Acta Psychologica 141 (2012) 250–260

Contents lists available at SciVerse ScienceDirect

Acta Psychologica

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

Goal-neglect links Stroop interference with working memory capacity ☆

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ARTICLE INFO

Article history:
Received 15 July 2011
Received in revised form 16 May 2012
Accepted 31 May 2012
Available online 30 June 2012

PsycINFO classification:
2300
2340
2346

Keywords:
Working memory
Stroop
Executive control
Goal-neglect
Selective attention

ABSTRACT

Relationships between Stroop interference and working memory capacity may reflect individual differences in resolving conflict, susceptibility to goal neglect, or both of these factors. We compared relationships between working memory capacity and three Stroop tasks: a classic, printed color-word Stroop task, a cross-modal Stroop, and a new version of cross-modal Stroop with a concurrent auditory monitoring component. Each of these tasks showed evidence of interference between the semantic meaning of the color word and the to-be-named color, suggesting these tasks each require resolution of interference. However, only Stroop interference in the print-based task with high proportions of congruent trials correlated significantly with working memory capacity. This evidence suggests that the relationships observed between Stroop interference and working memory capacity are primarily driven by individual differences in the propensity to actively maintain a goal.

1. Introduction

Anyone who has experienced the sensation of arriving in one room and forgetting the reason for entering it understands that in the space of mere seconds, it is possible to forget what one is doing, or to forget the goal currently motivating behavior. This phenomenon is thought to be one factor underlying Stroop interference (Kane & Engle, 2003), in addition to the competition that arises from the conflict between perceiving some color and reading the name of another color: confronted with two operations that might be performed on the stimulus, participants forget to name the ink color and read the word instead. Thus, both resolving conflict arising from the irrelevant information and maintaining activation of goals contributes to successful selective attention performance. However, working memory capacity, which is believed by many to reflect ability to control attention (e.g., Cowan et al., 2005; Kane, Bleckley, Conway, & Engle, 2001) does not always predict ability to ignore irrelevant information as expected. We aim to test the hypotheses about attention and goal neglect raised by Kane and Engle, and thereby clarify expectations about relationships between working memory capacity and selective attention using a variety of Stroop tasks to measure selective attention in contexts varying in their propensity to induce goal neglect and in the ease of goal recovery following an attentional lapse.

Kane and Engle (2003) compared groups of participants with extremely low or high working memory capacity on two versions of Stroop task, one in which the ink color and word were congruent on the majority of trials, and one in which the ink color and word were rarely or never congruent. They observed large differences in error rates between low- and high-capacity extreme groups as a function of the proportion of congruent Stroop trials: when most trials included congruent ink colors and words, the low-capacity individuals committed significantly more errors than the high-capacity individuals (consistently with the expectations of Long and Prat (2002), that low-capacity individuals will not allocate much attention to maintaining the task goal), but when the ink color and word were usually incongruent, low- and high-capacity individuals did not differ in error rates. Kane and Engle suggested that the rarely-congruent context supported the ink-color naming goal best because reading the word would usually result in an error whereas in the frequently-congruent context, errors were rarely a consequence for reading the word because doing so

☆ The research described in this manuscript was completed in partial fulfillment of the M.A. degree requirements of Jody Wiggers. Thanks to Gerdien Boven, Malte Bieler, Rieka Buggentien, Andrej Krakau, Irene Krap, Helene Meißner, Anne Muth, Sophia Oelmann, Nelly Rahmede, and Michael Wolff for assistance with data collection. Jill T. Shelton is now at the Department of Behavioral and Social Sciences, Lee University, Cleveland, TN and Sharon Eaves is now at the Department of Social Sciences, Shawnee State University, Portsmouth, OH.

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doi:10.1016/j.actpsy.2012.05.013

usually produced the correct response. The group differences they uncovered suggested that this contextual support for goal maintenance was critical only for the low-capacity individuals; high-capacity individuals seemed to maintain the goal of naming the ink color even in the less supportive context, a finding which has been confirmed (Hutchison, 2011). This proposition was also supported by reductions in errors by low-capacity individuals when they completed the frequently-congruent block after the rarely-congruent block. Kane and Engle suggested that individual differences in selective attention, as measured by Stroop interference, depend on individual differences in maintaining the task goal, perhaps in addition to individual variability in resolving the response competition evoked by task-irrelevant information.

This distinction between maintaining a task goal and attending to some stimulus while excluding another may potentially explain the perplexing relationships observed between working memory capacity and the ability to ignore distracting information. Controlled attention views of working memory capacity predict that individuals with high working memory capacity will more effectively exclude task-irrelevant information from mind than individuals with low working memory capacity. This has been demonstrated in dichotic listening, with low-capacity individuals noticing their name in the unattended channel more frequently than high-capacity individuals (Conway, Cowan, & Bunting, 2001). Visual change detection research also suggests that memory capacity and ability to filter task-irrelevant distractors are correlated (Vogel, McCullough, & Machizawa, 2005). However, evidence from two logically similar methods, the irrelevant sound paradigm and the cross-modal Stroop paradigm, is mixed or contradictory. In both of these paradigms, robust impairing effects of auditory distractors on performance are observed, but these effects do not consistently correlate with working memory capacity.

