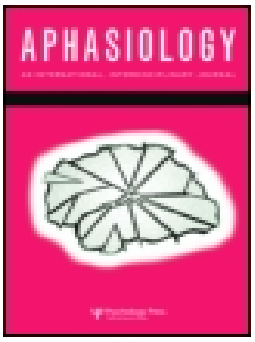

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Predictors of object naming in aphasia: does cognitive control mediate the effects of psycholinguistic variables?

Leena Maria Heikkola [a,b], Ekaterina Kuzmina [b] and Bård Uri Jensen [b,c]

[a]Department of Finnish Language, Åbo Akademi University, Turku, Finland; [b]Center for Multilingualism in Society across the Lifespan, Faculty of Humanities, University of Oslo, Oslo, Norway; [c]Faculty of Education, Inland Norway University of Applied Sciences, Hamar, Norway

ABSTRACT

Background and Aims: Previous studies have shown that age of acquisition affects language production in persons with aphasia (PWA), specifically, earlier-acquired words are better preserved compared to later-learned ones (for review, see Brysbaert & Ellis, 2016). Also, it has been argued that naming objects with lower name agreement requires inhibition of alternative names (Alario et al., 2004), and therefore puts higher demands on cognitive control. Bose and Schafer (2017) showed that although both PWA and healthy controls performed better at naming words with high naming agreement, the difference between the naming conditions was significantly greater for PWA. This could be due to reduced ability to inhibit irrelevant information in PWA. The current study aims to investigate whether cognitive control mediates the effects of psycholinguistic variables on object naming accuracy in aphasia.
Methods and Procedures: Participants (N = 31, 32% female) were right-handed, native Russian speakers with preserved visual and hearing abilities diagnosed with mild to moderate post-stroke aphasia. They were aged 40–70 (mean = 59.5, SD = 8.6). The participants were tested on a picture-naming task including 247 items and 2 subtests from the Russian Birmingham Cognitive Screen, namely Auditory attention, and Rule Finding tasks.
Outcomes and Results: To define whether cognitive control mediates the effect of psycholinguistic variables on naming response accuracy, multiple linear regression was used. Significant main effects of log-transformed word frequency, AoA, and cognitive control were found, as well as a significant interaction between log-transformed word frequency and cognitive control.
Conclusions: Our findings suggest that cognitive control mediated the effect of word frequency in naming in aphasia. PWA with weaker cognitive control name pictures depicting less-frequent words less accurately than more frequent words. This points to the fact that PWA have difficulty in lexical access when producing language. The implications of the study are that the focus of aphasia rehabilitation should be on very frequent structures and words as these are usually more preserved in PWA with weaker cognitive control.

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CONTACT Leena Maria Heikkola lheikkol@abo.fi Department of Finnish Language, Åbo Akademi University, Turku, Finland

Supplemental data for this article can be accessed here.

Introduction

Many studies have investigated how psycholinguistic variables (e.g., word frequency, age of acquisition, etc.) influence naming latencies and accuracy in neurologically healthy adults (see, e.g., Snodgrass & Vanderwart, 1980; Tsaparina et al., 2011), as well as clinical populations, such as persons with aphasia (PWA) (Bose & Schafer, 2017; Indefrey, 2011; Johnson et al., 1996). Although it has been suggested that "*investigation into detailed executive control processes that underpin lexical selection in healthy and impaired populations would be a productive avenue for research*" (Bose & Schafer, 2017, 1159), to our knowledge, there are no studies investigating whether and how these effects of psycholinguistic variables are modified by cognitive control. In the present study, we investigate whether age of acquisition (AoA), word frequency, name agreement, imageability, and number of syllables (i.e., word length), are linked to cognitive control and whether interactions between these psycholinguistic variables and cognitive control affect naming accuracy in PWA.

Psycholinguistic variables and stages of spoken picture naming

Cognitive models of spoken picture naming typically contain three main successive stages: firstly, the depicted entity should be visually perceived and recognized (i.e., object recognition); secondly, the entity should be semantically, lexically, and phonologically identified and coded (i.e., semantic activation and lexical access), and finally, it should be produced orally (Levelt, 1999; Levelt et al., 1999; Dell et al., 1997; Indefrey, 2011). It has been argued that psycholinguistic variables contribute differently to the different stages of this process (see Table 1; see also Alario et al., 2004, p. 141).

Below we will provide a brief review of the variables that are related to the second and third stages because these are the stages where PWA are assumed to have impairments. We will thus not present the first stage because it is mostly related to disturbances in visual recognition processes that are not directly related to language impairment in aphasia.

Table 1. Psycholinguistic variables and the three suggested stages of spoken picture naming.

