here we specifically refer to "stimulus" selective stopping task,[2] SST) differs from the simple stop-signal paradigm (i.e., stop all responses when a stop signal occurs; here we refer to global stopping task, GST) involving two stop signals. One stop-signal tells participants to stop their responses, and the other stop-signal tells participants to ignore the signal and continue responding.

With the stimulus-selective stopping task, Bissett and Logan (2014) discovered that there might be individual differences in task-performing strategies among young adults. This suggests an individual-subject rather than group approach to classification. They identified at least two plausible strategies. The first type was the "Discriminate then Stop" strategy, in which participants discriminated the signal before deciding to stop. Bissett and Logan (2014) later distinguished two variants of this strategy: (1) Independent Discriminate then Stop and (2) Dependent Discriminate then Stop. The former variant accords with the conventional horse-race model in which going and stopping processes are independent (Logan & Cowan, 1984). In contrast, Dependent Discriminate then Stop violates the assumption of the independent horse-race model in which the requirement to discriminate stop and ignore signals interacts with the go process and prolongs go RT whenever a signal occurs. The second strategy is "Stop then Discriminate", in which participants inhibit the response whenever a signal occurs and then discriminate the signal to determine whether to respond or withhold (De Jong, Coles, & Logan, 1995).

To the best of our knowledge, there are no studies about aging (e.g., Bedard et al., 2002; Van de Laar, van den Wildenberg, van Boxtel, & van der Molen, 2011) that have directly studied whether performing these selective stop-signal paradigms changes with age using an individual-subject approach as discussed in Bissett and Logan (2014). For example, it is likely that older adults use the faster non-selective stopping mechanism (Stop then Discriminate strategy) more frequently than young adults to facilitate their inhibition. Most literature about aging has examined older adults' inhibition function via a simple stop-signal task in which the SSRT estimation has largely agreed with the prediction of the independent horse-race model (Anguera & Gazzaley, 2012; Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Kray, Kipp, & Karbach, 2009; May & Hasher, 1998; Ridderinkhof, Band, & Logan, 1999; Williams, Ponesse, Schachar, Logan, & Tannock, 1999). Thus, the issue of different performance strategies is less concerned with a simple stop-signal task (but see Verbruggen & Logan, 2015 for a different point of view to be elaborated in the Discussion). However, this simple stop-signal task does not capture adaptive control process as often required in everyday life scenarios (Aron, 2011).

One representative scenario is driving. For example, unexpected road conditions (such as a pool of water versus a physical obstruction) require that the driver quickly decides whether it is better to keep driving or to stop. Such adaptive acts of control depend on an intricate interplay between activation and inhibitory control and agree with a much more flexible inhibition process than a non-selective, stop-all inhibition. The stimulus-selective stop-signal task in the laboratory requires additional discriminating stop signals to be identified as opposed to ignored signals. As such, it may be more ecologically valid and more sensitive to aging than a simple stop-signal task. Somewhat surprisingly, very few studies have yet to examine age-related inhibition via the selective stop paradigm. Furthermore, those studies (Bedard et al., 2002; Van de Laar et al., 2011) have not employed the individual-subject approach to classify performance strategies. Hence, this study will fill this gap.

One major aim of this study was to distinguish whether different age groups exhibited different strategy distributions for the stimulus-selective stop-signal tasks based on analyses at the level of individual-subject behavioral RTs. Bissett and Logan (2014) focused on three behavioral measures collected from the stimulus-selective stop-signal task to delineate these three strategies: (1) no-signal RT; (2) failed-to-stop RT; and (3) ignore RT. Younger adults rarely used the Discriminate then Stop strategy with independence between going and stopping (Independent Discriminate then Stop). Rather, the non-selective stopping strategy (All Stop then Discriminate) or a variation of the Discriminate then Stop strategy with dependence between going and stopping (Dependent Discriminate then Stop) was a more common choice for that group.

Hence, it was interesting to study if the elderly have similar or different types of performance strategies than younger adults. In addition to examining age-related reactive control and classifying performance strategies based on RT patterns, we also examined age-related proactive controls. The importance of examining both reactive and proactive controls in aging research has been advocated by Braver (2012) using other task paradigms (such as AX version of the continuous performance task, AX-CPT[3]) in which a dual-mechanisms for the control framework has been proposed. According to the dual mechanism of cognitive control, proactive control refers to active maintenance of goal-relevant information before performing a task event that requires sustained monitoring. Reactive control refers to a mechanism that is only recruited to suppress interference that has originated from specific events. Braver and colleagues have observed that aging populations have differential reliance on reactive versus proactive control than younger subjects. In particular, they observed that older adults preferred a reactive to proactive control strategy (Paxton, Barch, Racine, & Braver, 2008). Nevertheless, Braver (2012) also indicated that some variables and factors may bias the choice of control strategy due to the complementary computational tradeoffs between proactive and reactive controls.

For example, if the expected duration before a task event is short (the cue-probe interval in the AX-CPT task), then continuous maintenance of the task goal (proactive control) could be achieved. If the duration is long, then continuous goal maintenance may be impractical. Accordingly, older adults may not always prefer a reactive to proactive control strategy. Hence, research investigating age-related response inhibition via stop-signal tasks should also consider proactive controls in addition to reactive controls to delineate if there are age-related differences in the dual-mode control system as proposed by Braver (2012). Although some previous studies using stop-signal tasks have shown that while there is an age-related decline in reactive inhibitory control, an age-related decline in proactive inhibitory control did not necessarily occur (Kleerekooper et al., 2016; Smittenaar et al., 2015; Vink et al., 2005; Zandbelt & Vink, 2010). Conversely, Van de Laar et al. (2011) showed a different result. They demonstrated an age-related increase in proactive control. Given the discrepancy regarding age-related control, it is important to study if there are age-related differences in proactive and/or reactive inhibitory controls.

To achieve this goal, we designed three task blocks to examine both proactive and reactive control processes. While the reactive control efficacy is directly indexed by the SSRT, the proactive inhibitory control efficacy refers to the RT toward the go trials in the pure choice RT (CRT) task block versus those in the task block with a stop-signal. Both GST and SST task blocks were examined in this study. In the stop-signal experiments, the participants were instructed not to wait for a stop signal to occur. Previous research has demonstrated that participants tend to delay their response when the stop signal was inserted into the CRT blocks (Logan & Burkell, 1986). This manifests as a proactive control (such as anticipation of stopping) (Kleerekooper et al., 2016;

[2] In some stop-signal studies including this study, the ***selective*** stop-signal involves the discrimination between more than one presented stop signal (i.e., at the ***perceptual*** level with one valid stop signal and an invalid one; Sharp et al., 2010; Van de Laar et al., 2010; Van de Laar et al., 2011). In contrast, some stop-signal studies refer to the discrimination between choices of responses (i.e., at the ***motor*** level: some responses should be inhibited, but not others; Aron & Verbruggen, 2008; De Jong et al., 1995; van de Laar et al., 2010).

[3] In the AX-CPT, participants are presented with cue-probe pairs and instructed to make a target response to an X-probe, but only when it follows an A-cue.