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Types of interference and their resolution in monolingual word production☆

Małgorzata Korko[a,*], Mark Coulson[b], Alexander Jones[c], Paul de Mornay Davies[c]

[a] Department of Education, The Maria Grzegorzewska University, ul. Szczęśliwicka 40, 02-353 Warszawa, Poland
[b] School of Psychology, Faculty of Social Sciences, University of East Anglia, Norwich Research Park, Norwich NR4 7TJ, UK
[c] Department of Psychology, School of Science and Technology, Middlesex University, The Burroughs, Hendon, London NW4 4BT, UK

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ABSTRACT

There is growing evidence that speakers recruit inhibitory control in situations of high within-language interference, e.g., when selecting from among competing lexical entries or when tailoring utterances to the communicative needs of the addressee. However, little is known about the types of cognitive control mechanisms that are involved in the speech production process. This study examines the relative contribution of various forms of interference arising at different stages of information processing as well as their control to object naming under conditions of prepotent and underdetermined competition. Eighty-nine unimpaired native English speakers completed three inhibitory control tasks (arrow flanker, Simon arrow and anti-saccade) and two object naming tasks (picture-word interference, PWI, and name agreement, NA). Analyses of mean RT and RT distribution (delta plots) showed that only the flanker effect was a significant predictor of the PWI but not NA effect, while the remaining inhibitory measures made no significant contribution to either the PWI or NA effect. Participants with smaller flanker effects, indicative of better resolution of representational conflict, were faster to name objects in the face of competing stimuli. The pattern of results suggests that delays in production can be an outcome of inefficient resolution of interference traced to intermediate rather than late stages of processing, at least as far as the PWI task is concerned.

1. Introduction

The more attentive listener will occasionally hear in the speech of his interlocutor, or indeed produce in one's own verbal output, an erroneous word or sound. For example, he may say "We will make breakfast.. Brexit, a success" (Andrew Davies addressing a party conference, October 2016) or infelicitously turn "an erotic spasm" into "an exotic spresm" (Vince Cable addressing a party conference, September 2018). What these and other naturally occurring speech errors illustrate is that a broader set of concepts, lemmas, phonological segments and/or motor response codes may become activated that potentially competes for the speaker's attention (e.g., Breining et al., 2016; Levelt et al., 1999; Wheeldon, 2003). Nonetheless, despite this background activation, the selection of words and their combination into longer utterances is fairly precise and efficient. Speaking unfolds at the rate of up to six words per second (Levelt et al., 1999), with few errors (one error per 1000 words; Levelt et al., 1999) and relatively few disfluencies (ca. six per 100 words; Fox Tree, 1995). What mechanisms allow us to manage the conflicting demands of online language production so that what comes out of one's mouth is purposeful, smooth and intelligible?

Several authors have proposed that the resolution of interference in the form of co-activated but unwanted linguistic representations is mediated by inhibitory control function (inhibition, for short) (e.g., Engelhardt et al., 2013; Shao et al., 2012; Shao et al., 2013; Shao et al., 2014; Veenstra et al., 2018). Specifically, poorer inhibition abilities have been linked to slower naming (e.g., Shao et al., 2012), diminished fluency (e.g., Engelhardt et al., 2013) and higher rates of lexical, grammatical and pragmatic errors (e.g., Veenstra et al., 2018; Wardlow, 2013). A sizeable proportion of these studies view inhibition as a general cognitive function, with little differentiation between its various types or component processes. This is problematic in light of both theoretical (e.g., Kok, 1999; Nigg, 2000; Verbruggen et al., 2014) and empirical

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* Corresponding author.
E-mail address: mkorko@aps.edu.pl (M. Korko).

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findings (e.g., Chuderski et al., 2012; Friedman & Miyake, 2004; Rey-Mermet et al., 2018; Stahl et al., 2014), which question the notion of inhibition as a single psychological construct. Where a separate mechanisms view of inhibition has been applied to language production research (e.g., selective vs. non-selective inhibition, resistance to distractor interference vs. resolution of proactive interference), the evidence is either inconclusive (e.g., differential recruitment of selective and non-selective inhibition in Shao et al., 2013 and Sikora et al., 2016; recruitment of inhibition in one production task, e.g., picture-word interference, but not the other, e.g., colour-word Stroop in Shao et al., 2015), conclusions are based solely on statistical proxies (e.g., the slope of the slowest delta segment in a distributional RT analysis taken to index selective inhibition) or behavioural proxies (e.g., greater anxiety taken to reflect reduced inhibition; Snyder et al., 2010) or the proposed classification is not always clear-cut (e.g., conflating the type and locus of interference).

With these challenges in mind and to better understand the type of inhibitory processes underlying production of words under conditions of increased interference, the current study investigated the extent to which resolution of conflict arising at distinct stages of information processing supports lexical selection across different production contexts. Motivated by the need for "more direct" (Shao et al., 2015, p. 1816) or "more independent" (de la Vega et al., 2014, p. 3) measures of inhibition, we utilised three behavioural tasks that have been described in the literature as indices of conflict at the representational (the arrow flanker task), response selection (the Simon arrow task) and response execution (the anti-saccade task) stages. We also employed two object naming tasks that are thought to reflect different inhibitory demands: the picture-word interference (PWI) task, in which a word is selected in the face of co-activated but irrelevant representations (prepotent competition), and picture naming with name agreement manipulation (henceforth, the NA task), in which an object's name is selected from among co-activated, equally legitimate response options (underdetermined competition).

Identifying the type of inhibition that is most critical to production of words under different competition demands could inform the debate about the nature of lexical access. It is still unclear whether lexical selection is hampered by co-activation of related representations, which must be suppressed for the most sought-after word to be isolated (e.g., Abdel Rahman & Melinger, 2009, 2019; Levelt et al., 1999; Piai et al., 2012; Starreveld & La Heij, 1995), or whether it proceeds independently of the "background noise", with occasional errors, delays, and disfluencies in speech interpreted as by-products of some decision processes (e.g., Dhooge & Hartsuiker, 2010, 2012; Finkbeiner & Caramazza, 2006; Mahon et al., 2007). If resolution of representational conflict plays a major role in object naming under increased competition demands, this would lend credence to competitive claims of language production. If, on the other hand, resolution of within-language interference can be explained solely or in great part by late inhibitory processes (at the level of response selection or response execution) then overt speech errors could be viewed as the outcome of an inefficient stopping mechanism (inability to stop an activated but incorrect response in its tracks) while delays in production could reflect the extra time needed to successfully engage such a mechanism at the output stage.

1.1. Types of inhibition in monolingual language production

The language production literature has traditionally conceived of inhibition as a global cognitive function, with limited consideration given to its different facets or subcomponents (see Table 1 for an overview of inhibitory control frameworks adopted in the reviewed language production studies). For example, in a communicative context, general inhibition ability predicted the use of referential expressions (Long et al., 2018; Wardlow, 2013). Speakers with superior inhibitory capacity refrained more effectively from producing modifiers that could be deemed redundant from the perspective of the listener (e.g., saying "the big circle" when two circles are visible to the speaker, but only one to the listener). Better inhibition abilities have also been linked to faster picture naming, and are thought to be engaged most of the time during the more demanding task of action naming, but only on the most difficult (slowest) trials during object naming (Shao et al., 2012).

The latent variable studies, in which a general factor of inhibition is derived from the variance in performance shared across several, often arbitrarily aggregated, inhibitory control tasks, have also argued for its involvement in aspects of language production. In Engelhardt et al. (2013), approximately 12% of the variance in utterance repairs (abandoning the original, incorrectly selected syntactic structure and replacing it with a correct phrase) was explained by individual differences in inhibitory control. Veenstra et al. (2018) found that inhibition was a significant predictor of number agreement production in ten- to twelve-year-olds. Children who experienced greater interference in the inhibitory control tasks had higher agreement error rates. In Nozari and Omaki (2018), susceptibility to interference explained 20% of the variance in the production of subject-verb agreement errors by adult speakers.

With the concept of inhibition as a global cognitive function being increasingly called into question, some attempts have been made to differentiate between its various forms in the language production domain. To study the role of inhibition in object naming, Shao et al. (2013, 2015), for example, adopted the distinction proposed by Forstmann et al. (2008) between selective and non-selective inhibition (see Table 1 for explanation of these terms). Based on this dichotomy and using a distributional reaction time analysis (delta plots), Shao et al. concluded that selective inhibition plays a role in the resolution of semantic interference in picture-word interference (Shao et al., 2013, 2015), picture naming with name agreement manipulation (Shao et al., 2014) and semantic blocking tasks, but not in the Stroop task (Shao et al., 2015). Non-selective inhibition, in turn, did not appear to underlie performance on any of these production tasks and was unrelated to selective inhibition, implying that the two were separable processes. A different conclusion was reached by Sikora et al. (2016), in whose study both selective and non-selective inhibition were involved in phrase production, although this discrepancy may have resulted from the way the semantic interference effect was calculated. To index the speaker's inhibition ability, the authors used the mean RT difference between incompatible trials (e.g., FORK-*spoon*) and compatible trials (e.g., FORK-*fork*) instead of the standard RT difference between semantically related and unrelated conditions, which may have artificially inflated the magnitude of the effect. Phrase production, e.g. saying "a green fork" is also more demanding than referring to an object with its basic name, e.g. saying "fork". The production task employed by Sikora et al. could thus have provided greater scope for non-selective inhibition to become evident.

