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Goal neglect, fluid intelligence and processing speed: Manipulating instruction load and inter-stimulus interval

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ABSTRACT

Goal maintenance is the process where task rules and instructions are kept active to exert their control on behavior. When this process fails, an individual may ignore a rule while performing the task, despite being able to describe it after task completion. Previous research has suggested that the goal maintenance system is limited by the number of concurrent rules which can be maintained during a task, and that this limit is dependent on an individual's level of fluid intelligence. However, the speed at which an individual can process information may also limit their ability to use task rules when the task demands them. In the present study, four experiments manipulated the number of instructions to be maintained by younger and older adults and examined whether performance on a rapid letter-monitoring task was predicted by individual differences in fluid intelligence or processing speed. Fluid intelligence played little role in determining how frequently rules were ignored during the task, regardless of the number of rules to be maintained. In contrast, processing speed predicted the rate of goal neglect in older adults, where increasing the presentation rate of the letter-monitoring task increased goal neglect. These findings suggest that goal maintenance may be limited by the speed at which it can operate.

1. Introduction

Goal maintenance is the ability to keep task-relevant rules and instructions active and accessible in working memory while performing a task, so that they may control and guide appropriate behavior. Goal neglect occurs when these rules and instructions are ignored, despite the task requirements being clearly understood and kept in mind. The phenomenon of goal neglect has been reported in patients with lesions in the frontal lobes (Duncan, Burgess, & Emslie, 1995; Luria, 1966; Milner, 1963) but also in healthy individuals (Altamirano, Miyake, & Whitmer, 2010; Duncan, Emslie, Williams, Johnson, & Freer, 1996; Duncan et al., 2008; Preacher & Hayes, 2004; Towse, Lewis, & Knowles, 2007). It manifests as an overall difficulty obeying novel rules (e.g., Duncan, Schramm, Thompson, & Dumontheil, 2012) or a failure to correctly complete the task (Duncan et al., 1996).

Goal neglect has been considered to be the result of over-taxing a limited capacity system reliant on working memory (Duncan et al., 2008; Kane & Engle, 2003). The nature of this limitation has been investigated in several ways. Using a Stroop task, Kane and Engle (2003) have shown that the goal maintenance system is limited by the amount of competition between rules that it can control at any one time. When a greater proportion of congruent compared to incongruent color-ink trials are presented, the word-naming goal provides too much competition for the color-naming goal. The resulting neglect of the color-naming goal is problematic during incongruent trials, as only color-naming responses are correct (see also Morey et al., 2012). In contrast, using a letter- and number-monitoring task, Duncan et al. (2008), Experiment 3), have shown that the goal maintenance system is limited in the number of rules that it can keep active at any one time. Participants were presented with two subtask blocks – one in which pairs of letters appeared and one in which pairs of numbers appeared. Each subtask had specific instructions, requiring participants to either report letters or to sum numbers while only attending to one side of the pair. The relevant side was indicated by one cue presented at the start of the trial sequence and one cue presented near the end of the trial sequence. A mismatch in the direction indicated by the first and the second side cues would require participants to switch sides during the trial (e.g., first cue: watch right, second cue: watch left). Goal neglect was observed as a tendency to ignore the second cue when it indicated a switch and continue to respond to the stimuli on the initial side. Duncan et al. (2008) reported that this failure to follow the second side cue was more frequent if participants received instructions for both the letter-

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and number-subtask blocks at the start of the experiment, rather than receiving the relevant instructions at the beginning of each subtask. Increasing the number of instructions to be maintained increased the load placed on the goal maintenance system, and led to frequent neglect of a specific task rule.

Research has attempted to identify the cognitive abilities associated with goal neglect under high goal maintenance demands. In the letter- and number-monitoring task, Duncan et al. (2008) reported that the tendency to neglect the side-relevant task rules when more instructions had to be maintained (i.e., instruction load effects) was more prominent in individuals from the lower-end of the general fluid intelligence (gF) distribution. As a result, Duncan et al. proposed that gF supports the ability to maintain and follow a larger set of complex task rules, with high levels of gF resulting in improved goal maintenance abilities. This effect of introducing additional irrelevant instructions, and its association with gF, has since been demonstrated in other complex tasks (e.g., Bhandari & Duncan, 2014; Roberts & Anderson, 2014; Roberts, Jones, Davis, Ly, & Anderson, 2014).

Despite the reported association between the ability to deal with more instructions and gF, there has been little consideration of the role that other cognitive factors might play in goal neglect. One such factor is processing speed. Processing speed is a general cognitive factor which has been implicated in a wide range of complex behaviors (e.g., Johnson & Deary, 2011; Salthouse, 2005), such as the fast and efficient use of color-word instructions in the Stroop task (e.g., Salthouse & Meinz, 1995). In terms of goal maintenance, it is possible that enacting the relevant task goal (and avoiding goal neglect) depends on the speed at which the goal maintenance system can alter the attentional bias afforded to particular rules (Notebaert, Gevers, Verbruggen, & Liefooghe, 2006; Sharma, Booth, Brown, & Huguet, 2010). As gF and processing speed are strongly correlated (e.g., Bugg, Zook, DeLosh, Davalos, & Davis, 2006; Jensen, 2006; Johnson & Deary, 2011), this raises the possibility that previous studies showing a link between goal neglect and gF are actually measuring processing speed.