(1) (Visual) object recognition	(2a) Semantic/conceptual activation	(2b) Lexical access/selection and phonological encoding	(3) Articulatory-motor stage
Visual complexity (Humphreys et al., 1988)	*AoA* (Brown & Watson, 1987; Morrison & Ellis, 1995)	*AoA* (Alario et al., 2004)	*Word length* (Alario et al., 2004; Graves et al., 2007)
Name agreement (i.e., incorrect naming) (Vitkovich & Tyrrell, 1995)	*Name agreement* (i.e., activation of competing concepts) (Vitkovich & Tyrrell, 1995)	*Name agreement* (i.e., competing names) (Vitkovich & Tyrrell, 1995	
Image agreement (Alario et al., 2004; Cheng et al., 2010)	*Imageability* (Ghasisin et al., 2014)	*Word frequency* (Alario et al., 2004)	
	Conceptual familiarity (Ghasisin et al., 2014)		

Semantic/conceptual activation

Conceptual familiarity and ***imageability*** have been linked to the stages of semantic/conceptual activation. Pompeia and colleagues (2001) have reported that the more familiar an object is, the more directly it affects the activation of its conceptual representations. Cuetos et al. (2002) have proposed that because conceptual familiarity probably grows with an increasing number of encounters with an object in everyday life, these familiar objects become semantically richer, and are thus recognized more quickly and more accurately, and are more resistant to changes due to brain injury. Conceptual familiarity has been found to affect naming latencies in healthy adults (Ellis & Morrison, 1998; Jolicoeur, 1985), and to predict naming performance in progressive semantic dementia (Hirsh & Funnell, 1995) and aphasia (Feyereisen et al., 1988). It has also been reported that persons with progressive semantic dementia are better able to name objects with high concept familiarity than objects with low concept familiarity, even when controlling for AoA and frequency (Hirsh & Funnell, 1995; for a critical discussion on the usefulness of concept familiarity, see Funnell & Davies, 1996).

Imageability refers to the ease with which a mental image can be generated based on the presentation of a written word. Imageability is deemed to be linked to the semantic richness of a word (Tsaparina et al., 2011), for example, number of semantic features, semantic neighborhood density, semantic diversity, concreteness, and emotional valence (cf. Goh et al., 2016). Imageability has been shown to have an effect on naming latency in semantic tasks, such as generating word associations, in healthy adults (de Groot, 1989). It has been shown that the performance is significantly faster and more accurate, when naming highly imageable targets (Garbarini et al., 2020; see also Kiran & Tuchtenhagen, 2004; Hoffman et al., 2015). Plaut and Shallice (1993) have also found evidence for imageability having effects in people with deep dyslexia who are assumed to read exclusively by means of semantic representations. Garbarini and colleagues' (2020) brain imaging study supports the proposition that imageability is processed in the semantic phase of spoken picture naming. Interestingly, their results also point to the direction of semantic processing of imageability and activation of brain areas for oral production happening simultaneously, although only for highly imageable objects, compared to objects with low imageability. This may be due to the faster semantic processing of objects with higher imageability.

Also ***name agreement*** has been linked to the semantic activation stage in many models. Name agreement refers to the degree of agreement between different people on naming an object or action. Pictures that elicit only a single name across different people have the highest name agreement; the more names a picture elicits, the lower the name agreement (Bose & Schafer, 2017). Name agreement is suggested to be a part of three different stages of spoken picture naming, namely, visual recognition, semantic/conceptual activation, and lexical access/selection stages, and previous literature on name agreement within these three stages will be presented in the following section.

Lexical access/selection and phonological encoding

Alario and colleagues (2004) have suggested that ***image agreement***, namely, how well a picture corresponds to a person's mental representation, affects the visual recognition, while ***name agreement*** affects both the semantic/conceptual activation stage and lexical access/selection stage. This view is supported by Johnson (1992), who states that name agreement effects come after object identification, increasing naming latency but leaving object–decision times unaffected. However, Vitkovich and Tyrrell (1995) have proposed that name agreement has differentiated effects during the object recognition and lexical processing stages. When name disagreement is due to incorrect naming, it may also affect structural object recognition, seen as slower naming latency (e.g., *spider* for *ant*). This division of the sources of name agreement into two, namely *picture uncertainty*, where name agreement effects are due to accessing stored structural knowledge, and *alternative names for objects*, where name agreement effects occur after conceptual access, is also supported by Bonin and colleagues (2002). There is ERP evidence to support this distinction between the visual recognition and the semantic-lexical stages: name agreement affects both the object recognition reflected in the P1 component, and lexical selection reflected in the N2 component (Cheng et al., 2010).