Crowther and Martin (2014) showed distinct patterns of correlation for performance on the semantic blocking task and two inhibition tasks assessing resistance to distractor interference and resolution of proactive interference. Those showing more interference on the resistance to distractor interference measure had steeper slopes of increase in naming latencies across cycles in the related condition of the semantic blocking task, indicating that they dealt less effectively with the cumulative distractor interference. Unexpectedly, the resolution of proactive interference measure correlated negatively with the slopes of unrelated trials, reflecting repetition priming rather than inhibition of intrusive memory representations. Not only did the two inhibitory measures contribute differentially to object naming, but they were also uncorrelated, lending further support to the multi-dimensional view of inhibition.

A different classification of inhibition was endorsed by Snyder, Banich, and Munakata (2014) after Botvinick et al. (2001). Here, the authors distinguished between underdetermined and prepotent competition, linking them to dissociable inhibitory neural functions. Indirect evidence for the involvement of inhibition in the resolution of underdetermined competition comes from a pharmacological manipulation, whereby the administration of a gamma-Aminobutyric acid

Table 1
Overview of the inhibitory control frameworks applied in the language production studies.

Type of inhibition	Description	Inhibitory measure	Description	Language production measure	Description
General inhibition ability	A general ability to suppress prepotent actions and/or irrelevant information. It is measured with standard inhibitory control tasks that serve as stand-ins for global inhibition.	Arrow flanker task (e.g., Wardlow, 2013)	Participants are asked to identify the direction of the central arrow while ignoring the flanking arrows.	Perspective taking task	Participants are asked to describe an object in an object display to a listener. They either have to refer to the target object with a modifier to disambiguate it from distractor objects or refrain from using a modifier when distractor objects are occluded.
		Elevator task with distraction (e.g. Long et al., 2018)	Participants are asked to count low tones while ignoring interspersed high tones.	Perspective taking task	As above
		Stop signal task (e.g., Shao et al., 2012)	Participants respond to presented stimuli, e.g., by pressing relevant keys on the keyboard, but have to withhold their responses to a stop signal, e.g., a tone.	Speeded picture naming task	Participants are asked to name objects and actions before they disappear from view.
General inhibition ability	A general ability to suppress prepotent actions and/or irrelevant information. It is construed as a latent variable derived from the variance in performance common to a set of standard inhibitory control tasks.	Colour word Stroop task	Participants are asked to identify the colour of the target word, while ignoring the word itself.	Sentence production task	Participants are asked to produce a sentence using the names of the objects and the verb displayed on the screen. The objects are either animate or inanimate, while the verb is either in the past or past participle form. Incorrect syntactic structures (e.g., active voice) elicited by animacy manipulation must be suppressed to produce a structure that is compatible with a given verb. Disfluencies are measured.
		Stop signal task	As above		
		Hyperactivity -impulsivity questionnaire (Engelhardt et al., 2013)	Conner's behavioural rating scale, which measures executive dysfunction in everyday activities		
		Colour shape switching task	Participants are asked to select one of the two small objects that matches in either colour or shape with the large target object depending on the cue provided.	Picture description agreement task	Participants are asked to produce a sentence describing the position of objects in the display, which either match or mismatch in grammatical number.
		Fish flanker task (Veenstra et al., 2018)	Participants are asked to identify the direction in which the central fish is swimming while ignoring the flanking fish.		
		Fish flanker task	As above	Picture description agreement task	As above
		Simon task	Participants are asked to select the colour of the target object while ignoring its position on the screen.		
		Picture Stroop task	Participants are asked to name a picture with its canonical name in one block and to name it with another picture's name in another block.		
		Embedded Go/no go task (Nozari & Omaki, 2018)	Participants perform the fish flanker task and have to withhold their response when a spotted fish appears as target.		
Selective inhibition	A mechanism that serves to reduce interference between competing actions through suppression of incorrect response tendencies.	The slope of the slowest delta segment (Shao et al., 2013, 2014, 2015; Sikora et al., 2016)	The slope value of the slowest delta segment is derived from a delta-plot, an analysis of RT distribution, and is taken to index selective inhibition based on previous findings (e.g., Forstmann et al., 2008; Ridderinkhof et al. 2002; Ridderinkhof et al., 2005)	Picture-word interference task	Participants are asked to name an object while ignoring a visual or auditory distractor
				Object naming with name agreement manipulation	Participants are asked to name an object that is associated with one dominant name (high name agreement) or multiple alternative names (low name agreement).
				Semantic blocked cycling naming task	Participants are asked to repeatedly name pictures in sets of either semantically related or unrelated pictures.
Non-selective inhibition	Stopping of any motor response.	Stop signal task (Shao et al., 2013, 2014, 2015; Sikora et al., 2016)	As above		

(continued on next page)

Table 1 (*continued*)

Type of inhibition	Description	Inhibitory measure	Description	Language production measure	Description
Resistance to distractor interference	Selection of one representation or response from competing representations or responses that are derived from distracting stimuli present in the environment.	Colour word Stroop task (Crowther & Martin, 2014)	As above	Semantic blocked cycling naming task	As above
Resolution of proactive interference	Resolution of interference from persisting memory representations.	Recent negatives task (Crowther & Martin, 2014)	Participants are presented with a list of items followed by a probe, and must indicate whether the probe was in the list of items or not.		
Resolution of prepotent competition	Selection of a target word in the face of co-activated irrelevant representations	Anxiety as an indirect proxy of inhibition (Snyder, Banich, & Munakata, 2014)	Greater anxiety associated with reduced inhibitory (GABAergic) function	Semantic blocked cycling naming task	As above
Resolution of underdetermined competition	Selection of a target word in the face of co-activated task-relevant response options	Pharmacological effect of GABA agonist (midazolam) associated with increased inhibition (Snyder et al., 2010)	Based on pharmacological manipulation	Verb generation task	Participants are asked to produce a verb to a noun (e.g., ball) that affords multiple optional verbs (e.g., *kick, throw, bounce*) as opposed to a noun (e.g., *scissors*) that collocates with fewer alternative verbs.

(GABA) agonist (*midazolam*) to healthy participants resulted in more efficient lexical selection in a verb generation task (Snyder et al., 2010). Performance on word production tasks tapping prepotent competition (semantic blocking) and underdetermined competition (verb generation) was also adversely affected by anxiety, which has been linked to reduced neural inhibition (GABAergic function) in previous studies (Snyder et al., 2010; Snyder, Kaiser, et al., 2014).

1.2. *The current study*

There is thus some support for the claim that inhibitory control underlies monolingual language production. Where the findings appear to diverge is in the type of inhibitory processes that contribute to its efficacy. Some of the discrepancies in the literature may result from the way in which inhibition is construed (i.e., as a general cognitive ability or multiple cognitive constructs), the taxonomy that is applied and the nature of the production task used. The aim of this study is to further explore the various inhibitory processes that may support single word production under distinct interference conditions. In doing so, we extend previous work on the relationship between inhibitory control and lexical selection in the following ways.

First, the study takes a deconstruction approach towards the concept of inhibition, adopting an inhibitory control framework based on the temporal locus criterion, i.e., whether the resolution of interference occurs at early (sensory), intermediate (representational) or late (response selection and response execution) processing stages. This distinction corresponds most closely to the taxonomy of inhibition posited by Stahl et al. (2014), but is not dissimilar to other temporal viewpoints of selection processes (e.g., Banich, 2009). Stahl et al. (2014) provide empirical support for three distinct sources of interference: stimulus interference (i.e., distracting information in the environment that may involuntarily capture one's attention), proactive interference (i.e., goal-irrelevant cognitions or representations) and response interference (i.e., involuntarily activated, task-irrelevant response options). There is evidence for further dissociation between inhibition at the response selection and response execution level (Aron, 2011; Nee et al., 2007; Stahl et al., 2014). The former refers to the selection of a response from two equipotent response codes. The latter applies to withholding, modification or stopping of an already selected response.

Second, we employed more direct, behavioural measures of inhibition, each tapping resolution of interference at a different level of information processing. The arrow flanker task was used primarily to capture resolution of representational conflict, with incompatible trials (flanking arrows facing in the opposite direction to the middle target arrow) also imposing conflict at the level of stimulus processing, some conflict at the level of response selection (the conflicting arrows may also automatically activate competing response codes), and little to no conflict at the level of response execution (Nee et al., 2007; van den Wildenberg et al., 2010). The effect in the Simon[1] arrow task is commonly attributed to response selection processes (e.g., Lu & Proctor, 1995), while it inherently avoids interference associated with perceptual conflict (Ridderinkhof et al., 2004; van den Wildenberg et al., 2010). The arrows presented on one side of the screen may automatically trigger the activation of a motor response that corresponds to the location of the stimulus on the screen. This activation may clash with a more controlled process of mapping a different, possibly less salient, feature (direction of the arrows) on to the correct motor action. Hence conflict in the Simon task is said to arise between two response codes that are activated in parallel, one of which must be suppressed. The anti-saccade task is a measure of the ability to stop an already initiated action (an incorrect eye saccade) rather than an ability to select between two competing responses (pro- and anti-saccade) (Friedman & Miyake, 2004; Munoz & Everling, 2004; Pettigrew & Martin, 2014; Stahl et al., 2014). Moreover, stopping occurs in response to an internally generated goal as opposed to an externally presented cue as characteristic of the stop signal task, for instance (Aron et al., 2014). Performance on anti-saccade tasks is therefore thought to reflect conflict resolution at the motor output level. We did not include any measures that would specifically assess resolution of stimulus interference because neither the PWI nor the NA task involves conflict at the input level. The external word distractors in the semantically related and unrelated conditions of the PWI task were equally salient, so any effect arising from interference at the perceptual input level would be cancelled out. No external distractors that could involuntarily capture the speaker's attention, in turn, were used in the NA task.