2. A combined analysis of three experiments

In the current study, we further explore the relationship between goal neglect, goal maintenance load, and both gF and processing speed. Initially, we present a series of three experiments which manipulated goal maintenance load through the number and complexity of instructions to be maintained by participants (i.e., instruction load). Each experiment presented participants with either 3 task instructions (low instruction load) or more task instructions (4 or 5 instructions; high instruction load). Although the three experiments manipulated instruction load in subtly different ways, they adopted very similar methodology and involved very similar groups of participants. As such, they are reported together to facilitate comparisons between the conditions and to improve statistical power.

The contribution of both gF and processing speed to goal neglect was assessed across the 3 experiments. If, as suggested by previous work (e.g., Duncan et al., 1996), higher gF is related to the ability to maintain more task rules, then associations between gF test scores and the rate of goal neglect should be particularly strong when the instruction load is high. Instead, if processing speed is related to improved goal maintenance abilities, then controlling for individual differences in processing speed should attenuate any association between gF and goal neglect.

We examined the frequency of goal neglect separately in two age groups: younger and older adults. Several goal maintenance studies to date (e.g., Duncan et al., 2008) have recruited middle-aged or older adults in order to gain a wider distribution of gF scores, which is partly the result of age-related declines in gF (Horn & Cattell, 1967). However, declines in gF are accompanied by age-related slowing (e.g., Salthouse, 1996; Salthouse & Meinz, 1995), and statistically controlling for processing speeds has been shown to attenuate age-related differences on goal maintenance tasks (Fisk & Warr, 1996). Furthermore, the relationship between gF and processing speed is particularly strong in older adults (Bugg et al., 2006). It is therefore unclear whether individual differences in gF and processing speed are independent predictors of goal neglect in older adults, and whether younger adults might show similar associations despite their intact abilities. Age differences were not directly assessed, as more frequent goal neglect with increased instruction load should be observable in any individual who demonstrates lower levels of gF or processing speed, regardless of age (see Duncan et al., 2012).

2.1. Methods

2.1.1. Participants

A power analysis based on the effect size of the interaction between instruction load and gF (d = 0.8) reported in Duncan et al. (2008) suggested that a minimum of 21 participants were required in each instruction load condition to achieve a power of 0.8.

In the first experiment, 48 older adults (aged 60–78 years) and 66 younger adults (aged 18–32 years) were recruited. In the second experiment, 44 older adults (aged 61–80 years) and 44 younger adults (aged 18–35 years) were recruited. In the third experiment, 41 younger adults (aged 18–34 years) were recruited; no older adults took part in this experiment. None of the participants took part in more than one of the experiments described, thus ensuring that the tasks and their rules were novel. Tables 1 and 2 provide the demographic information for younger and older adults in each condition.

Table 1
Means and standard deviations (SD) for the younger participants performing in Experiments 1, 2 and 3.

	Experiment 1						Experiment 2				Experiment 3			
	3 Instructions		4 Instructions		5 Instructions		3 Instructions		4 Instructions		3 Instructions		4 Instructions	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Age (years)	21.68	3.50	22.27	3.40	21.41	3.29	23.50	3.99	23.68	4.08	22.62	4.18	22.05	3.14
Gender (male/female)	9/13		8/14		4/18		5/17		10/12		7/14		4/16	
Full-time education (years)	16.00	2.60	16.57	2.03	16.18	1.92	17.64	2.98	17.05	2.65	16.81	1.99	16.30	2.00
Handedness (L/A/R)	4/1/17		2/1/19		1/0/21		4/0/18		4/0/18		1/0/20		6/1/13	
ACE-R (max = 100)	93.80	4.89	96.10	3.75	96.36	3.43	96.41	2.97	94.64	5.61	96.24	2.21	97.35	1.53
Fluid intelligence (IQ)	120.95	16.25	120.32	14.46	118.95	15.69	119.23	18.10	116.82	16.74	125.24	18.12	119.85	11.75
Inspection time (ms)	37.17	9.14	41.06	15.02	39.85	11.41	43.74	11.81	34.49	10.15	36.24	10.00	39.28	9.50
Correct reaction time (ms)	523.09	65.38	510.59	56.51	524.09	65.21	540.73	72.70	515.18	70.93	517.57	45.39	543.80	68.13
Pre-SSI proportion correct	0.99	0.01	0.98	0.02	0.99	0.02	0.98	0.03	0.99	0.02	0.98	0.03	0.98	0.03
MSE score	0.05	0.08	0.05	0.08	0.04	0.05	0.11	0.14	0.05	0.08	0.03	0.04	0.01	0.03

L = left, A = ambidextrous, R = right; ACE-R = Addenbrooke's Cognitive Examination-Revised; SSI = Second Side Error; MSE = Mean Side Error.