A critical difference between selective attention tasks that correlate with working memory capacity and selective attention tasks that do not could be the level of support for goal recovery offered by the task's context. In the irrelevant sound paradigm, serial memory performance is compared for visually-presented lists that are delivered in conditions of silence or during the auditory presentation of irrelevant words or tones. Elliott and Cowan (2005) examined relationships between memory span and the difference between list recall in silence or with irrelevant sounds, and only sometimes observed small correlations between working memory span and irrelevant sound effects (ISEs). Beaman (2004) examined relationships between operation span scores and the size of an ISE on memory for lists of digits or words, and found no difference between the size of the ISE for individuals with high versus low working memory capacity; in fact, the average ISE for high-capacity individuals was sometimes numerically larger than that for low-capacity individuals. In Beaman's series of studies, irrelevant speech only differentially impaired recall performance of low-capacity individuals when the irrelevant words were semantically related to the memoranda; under this circumstance, low-capacity individuals were more likely to recall a related, spoken item as though it were one of the studied memoranda. Possibly, when the lists contained semantically related words, keeping track of which list should be attended required more attention. Elliott, Barrilleaux, and Cowan (2006) showed using regression that the presence of irrelevant sounds affected low-capacity participants more than high-capacity participants. Even so, this significant result held only for operation span and not for running span, which should also measure working memory capacity, and the proportions of variance that could be accounted for by this relationship were small. Thus, the costs of resolving conflict between irrelevant sounds and memoranda do not show a consistent pattern of relationships with working memory capacity, despite predictions that they should.

Importantly, there is currently no evidence suggesting that individual differences in working memory affect Stroop interference as measured by cross-modal Stroop tasks. In cross-modal Stroop tasks, participants name the color of a square while distracting sounds are presented (e.g., Cowan & Barron, 1987; Elliott & Cowan, 2001; Elliott, Cowan, & Valle-Inclan, 1998). When the distracting sound is a color word whose meaning is incongruent with the color of the to-be-named square, significant slowing in color naming is observed compared with color-naming speed with no distracting sound or with a congruent color word. Although this slowing is not as large as that observed in printed-word Stroop tasks, cross-modal Stroop produces scale changes between incongruent and neutral response time distributions similar to those observed with print Stroop (Elliott, Morey, Morey, Eaves, & Shelton, in prep.). This is consistent with the idea that in both the print and cross-modal Stroop tasks, slowing occurs because of conflict between the semantic meaning of the irrelevant word and the goal to name the color. However, no previous study measuring cross-modal Stroop interference and working memory capacity has uncovered any evidence that cross-modal Stroop interference and working memory capacity are negatively correlated (Elliott et al., 2006), a prediction that would follow logically from the supposition that working memory tasks measure one's ability to effectively cope with interference. Moreover, facilitation of congruent words on color naming is rarely observed during cross-modal Stroop, though such facilitation is consistently found in print-based Stroop tasks, even when the to-be-named color and the to-be-ignored word are spatially (MacLeod, 1998; Spieler, Balota, & Faust, 2000) or temporally (Roelofs, 2010) separated. Although facilitation may in part occur because of converging information (see Roelofs, 2010), facilitation may also reflect trials on which participants forgot that their goal was to name the color and instead quickly read the word (MacLeod & MacDonald, 2000). The absence of facilitation in cross-modal Stroop may suggest that goal recovery is less of a problem during cross-modal than print-based Stroop, but this task difference has not previously been examined.

The absence of any relationship between cross-modal Stroop interference and working memory capacity and the inconsistency of relationships between the size of ISEs and working memory capacity is surprising if one believes that working memory capacity is critically related to controlling attention, and that controlling attention is necessary for efficiently resolving conflicts between attended and irrelevant information. However, while performance in dichotic listening, cross-modal Stroop, and print-based Stroop tasks reflects some level of interference resolution, these tasks may differ in the level of contextual support typically provided for maintaining the appropriate task goal. Consider the situation presented in the cross-modal Stroop paradigm, supposing that with some frequency, participants' attention will lapse and they will momentarily forget the goal to name colors. In this scenario, the participant recovers from an attentional lapse, focuses on the screen and sees a colored square. It is difficult to imagine what the participant would consider doing with this colored square besides naming the color; no competitive alternative, such as inadvertently reading the word in print-based Stroop, is apparent. Cross-modal Stroop is logically similar in this respect to spatially-separated Stroop paradigms. Evidence suggests that compared to traditional administrations of print-based Stroop, spatially-separated Stroop offers a context more supportive for reducing the impact of goal neglect on Stroop interference, reducing the incidence of very slow responses that might reflect attentional lapses rather than only interference resolution processes (Kane & Engle, 2003; Spieler, Balota, & Faust, 2000). Cross-modal Stroop is an even more drastic example, because there is no visually-presented word at all to be read. If the variation that is shared between print-based Stroop and working memory capacity reflects differences in the tendency to forget that the goal is to name the ink color in addition to individual differences in the ability to resolve conflict between the semantic meaning of the ink color and the intended word response, then the absence of any relationship between cross-modal Stroop and working