Third, two object naming tasks were employed with different

[1] The Simon arrow task is also known in the literature as the "non-verbal Stroop" or "spatial Stroop" task. We use the term "Simon arrow task" to distinguish it from the version in which words denoting direction (e.g. RIGHT, UP) rather than arrows are used as stimuli.

inhibitory demands: the PWI task (associated with prepotent competition) and the NA task (associated with underdetermined competition). The typical PWI effect (longer response latencies and higher error rates for categorically related target-distractor pairs than for unrelated pairs) is thought to arise due to higher activation of categorically related distractor words (e.g., DOG-horse) relative to their unrelated controls (e.g., DOG-table). Essentially, distractors that belong to the same semantic category as targets are activated both indirectly by the target picture through the process of spreading activation (i.e., the processing of DOG activates its related semantic nodes, such as ANIMAL, CAT, HORSE, HAS LEGS, HAS FUR, etc. which, in turn activate their corresponding lexical representations: *animal, cat, horse*) and directly by the distractor word itself (*horse*). The lexical node *horse* thus receives activation from two sources (the target and the distractor). By comparison, an unrelated distractor (e.g., *table*) receives activation from a single source - the distractor word alone (DOG is unlikely to spread activation to *table*). A categorically related distractor is therefore a stronger competitor than an unrelated distractor, delaying the selection of the target word.

The NA task draws on the observation that low name agreement objects that are associated with multiple names (e.g., COINS could be labelled as "coins", "money", "pennies", etc.) are named more slowly than high name agreement objects with one dominant name (e.g., TOMATO is usually labelled as "tomato"). This observation holds after controlling for other psycholinguistic variables known to affect picture naming, such as frequency of occurrence and age of acquisition (e.g., Alario et al., 2004). Prolonged naming latencies in low name agreement versus high name agreement trials (the NA effect) are thought to reflect the activation of more than one lexical representation, which creates greater selection demands and potentially necessitates recruitment of cognitive resources involved in conflict resolution (e.g., Alario et al., 2004; Bose & Schafer, 2017; Hartsuiker, & Notebaert, 2010). The origins of the effect can be traced to lexical encoding, but only for objects with low name agreement due to the availability of alternative names and not visual or conceptual ambiguity (Britt et al., 2016; Vitkovitch & Tyrrell, 1995).

In addition to using different inhibitory control measures and spoken word production tasks reflecting distinct inhibitory demands, individual variation in lexical knowledge was assessed with the vocabulary subtest of the Wechsler Adult Intelligence Scale III, WAIS-III (Wechsler, 1997). The inclusion of this measure in the statistical analysis was motivated by the premise that both the PWI and NA effects are contingent on spreading activation, which varies among individuals. Activation in individuals with larger vocabularies (more robust semantic-lexical networks; Mainz et al., 2017) may spread to a greater number of neighbouring representations, inducing more competition and thereby creating an increased need for inhibitory control, compared with activation in individuals with smaller vocabularies. By including the WAIS vocabulary measure as a control variable it was possible to assess the role of inhibitory control independent of the degree to which within-language competition is induced in speakers with different vocabulary sizes. The mean RT of the neutral condition in the arrow flanker task and of the pro-saccade condition in the anti-saccade block served as a control variable to account for variation in general processing speed, which could modulate interference effects.

Furthermore, we extended the standard mean-RT-based analyses of the experimental effects obtained from the inhibitory and word production measures with analyses of the RT distribution using the delta plot technique (e.g., De Jong et al., 1994). Delta plots are graphical representations of experimental effects (typically in conflict paradigms) as a function of response speed and are used to determine whether the experimental manipulation has a larger effect on the relatively fast or relatively slow responses. They are constructed by first rank ordering RTs for each individual for each condition (congruent vs. incongruent), dividing the so ordered data points into equal-size bins (quantiles) and calculating the experimental effect (delta) for each bin. Larger effects for relatively fast responses (first segments of the delta plot) are typically demonstrated in the canonical Simon task (e.g., De Jong et al., 1994; Forstmann et al., 2008) in contrast to larger effects for relatively slow responses (last segments of the delta plot) in other conflict paradigms including the arrow-based Simon task (e.g., Luo & Proctor, 2018; Pellicano et al., 2009; for reviews, see Pratte et al., 2010; Schwarz & Miller, 2012). Based on studies with normal (e.g., Ridderinkhof, 2002b; Forstmann et al., 2008) and clinical populations (e.g., Ridderinkhof et al., 2005; Wylie et al., 2009), the negative going slopes of the delta segments have been interpreted as a sign of increased selective inhibition in accordance with the activation-suppression model (Ridderinkhof , 2002). We reasoned that the additional delta plot analyses performed on the current data would not only allow us to make distributional comparisons with previous studies, but also provide a more sensitive measure to detect an effect that could otherwise be obscured by analyses of mean RTs alone (e.g., Balota & Yap, 2011; Schwarz & Miller, 2012).

We posited that to the extent that selection from competing inputs is involved, performance assessed with the standard inhibitory control tasks should predict the magnitude of interference effects in the object naming tasks. Similarly, the slopes of the slowest delta segments in the arrow flanker and Simon arrow tasks should be related to the interference effects in the word production tasks. Individuals with steeper slopes in the arrow flanker and Simon arrow tasks, indicative of poorer inhibition, should thus show larger inference effects on the PWI and NA tasks. In addition, as each inhibitory control task captures resolution of conflict at different points in the information flow, performance on these tasks may differentially contribute to the speed with which objects are named across the two production contexts. We did not specify a priori which inhibitory component would make the strongest contribution to object naming under prepotent or underdetermined competition, although it may be speculated based on the rival (competitive versus non-competitive) accounts of the PWI effects that if performance on the PWI task is predicted mainly by late inhibitory processes (Simon arrow and anti-saccade effects), this would speak in favour of a post-lexical locus of interference and undermine the role of lexical competition. If, on the other hand, the PWI effect is predicted uniquely by representational conflict (flanker effect) this could provide support for a lexical locus of the PWI effect, and possibly for the competitive nature of word selection. To the extent that the NA effect reflects competition between competing lexical representations, its magnitude should be uniquely predicted by the flanker effect. As the task involves no external distractors, it is unlikely that late-stage aspects of selection (the Simon or the anti-saccade effect) would contribute to the NA effect, although the role for a late-stage response evaluation mechanism (e.g., whether the selected response option is most appropriate in the given context) cannot be ruled out.

2. Method

2.1. Participants

Ninety-seven native English speakers ($N_{males} = 26$; $M_{age} = 21.9$ years, $range_{age}$ 18–44 years), recruited from Middlesex University, took part in the study. All participants reported English to be their dominant language, but only those who were born in the UK or arrived in the country by the age of five years were included in the final analysis. All had normal or corrected-to-normal vision and reported no cognitive deficits and no history of neurological impairment. Eight participants were excluded from the analysis either for failing to meet the inclusion criteria, scoring below chance in the anti-saccade task or failing to complete all parts of the experiment. The final sample comprised eighty-nine participants.

2.2. General procedure

Participants were tested individually in a sound-attenuated room. After signing the consent form and completing a short demographic and language background questionnaire, participants performed three inhibitory control tasks (anti-saccade task and arrow flanker task with an embedded Simon arrow task), two object naming tasks (PWI and NA) and the WAIS vocabulary test. The order of the inhibitory control and object naming tasks was counterbalanced across participants. The WAIS vocabulary test was always administered last. All tasks except for the WAIS vocabulary test were run on a computer using *E*-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA). Responses from the inhibitory control tasks and the object naming tasks were collected using the same software. All vocal responses were audio-recorded for later scoring. Speech onset latencies in the object naming tasks were registered online via a voice key. In addition, they were coded manually using Audacity ® 2.2.1 recording and editing software to avoid unnecessary data loss (e.g. failure of the voice key to detect a response) and to correct for inaccuracies (the voice key being triggered by irrelevant noises, or being unable to detect voiceless consonants). The testing session lasted approximately 1 h.

2.3. Materials, design, procedure and analysis for individual tasks

2.3.1. Inhibitory control measures

To assess different forms of inhibitory control, we utilised three tasks: the anti-saccade task and the arrow flanker task with an embedded Simon arrow task. For visual presentation of the low and high interference conditions across these three tasks, see Fig. 1.

2.3.1.1. Anti-saccade task

2.3.1.1.1. Materials, procedure and design. We used the version of the anti-saccade task from Ortells et al. (2016) consisting of two blocks: pro-saccade and anti-saccade. In the pro-saccade block, participants must look in the direction of a peripheral stimulus (an asterisk that flashes either to the right or left of the fixation point) in order to identify the target letter (Q or O) that appears briefly in the same location. In the anti-saccade block, participants must look away from the peripheral stimulus as quickly as possible, since the target letter appears on the opposite side of the asterisk. Participants pressed the designated keys (“B” and “N”) on the keyboard using the index and middle fingers of their dominant hand. Both speed and accuracy were emphasised. All participants received 12 practice trials per block, with online feedback for incorrect responses. If a participant’s accuracy in the practice trials was lower than 50%, an additional practice block was administered. There were 96 trials in total: 48 in the anti-saccade block and 48 in the pro-saccade block. The order of the blocks was counterbalanced across participants: half received the pro-saccade block first, while half received this second. The position of the response keys was also counterbalanced across participants.

The design and the timing of trials were identical to Ortells et al. (2016) and are presented in Fig. 2.

2.3.1.1.2. Data analysis and screening. Only correct responses were included in the analysis of response latencies (24.3% of trials were removed). In addition, responses shorter than 200 ms and longer than 1700 ms and those 3 SD or more beyond individuals’ means were discarded (2.6% of the trials). The two dependent variables were the anti-saccade effects quantified as 1) mean reaction time (RT) in the anti-saccade block minus mean RT in the pro-saccade block and 2) mean error rate (ER) in the anti-saccade block minus mean ER in the pro-saccade block. Larger interference effects indicate poorer inhibitory control.

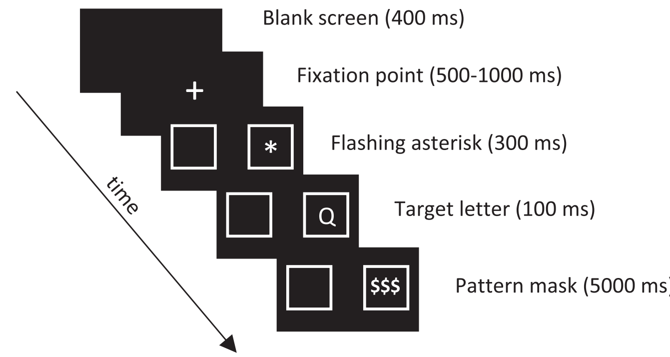

Fig. 2. Presentation order and timing of trials in the anti-saccade task.

2.3.1.2. Flanker arrow with embedded Simon arrow task

2.3.1.2.1. Materials, procedure and design. A version of the Simon task (Simon, 1967) was embedded within a version of the Eriksen flanker task (Eriksen & Eriksen, 1974). Participants were instructed to identify the direction of a target arrow flanked on each side by two irrelevant stimuli (flankers). The flankers could either be squares (neutral condition), arrows facing in the same direction as the target (stimulus-compatible) or arrows facing the opposite direction to the target (stimulus-incompatible). The stimuli could be presented in the centre of the screen (neutral condition), on the same side as the response key (response-compatible) or on the opposite side to the response key (response-incompatible). Participants were instructed to use both hands to press a designated key (“L”) on the right when the central target arrow pointed to the right and a designated key (“A”) on the left when the central target arrow pointed to the left. They were told to respond as quickly as possible without sacrificing accuracy.

There were five conditions containing 40 trials each: 1) neutral; 2) stimulus-compatible, response-compatible; 3) stimulus-incompatible, response-compatible; 4) stimulus-compatible, response-incompatible; and 5) stimulus-incompatible, response-incompatible. The trials and conditions were intermixed in a random order. The 200 trials were divided into four blocks of 50 trials each, separated by three short breaks. There were 20 practice trials with all conditions represented

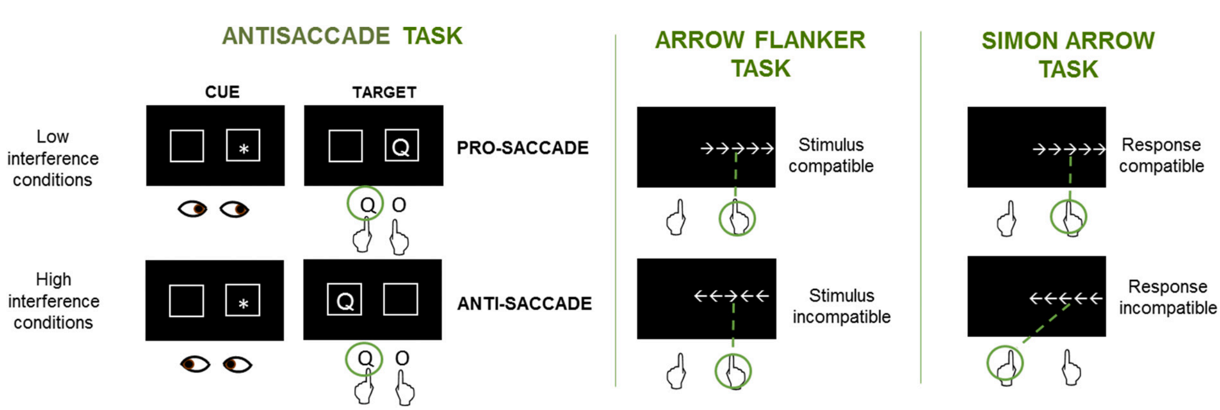

Fig. 1. Low and high interference conditions across the anti-saccade, the arrow flanker and the Simon arrow tasks.

equally. Online feedback for incorrect ("INCORRECT") and undetected ("FASTER") responses was provided during practice.

Each trial began with a 100 ms blank screen followed by a fixation point for a varied duration of 500–1400 ms. The targets and flankers were presented in 22-point, bold white font against a black background, with the spatial separation of the symbols identical to the spacing of symbols in a printed word (0.16 cm), and remained on the screen for the duration of 1700 ms or until the participant's response.

2.3.1.2.2. Data analysis. Only correct responses were included in the analysis of response latencies (7.5% of the data were removed). There were two dependent measures: 1) the arrow flanker effect expressed as the difference in mean RTs between the stimulus-incongruent, response-congruent condition and the stimulus-congruent, response-congruent condition and 2) the Simon arrow effect expressed as the mean RT difference between stimulus-congruent, response-incongruent and stimulus-congruent, response-congruent conditions. Mean error rates were also calculated for these tasks. Larger effects denote poorer inhibitory control.

2.3.2. Word production measures

2.3.2.1. Picture word interference (PWI) task

2.3.2.1.1. Materials. Sixty-two high quality colour images of objects and their normative data were taken from the Bank of Standardized Stimuli, BOSS (Brodeur et al., 2014). Eight images were used for practice. Twenty-seven served as target images and twenty-seven as filler images. The latter were used to increase the proportion of no-distractor trials to minimise participants' strategy use. All the images were scaled to 300 × 300 pixels and were presented in the centre of the screen on a white background.

In addition, sixty-two distractor words were selected from the labels of BOSS objects and from the MRC Psycholinguistic Database (Coltheart, 1981), eight to serve as distractor words for the practice trials and fifty four to serve as distractor words in the experiment. They were either categorically related to the target images or unrelated (associatively, semantically or phonologically). Association norms were obtained from the University of South Florida Free Association Norms (Nelson et al., 2004) and the Edinburgh Associative Thesaurus (Wilson, 1988). The two sets of distractor words were matched on the frequency of occurrence (CELEX), length (syllables, phonemes and letters), familiarity, imageability and association strength. These norms were obtained with the N-Watch program (Davis, 2005) and are presented in Appendix A. The pairings of the target images and the distractor words are presented in Appendix B. The distractor words were superimposed centrally on the images on a white background such that they did not obscure the images themselves. They were printed in lower case in black bold 28 Arial font.

2.3.2.1.2. Procedure. Participants were required to name the displayed images using a single name as quickly and as accurately as possible, while ignoring a distractor word when one was present. Before testing, participants completed a familiarisation phase during which all the images and their names were presented on the computer screen in a randomised order with the object's name displayed below the image. Participants were asked to read the names aloud; they then received eight practice trials containing practice images with superimposed practice distractor words. Correct feedback was provided on the computer screen if the participant produced the wrong name.

During the experimental phase, stimuli were presented in three blocks of 36 trials each, separated by two short breaks. Each block contained 9 categorically related trials, 9 unrelated trials, 9 no distractor trials and 9 filler images. Every target image appeared three times in the experiment (with categorically related distractors, with unrelated distractors and with no distractors), but only once per block. The presentation order of blocks was counterbalanced across participants, as was order of conditions across blocks. Trial presentation was pseudorandomised such that the same condition did not occur more than twice in a row and items that were semantically or phonologically related did not appear in succession.

Each trial began with a blank screen for 500 ms, followed by a fixation point with a varied duration of 500–1000 ms. The target was then presented for 3000 ms together with a distractor word (SOA = 0 ms) or until the voice key was triggered by the participant's response. A tone lasting 380 ms occurred prior to the onset of the target image. The trials are presented in Fig. 3.

2.3.2.1.3. Data analysis. Reaction times and accuracy were measured manually using Audacity ® 2.2.1 recording and editing software. The analysis of naming latencies was based only on correct responses (1.2% of the data were removed due to errors). Responses shorter than 250 ms and longer than 3000 ms as well as those falling ≥3 SD beyond individual means were excluded (2.2% of the data). To measure speech onset latency, a cursor was placed at 380 ms from the onset of the tone and moved across to the onset of the correct name produced by the participant as demonstrated in Fig. 4. The naming RT difference between the categorically related and unrelated conditions was used to index the size of the PWI effect. Larger effect sizes indicate less efficient resolution of within-language interference and thus reflect poorer inhibition.

2.3.2.2. Name agreement (NA) task

2.3.2.2.1. Materials and design. Fifty two high quality colour images and their normative data were obtained from the BOSS database (Brodeur et al., 2014). These were different from those used in the PWI task. Four images served as practice and forty-eight as experimental stimuli. All images were scaled to 300 × 300 pixels and were presented in the centre of the screen on a white background. There were 24 images of low NA and 24 images of high NA (Appendix C). The grouping was based on the percentage of individuals who produced the same name for a given picture as reported in Brodeur et al. (2014). The low and high NA images were matched on a number of psycholinguistic variables known to affect naming speed. For means, standard deviations and *p*-statistics for picture name agreement and psycholinguistic variables on which the two sets of images were matched, see Appendix D.

Images appeared on a computer screen one at a time and participants were instructed to name the displayed item using one word as quickly and as accurately as possible. Before testing, participants received four practice trials displaying images that were not part of the experimental set. The experimental phase consisted of two blocks of 24 intermixed (both low and high NA) images each; a short break was provided between blocks. Order of blocks was counterbalanced across participants and order of trials was pseudorandomised such that consecutive trials were not semantically or phonologically related. A trial consisted of a blank screen (500 ms), followed by a fixation point for a varied duration between 500 ms and 1000 ms, and a target image, which remained onscreen for 3000 ms or until the voice key was triggered. Each item was preceded by a 380 ms tone to indicate the start of the trial.

2.3.2.2.2. Data analysis. Naming latencies were coded manually using Audacity ® 2.2.1 recording and editing software. Only correct names and their alternatives were included in the analysis of naming latencies (6.1% of the data were removed due to errors). Incorrect

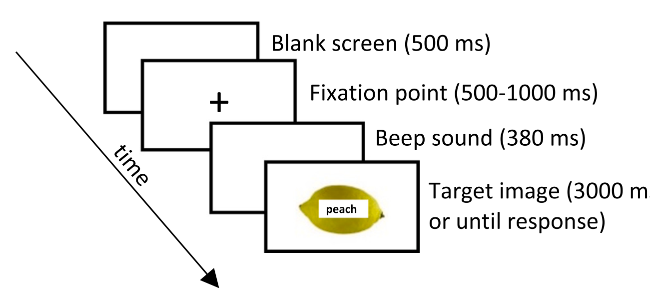

Fig. 3. Presentation and timing of trials in the picture word interference task.

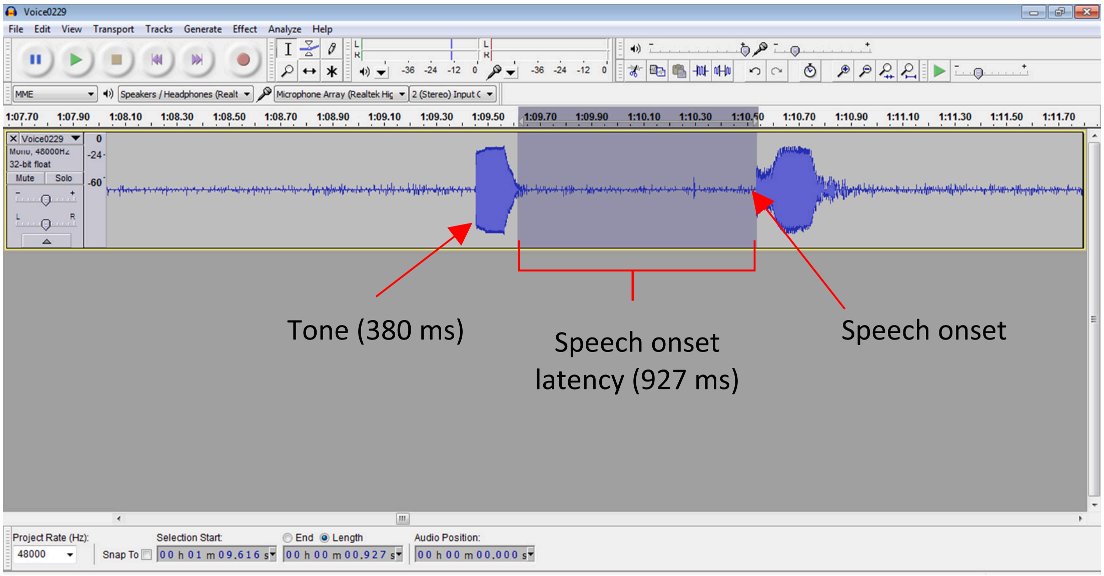

Fig. 4. An example of speech onset latency measurement in Audacity ® 2.2.1.

names, e.g. “screwdriver” or “nail” for SCREW were discarded. Semantically viable alternatives (e.g. “scale” for RULER, “ciggie” for CIGARETTE) were accepted as correct. In addition, naming latencies shorter than 250 ms and longer than 3000 ms as well as those falling ≥3 SD beyond individual means were discarded (1.4% of the data). Latencies included the time from the end of the tone to the onset of the participant’s response, including hesitations and repairs prior to the correct response word. The NA effect was calculated as mean RT difference between low NA and high NA conditions. The larger the effect size, the less efficient the resolution of within-language competition (i.e., poorer inhibition).

2.3.3. Control measures

2.3.3.1. WAIS-III vocabulary subtest. In the vocabulary subtest of WAIS-III (Wechsler, 1997) participants must provide definitions to a list of words (e.g. “Tell me what *consume* means”). The original list was shortened to 26 items as the first seven items were not discriminating enough for a group of students (Tan et al., 2017). Participants were told that the task was not a speeded task and that there were no penalties for wrong answers. They were allowed to skip any word that was unknown. Responses were audio-recorded and scored according to the WAIS manual, with 2 points awarded for a correct and complete answer, 1 point for a correct but incomplete answer and 0 points for an incorrect or no answer. The maximum score was 52 points.

2.3.3.2. Processing speed. Processing speed was calculated as an average RT score of the neutral condition in the arrow flanker task and pro-saccade condition of the anti-saccade task.

2.3.4. Delta plot analyses

RT data from the arrow flanker, Simon arrow, PWI and NA tasks were subjected to delta plot analyses. To this end, RTs in each task were first rank ordered for each participant for each condition (e.g., compatible vs. incompatible). Due to a relatively low number of trials in the NA tasks, the rank ordered data points were divided into three bins of comparable size, i.e., tertiles (cf. Forstmann et al., 2008; Shao et al., 2015). The data in the arrow flanker, Simon arrow and the PWI tasks were divided into four bins of comparable size (quartiles). Delta plots for the arrow flanker, Simon arrow, PWI and NA effects were obtained by computing for each bin the mean RT difference (delta) between the two conditions and the mean RT of the two conditions. To determine whether selective inhibition is related to the interference effects in the word production tasks, the slopes of individual delta segments for the arrow flanker and Simon arrow tasks were correlated with the PWI and NA effects, on the one hand, and the slopes of their corresponding delta segments in the two production tasks, on the other. Slope values for the delta segments connecting the data points of consecutive quantiles (e.g., q1-q2, q2-q3, q3-q4) were computed with the following formula: slope(q1,q2) = delta (q2) − delta(q1) / mean(q2) − mean(q1) (De Jong et al., 1994; Ridderinkhof, 2002a; Ridderinkhof et al., 2005).

3. Results

Results are reported in three stages. First, we analysed the interference effects in the inhibitory control and object naming tasks in terms of their mean RT, mean ER and RT distribution. Second, we examined the correlational patterns of all the tasks. Third, we investigated the relationship between individual tasks using multiple hierarchical regression analyses.

3.1. Interference effects

Data from the standard inhibitory control tasks and tasks of object naming with interference manipulation were analysed to determine the impact of interference on both response times and error rates. Mean reaction times and error rates per condition are presented in Table 2. Delta plots for the arrow flanker, the Simon arrow, the PWI and the NA tasks are shown in Fig. 5.

Participants produced over twice as many errors in the anti-saccade than in the pro-saccade block. Responses were also on average 70 ms slower in the anti-saccade than in the pro-saccade block. Typical flanker and Simon interference effects were observed, both in terms of RT and ER. Participants made ten times more errors on stimulus incompatible trials than on stimulus compatible in the flanker arrow task. They were also 200 ms quicker to identify the direction of the target arrow when it was facing in the same direction as the flankers than when it was facing in the opposite direction. The flanker effect correlated with the slopes of all the delta segments: q1-q2 ($r = 0.454$, $p < .001$), q2-q3 ($r = 0.335$, $p < .001$) and q3-q4 ($r = 0.295$, $p = .005$). In the Simon arrow task, the percentage of incorrect responses was over twice as high when the stimuli appeared on the opposite side of the response key than when they were presented on the same side as the response key. Responses were also on average 22 ms faster to stimuli presented on the same side

Table 2
Mean reaction times (in milliseconds) and mean error rates (in percent) per condition for the Anti-saccade, Arrow flanker, Simon arrow, picture-word, PWI, interference and name agreement, NA, tasks.

Task	Condition	Reaction time (ms)		*t*	*p*	*d*	Error rate (%)		*t*	*p*	*d*
		M	*SD*				*M*	*SD*			
Anti-saccade	Pro-saccade	460	111	−6.2	<.001	0.65	7.9	9.6	−7.0	<.001	0.74
	Anti-saccade	527	130				16.5	11.4			
Arrow flanker	Stimulus compatible	620	70	−22.4	<.001	2.3	0.55	1.4	−7.2	<.001	0.76
	Stimulus incompatible	820	112				5.5	6.6			
Simon arrow	Response compatible	620	70	−6.5	<.011	0.69	0.55	1.4	−3.5	.001	0.38
	Response incompatible	642	76				1.5	2.6			
PWI	Related	604	120	7.9	<.001	0.83	1.4	2.7	1.5	.12	–
	Unrelated	548	83				1	2.7			
NA	High	637	122	14.9	<.001	1.59	5.9	5.5	0.69	.49	–
	Low	806	175				6.3	5.7			

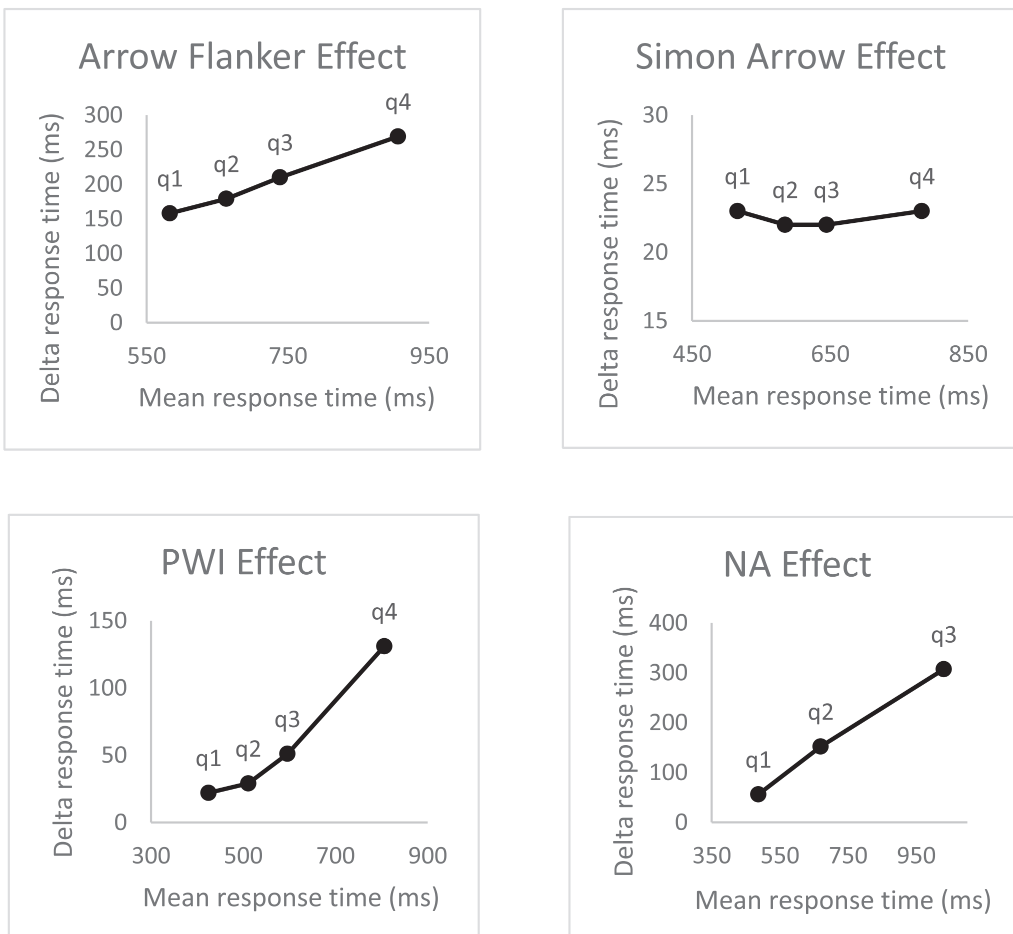

Fig. 5. Delta plots for the arrow flanker (top left), Simon arrow (top right), PWI (bottom left) and NA tasks (bottom right). Delta response times denote the difference between the experimental conditions per quantile. Mean response times denote mean RT of both experimental conditions per quantile.

as the response key than when they were presented on the opposite side. The Simon effect correlated most strongly with the slopes of the middle ($r = 0.344$, $p = .011$) and the last ($r = 0.366$, $p < .001$) delta segments, with the correlation between the slope of the first delta segment ($r = 0.239$, $p = .024$) and the Simon effect being only marginally significant (after correcting for multiple comparisons).

The results from the PWI task showed a significant semantic interference effect, but only in terms of response latencies. Participants were on average 60 ms slower to name objects with categorically related distractors than objects with unrelated distractors. Similarly, a significant NA effect was obtained only in the RT analysis. Participants were on average 170 ms faster to name objects in the high NA than in the low NA condition. The PWI effect was most strongly correlated with the slope of the middle delta segment ($r = 0.472$, $p < .001$), followed by the slope of the first delta segment ($r = 0.388$; $p < .001$), but its correlation with the slope of the last delta segment was non-significant ($r = -0.40$, $p = .19$). The slopes of both the slower ($r = 0.450$, $p < .001$) and faster ($r = 0.498$, $p < .001$) delta segments in the NA task correlated positively with the NA effect.

3.2. Correlational patterns

Next, we examined the relations between the inhibitory control and word production measures and whether these relations would remain after controlling for vocabulary knowledge and processing speed. Bivariate and partial Pearson's correlations between these measures are presented in Table 3. Additionally, we correlated the slopes of all the delta segments in the inhibitory control tasks with both the interference effect and the slopes of delta segments in the word production tasks. Correlation analyses were applied separately to the anti-saccade effects and the slopes of all the delta segments in the word production tasks. The slope of the first delta segment of the flanker effect correlated significantly with the slope of the middle segment of the PWI effect ($r = 0.244$, $p = .021$). The slope of the last delta segment in the Simon arrow task correlated significantly with the slope of the last segment in the NA task ($r = 0.227$, $p = .033$). There were no correlations between the slopes of the remaining delta segments across the tasks. The anti-saccade effects did not correlate with the slopes of any of the segments in the word production tasks. No correlation was observed between the slopes of any of the delta segments in the word production tasks.

3.3. Regression analyses

Two hierarchical multiple regression analyses were performed, with the PWI and NA effect scores as criterion variables, and the WAIS vocabulary, processing speed, anti-saccade, flanker, and Simon effects (both RT and ER) as predictor variables. The assumptions for multiple regression were satisfied, with none of individual cases unduly influencing the model. To ensure that neither WAIS vocabulary nor processing speed score explains away the entire association between the ability to resolve within-language interference and the ability to resolve interference in the non-verbal domain, both control variables were entered into the model first using the forced entry method. The anti-saccade, flanker and Simon effects were entered into the second block using the same method.

Both models, vocabulary knowledge with processing speed (model 1), and vocabulary knowledge, processing speed plus the standard inhibitory control measures (model 2) significantly predicted the resolution of within-language interference in the PWI task, F_1 (2,86) = 5.99, $p = .004$; F_2 (8,80) = 2.97, $p = .006$ respectively. Nearly 12% of the variability in the PWI effect scores was accounted for by the WAIS vocabulary and processing speed scores (adjusted $R^2 = 0.102$). This increased to 23% (adjusted $R^2 = 0.152$) when the inhibitory control measures were added to the model. In the final model, only the WAIS score and the flanker effect (RT) were significant predictors of the PWI effect. Vocabulary knowledge uniquely explained 11% of the variance in the resolution of interference in the PWI task ($\beta = -0.359$, $t = -3.42$, $p = .001$). The flanker effect explained 6% of the variance in the resolution of PWI interference ($\beta = 0.298$, $t = 2.55$, $p = .013$) above and beyond vocabulary knowledge, processing speed, the anti-saccade and the Simon effects.

A separate analysis was conducted for the NA effect as a criterion variable. However, neither vocabulary knowledge, processing speed nor any of the standard inhibitory control measures predicted underdetermined interference resolution in the NA task, F_1 (2,86) = 0.27, $p = .768$; F_2 (8,80) = 0.75, $p = .649$. The unstandardized beta (*b*), standardized beta (*β*) scores and their standard errors (*SE b*) as well as the associated *t* and *p* values are displayed in Table 4.

4. Discussion

This study examined the unique contribution of different types of inhibitory control reflecting resolution of conflict at various stages of information processing to the production of words in the context of prepotent and underdetermined competition. To this end, we used three behavioural measures of inhibitory control (the arrow flanker task, the Simon arrow task and the anti-saccade task) and two object naming tasks (picture-word interference, PWI, and name agreement, NA) that impose distinct competition demands. We analysed the interference effects not only in terms of their mean RTs and ERs, but also in terms of

Table 3
Pearson's bivariate and partial correlation coefficients for WAIS vocabulary scores, global processing speed, interference effects obtained in the non-verbal inhibitory control tasks and in the object naming tasks.

Bivariate correlations between individual measures

	1	2	3	4	5	6	7	8	9	10
1. WAIS vocabulary	1	−0.332**	0.046	−0.070	−0.072	−0.100	−0.167	−0.081	−0.291**	−0.060
2. Processing speed		1	−0.178	0.170	0.178	0.171	0.144	0.138	−0.086	0.067
3. Antisaccade effect (RT)			1	0.153	−0.067	0.044	0.041	0.119	0.039	−0.052
4. Antisaccade effect (ER)				1	0.041	−0.157	−0.134	−0.031	−0.124	0.076
5. Arrow flanker effect (RT)					1	0.309**	0.482**	−0.002	0.226*	−0.002
6. Arrow flanker effect (ER)						1	0.400**	0.215*	−0.008	−0.113
7. Simon arrow effect (RT)							1	0.184	0.156	0.134
8. Simon arrow effect (ER)								1	0.118	0.041
9. PWI effect (RT)									1	0.184
10. NA effect (RT)										1

Partial correlations controlling for vocabulary knowledge (WAIS) and processing speed

	1	2	3	4	5	6	7	8
1. Antisaccade effect (RT)	1.000	0.189	−0.037	0.077	0.068	0.147	0.021	−0.042
2. Antisaccade effect (ER)		1.000	0.011	−0.192	−0.166	−0.057	−0.124	0.065
3. Arrow flanker effect (RT)			1.000	0.287**	0.471**	−0.028	0.257*	−0.015
4. Arrow flanker effect (ER)				1.000	0.383**	0.195	−0.009	−0.128
5. Simon arrow effect (RT)					1.000	0.164	0.137	0.122
6. Simon arrow effect (ER)						1.000	0.126	0.030
7. PWI effect (RT)							1.000	0.189
8. NA effect (RT)								1.000

RT = reaction time.
ER = error rate.
Note. For interference resolution tasks, higher scores indicate larger interference effects and thereby poorer inhibition.
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Table 4
Hierarchical multiple regression analyses of variables predicting within-language interference resolution in the object naming tasks (final models).

	b	*SE b*	*Beta*	*t*	*p*	VIF
(a) *PWI effect as the criterion*						
WAIS vocabulary	−2.654	0.777	−0.359	−3.41	.001	1.15
Processing speed	−0.171	0.088	−0.216	−1.94	.056	1.28
Anti-saccade effect (RT)	0.034	0.069	0.051	0.49	.624	1.12
Anti-saccade effect (ER)	−0.892	0.616	−0.153	−1.45	.151	1.16
Arrow flanker effect (RT)	0.239	0.094	0.298	2.55	.013	1.41
Arrow flanker effect (ER)	−1.631	1.185	−0.154	−1.38	.172	1.31
Simon arrow effect (RT)	−0.007	0.261	−0.003	−0.03	.979	1.54
Simon arrow effect (ER)	3.940	2.866	0.142	1.37	.173	1.11
(b) *NA effect as the criterion*						
WAIS vocabulary	−0.214	1.341	−0.018	−0.16	.874	1.15
Processing speed	0.048	0.152	0.039	0.32	.751	1.28
Anti-saccade effect (RT)	−0.072	0.119	−0.070	−0.61	.544	1.12
Anti-saccade effect (ER)	0.796	1.062	0.087	0.75	.456	1.16
Arrow flanker effect (RT)	−0.100	0.162	−0.079	−0.61	.540	1.41
Arrow flanker effect (ER)	−3.099	2.045	−0.187	−1.52	.134	1.31
Simon arrow effect (RT)	0.827	0.451	0.245	1.83	.070	1.54
Simon arrow effect (ER)	1.738	4.946	0.040	0.35	.726	1.11

[a]*Note.* $N = 89$. $R = 0.48$, $R^2 = 0.23$, adjusted $R^2 = 0.15$, $SE = 62.5$.
[b]*Note.* $N = 89$. $R = 0.26$, $R^2 = 0.07$, adjusted $R^2 = 0.02$, $SE = 107.9$.

their RT distribution. Additionally, we factored in participants' vocabulary knowledge and processing speed, and used these as control variables.

Of the three inhibitory control measures, only performance on the arrow flanker task predicted the speed with which PWI interference was resolved. Object naming under prepotent competition was slower for speakers with greater flanker effects than for those with smaller flanker effects. This relationship remained significant after accounting for vocabulary knowledge, processing speed and the contribution of other inhibitory control measures. These findings based on mean RTs were partially borne out by the delta plot results in that we found significant correlations between the interference effects and the slopes of the slower delta segments in the arrow flanker, Simon arrow, PWI and NA tasks. However, only the slopes of the fastest rather than slowest responses in the arrow flanker task were predictive of the slopes of the slower responses in the PWI task. To the extent that the flanker effect reflects inhibitory processes and the PWI effect captures the resolution of interference as it occurs in natural language production, these results suggest that an inhibitory mechanism, at least one that resolves interference from competing representations, facilitates word selection in the face of prepotent competition.

It is not clear why the arrow flanker effects in the delta plot analysis were most pronounced for the fastest responses rather than, as commonly reported in the conflict-task literature for the slower ones (e.g., Ridderinkhof, 2002; Forstmann et al., 2008). It is important to note however, that delta plot patterns may vary (e.g., while the standard Simon effect is typically associated with a negative delta plot, with largest effects observed for fastest responses, the arrow-based Simon effect produces a reversed pattern; Pellicano et al., 2009) depending both on task parameters (e.g., proportion of congruent trials, stimulus type, stimulus set size and number of stimulus repetitions in the case of word production tasks) and the way the delta plots are computed (e.g., number of quantiles, inclusion or exclusion of incorrect RTs in the analysis; see a review by Schwarz & Miller, 2012). It is possible that a higher number of quantiles as computed in other studies allows for a more fine-grained analysis, with larger effects more likely to emerge for later rather than earlier delta segments.

The current results provide partial support for the findings reported by Shao et al. (2013, 2015) and Sikora et al. (2016) in that significant correlations were observed between the interference effects in the PWI task and the slopes of individual delta segments. Where the findings appear to diverge is in the portions of the RT distribution that were most affected by inhibition. In Shao et al. and Sikora et al., the semantic interference effects were related to performance on the slowest (most effortful) trials. In the current study, semantic interference effects were present for mid- and early delta segments, but not for the slowest responses. The current results are not inconsistent with Roelofs et al. (2011) however, who observed significant differences in semantic interference effects (between those with small and large PWI effects and between the more and less proficient bilingual speakers), but only in the mid-portions (q2-q3 and q3-q4) of the RT distributions, with the fastest and slowest responses being unaffected by inhibition. Following Roelofs et al. (2011) and De Jong et al. (1999), it can be reasoned that the absence of semantic interference effects in the slowest (most effortful) trials of the PWI task are down to diminished inhibition that can only be sustained up to a certain point during a trial rather than throughout a whole trial. Although the current results showed a positive correlation between the NA effects and the slopes of the slowest delta segment in the NA task, in line with Shao et al. (2014), further distributional comparisons for the NA task are difficult to make either because of the dearth of language production studies utilising RT distribution analyses or because when such analyses are performed, the correlations between the slopes of the fastest responses and the NA interference effects are unreported.

In the current study, neither the anti-saccade nor the Simon effect explained any variance in the PWI effect. Again, this was borne out by the delta plot results, according to which neither the anti-saccade effects nor the slopes of individual delta segments in the Simon arrow task were related to the slopes of the slower delta segments in the PWI task. Additionally, the anti-saccade effects did not correlate with the slopes of the delta segments in either the arrow flanker or Simon arrow task, indicating that the underlying inhibitory processes are dissociable. These results corroborate the findings reported by Shao et al. (2015), in which non-selective inhibition (inhibition of a motor response as indexed by the stop signal task), did not contribute to the resolution of inference in the PWI task. Neither was it related to selective inhibition. The reason for an absence of correlation between the anti-saccade and the Simon effects on the one hand, and the PWI effect, on the other, is that these tasks reflect different interference-resolution demands. Interference is argued to arise and be resolved at different loci between stimulus detection and response generation (Egner et al., 2007; Milham et al., 2001; Nee et al., 2007; Nelson et al., 2004). The anti-saccade task is primarily a motor response-execution paradigm (Munoz & Everling, 2004). The Simon effect is considered to be an index of response selection, independent of stimulus-identification or response-execution processes (Lu & Proctor, 1995; van den Wildenberg et al., 2010). The flanker task, in turn, is commonly thought to tap resolution of representational conflict. The unique contribution of the flanker effect to PWI performance, above and beyond the anti-saccade and the Simon effects, indicates that inhibitory mechanisms might be recruited in response to conflict occurring at a specific point in the information processing stream, one that in the context of the PWI task, happened to be most prominent at the representational level of processing. It could be that late-stage motor response inhibition does play a role in language production, but is only detectable under increased processing demands, such as producing a noun phrase with multiple sources of interference as in Sikora et al. (2016).

This pattern of results places the findings more in line with the competitive theories of spoken word production (production delays are attributed to conflict at an intermediate, lexical stage of processing) than non-competitive theories (production delays may reflect the workings of a monitoring mechanism, which upon detecting a conflict mobilises an inhibitory mechanism at the output stage). Although the locus of interference observed in the PWI task appears to be constrained to early rather than late, post-lexical stages, the current evidence does not allow us to establish whether it is lexically or conceptually based. It is conceivable that the flanker task, which involves resolution of conflict between representations of non-verbal stimuli (arrows), also engages a language component. The arrow stimuli are not completely arbitrary and thereby can potentially activate lexical representations associated with the concept of direction (LEFT and RIGHT). Conversely, it cannot be ruled out that at least part of the PWI effect may be attributed to perceptual interference (difficulty in recognising a depicted object due to conflicting information provided by the distractor) or conceptual interference (difficulty in identifying a depicted object due to conflicting semantic information activated by the distractor). Until this uncertainty is resolved, it cannot be fully confirmed that the source of interference as observed during object naming in the PWI task is strictly lexical.

A possible explanation for the lack of correlation between the PWI effect and the Simon effect, leaving aside a much smaller effect size, is that the Simon effect is taken to reflect resolution of conflict associated with the activation of two incompatible response codes. The location of the target stimuli induces the participant to press the key that is located on the side compatible with the effector (the hand pressing the key) but an arrow representation leads to the activation of the effector on the opposite side. This is analogous to the situation in which an automatic reading response code is activated by the distractor word in the PWI task but the target demands a more controlled action of naming the pictured object. However, since the PWI effect indexes a difference in mean response times between the related and unrelated conditions, both of which present distractor words, the response selection effect is cancelled out.

The current study also examined the contribution of different inhibitory control mechanisms to the resolution of underdetermined competition during object naming. However, none of the inhibitory control measures predicted the NA effect. A similar pattern of results was obtained with the delta plot analysis, with the exception of a correlation between the slopes of the slowest delta segments in the Simon arrow task and the slopes of the slowest delta segments in the NA task. This correlation failed to reach significance in the mean RT analysis. However, after controlling for the flanker effects with which the Simon effects were correlated, the slopes of the slowest delta segments in the Simon arrow task did not contribute to NA performance. Despite observing a correlation between the NA effects and the slopes of the slowest delta segments, indicating the role of selective inhibition, similarly to Shao et al. (2014), one must be cautious about extrapolating the delta plot findings from non-linguistic tasks that induce conflict between a correct and an incorrect response to word production tasks that entail selection of a target word from among responses that are all correct in a given context (e.g., saying *sofa*, *couch*, *settee*, *bed* to refer to an upholstered seat for several people). The fact that there was no relationship between the PWI and NA effects (as reflected in both mean RT and the slopes of the delta segments), on the one hand, and the non-verbal inhibitory control measures and the NA effect, on the other, does not necessarily argue against the role for inhibition in naming objects with low NA, but may suggest that these tasks capture different forms of interference and thereby are associated with distinct cognitive control mechanisms.

Alternatively, it could be argued that lexical selection in the NA task is governed by processes other than inhibition. As pointed out by Paivio et al. (1989), delays in the naming of objects with low name agreement (items associated with multiple names as opposed to one dominant name) may either reflect lateral inhibition, where the activated representations inhibit one another, thereby delaying the selection of the target, or diffuse activation, where concept-to-lemma mappings are spread over several pathways, making the activation of each individual pathway weaker compared to the activation of a single concept-to-lemma pathway in the case of an object with high name agreement.

Of course, another consideration is that the inhibitory control tasks selected for the purpose of this study can, by their nature, only index abilities that are either fully domain-general or at least closely yoked across domains. If lexical selection were dependent on language-specific inhibitory abilities, then non-verbal measures may have limited predictive power for word production tasks. This explanation is unlikely however, in view of previous findings (e.g., Nozari & Novick, 2017) and the association between the flanker and the PWI effects observed in the current study. A separate issue for future research to resolve would be to establish whether production delays, even when they are traced to intermediate stages of processing, reflect inhibitory abilities, conflict detection (monitoring) abilities or both.

Taken together, to the extent that the flanker effect is a valid index of the ability to resolve representational conflict and the PWI effect reflects competition as it occurs in natural spoken word production, the current study provides evidence for the involvement of inhibitory processes during object naming under prepotent, but not underdetermined competition. Until the pre-lexical source of interference in the PWI task is ruled out however, this remains a tentative conclusion.

CRediT authorship contribution statement

Malgorzata Korko	Conceptualisation, Investigation, Writing - Original Draft
Mark Coulson	Supervision
Alexander Jones	Supervision
Paul de Mornay Davies	Supervision, Writing - Review & Editing

Declarations of interest

None.

Appendix A. Word frequency, familiarity, length (in syllables, phonemes and letters) and imageability norms for distractor words in the related and unrelated conditions of the picture word interference task

	Relationship between target picture and distractor word	*M*	*SD*	*SE*	*t*	*p*
Word frequency (CELEX)	Related	32.86	46.84	9.01	−1	.32
	Unrelated	51.67	85.88	16.53		
Familiarity	Related	502.96	156.16	30.05	−0.58	.56
	Unrelated	525.11	121.78	23.44		
Length (syllables)	Related	1.48	0.58	0.11	0	1
	Unrelated	1.48	0.58	0.11		
Length (phonemes)	Related	3.96	0.81	0.16	0.52	.61
	Unrelated	3.85	0.77	0.15		
Length (letters)	Related	5.00	0.68	0.13	−0.2	.85
	Unrelated	5.04	0.71	0.14		
Imageability	Related	557.26	163.23	31.41	0.41	.74
	Unrelated	570.44	120.08	23.11		

Appendix B. Names of filler and target images with related and unrelated distractor words from the picture word interference task

Filler image	Target image	Related distractor word	Unrelated distractor word
Ladder	Broccoli	Potato	Anchor
Egg	Lion	Zebra	Nurse
Battery	Lemon	Peach	Brick
Comb	Bed	Table	Cloud
Feather	Guitar	Cello	Angel
Wallet	Cannon	Rifle	Penny
Barrel	Shirt	Dress	Chain
Axe	Scissors	Tape	Vase
Sink	Bike	Plane	Pillow
Crown	Trumpet	Drum	Soap
Mic	Cat	Duck	Rice
Swing	Hammer	Pliers	School
Glasses	Giraffe	Camel	Brush
Lips	Ship	Train	Uncle
Window	Pear	Cherry	Button
Bench	Tree	Flower	Butter
Chimney	Chair	Shelf	Arrow
Jug	Sock	Glove	Radio
Box	Ear	Foot	Tent
Drill	Shovel	Rake	Book
Bucket	Horse	Mouse	Torch
Razor	Toaster	Kettle	Circle
Fan	Lamp	Clock	Apron
Ashtray	Hand	Neck	Rain
Microwave	Onion	Carrot	Hanger
Lighter	Fridge	Dryer	Wheel
Nest	Camera	Phone	Stone

Appendix C. Names of target images in the two conditions of the name agreement task

Low name agreement images	High name agreement images
Mug	Candle
Bottle	Broom
Branch	Cigarette
Gift	Dice
Hat	Cd
Cup	Envelope
Bag	Handcuffs
Mixer	Key
Shoe	Kite
Pasta	Lipstick
Coins	Mattress
Wire	Microscope
Car	Mushroom
Container	Wheelchair
Tissue	Umbrella
Pin	Toothbrush
Couch	Tomato
Suitcase	Belt
Pushchair	Football
Monitor	Snowman
Trainer	Screw
Shell	Ruler
Gun	Ring
Cone	Leaf

Appendix D. Name agreement and psycholinguistic variable statistics for objects with high and low name agreement

	NA group	*M*	*SD*	*SE*	*t*	*p*
Name agreement (%)[a]	Low	44	11	2	−22.76	<.001
	High	98	3	1		
Word frequency (CELEX)	Low	26.54	27.52	5.62	1.6	.11
	High	15.25	19.91	4.06		
AOA	Low	138.00	131.09	27.33	1.3	.22
	High	89.92	133.58	27.27		
Familiarity	Low	4.30	0.37	0.08	−1.4	.19
	High	4.43	0.27	0.05		
Visual complexity	Low	2.44	0.44	0.09	1.6	.12
	High	2.25	0.38	0.08		
Object agreement	Low	3.94	0.44	0.10	−1.4	.17
	High	4.14	0.47	0.10		

[a] Name agreement (%) is the percentage of individuals who produced the same name for a given picture.

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