Alario et al. (2004) have argued that activation at the semantic level is similar both for words with higher and lower name agreement, and that this effect appears between the conceptual and lexical stages. Lower name agreement pictures evoke a greater number of names of the depicted items than higher name agreement pictures; thus, it takes longer for lower name agreement pictures to be named, i.e., to eliminate competitors, and to select one specific name (see also Neural, 2007). This is also supported by Johnson's (1992) findings stating that name agreement effects arise after object identification. Later, Johnson et al., (1996, p. 119) have suggested that the name agreement effect appears during "*name retrieval, response generation, or both*." At the lexical level, however, words with lower name agreement will be more strongly activated because more words correspond to the same semantic concept. Thus, the selection demands are higher for words with lower name agreement. This competition at the lexical level implies a controlled selection for words with lower name agreement to deliver the most suitable lemma (Neural, 2007; Ellis & Morrison, 1998; Alario et al., 2004; Vitkovich & Tyrrell; Hirsh & Funnell, 1995). If the target level does not exceed the critical threshold required for the selection, the wrong word will be selected. Thus, error analysis of these mistakes will give insight into how this competition may occur in PWA.

There is evidence that name agreement predicts naming latency in healthy adults (Hirsh & Funnell, 1995; Barry et al., 1997; Ellis & Morrison, 1998; Bonin et al., 2002; Alario et al., 2004) and accuracy in neurological populations, such as people with dementia and Alzheimer's disease (Harley & Grant, 2004; Rodríguez-Ferreiro et al., 2009), primary progressive aphasia (Kremin et al., 2001), and stroke-induced aphasia (Laiacona et al., 2001; Cameron-Jones & Wilshire, 2007; Bose & Schafer, 2017). Laiacona et al. (2001) found that name agreement was the strongest predictor of naming accuracy in PWA, followed by word frequency.

Bose and Schafer (2017) used high and low name agreement words to investigate the effects of name agreement on naming accuracy and error types in PWA and healthy adults (HA). HA performed better than PWA (Bose & Schafer, 2017), the difference in naming accuracy being larger for the HA than for the PWA. However, they only looked at accuracy, not naming latencies. There was also great variability within the PWA: some participants were more sensitive to the name agreement manipulation than others, and some did not show higher accuracy performance with the words with higher name agreement. This may point to the fact that aphasia may result in high levels of lexical competition. Bose and Schafer (2017, p. 17) speculate that their findings of the error patterns in PWA in the low name agreement condition may be due to heightened competition, and an investigation into detailed executive control processes underpinning lexical selection would be a "productive avenue for research." Bose and Schafer's (2017) results are in line with earlier literature: there is an overall better performance in words with higher name agreement, with substantial individual variability (Neural, 2007; Kremin et al., 2001; Laiacona et al., 2001).

Although a few studies have found evidence for name agreement being a strong predictor of naming accuracy and latency (Neural, 2007; Kremin et al., 2001; Laiacona et al., 2001), other studies have reported different findings (see, e.g., Kittredge et al., 2008). Also, very few studies have controlled for name agreement effects, and most studies have only used words with high name agreement (e.g., Bormann et al., 2008; Fieder et al., 2014). In addition, research on the possible effects of name agreement on naming in PWA is scarce, and scientists have called for more research on the different types of name disagreement in impaired populations (Bose & Schafer 2017, 1159). As the sources of possible name disagreements can be many, these disagreements have been proposed to influence two consecutive processes of lexical access: object recognition, and lexical selection and phonological encoding (Cheng et al., 2010; O'Sullivan et al., 2012; Vitkovitch & Tyrrell, 1995). Other studies have shown that the effects of name agreement on naming latency are independent of frequency and AoA, although it has been debated whether word frequency is linked to name agreement (Hirsh & Funnell, 1995).

In addition to name agreement, both AoA and word frequency have been linked to naming latency at the lexical selection stage in the picture-naming process (Alario et al., 2004). ***Age of acquisition*** (AoA) has been shown to be a robust predictor of naming accuracy and latency in aphasia (Brysbaert & Ellis, 2016; for a review, see Johnston & Barry, 2006): words with earlier AoA are accessed and produced faster and more accurately than words with later AoA in picture naming tasks (Brysbaert & Ellis, 2016; for a review, see Johnston & Barry, 2006). Rochford and Williams (1963) were the first to notice that the percentage of PWA who were able to name a specific picture was strongly negatively correlated with the age of acquisition of the corresponding word, and therefore they concluded that words learned first are the last to be lost. This finding has gotten extensive experimental support in different languages, such as English (Nickels & Howard, 1995; Ellis et al., 1996), Spanish (Cuetos et al., 2002), Persian (Bakhtiar & Weekes, 2015), and Russian (Tsaparina et al., 2011). In addition, AoA has been found to be a strong predictor for recovery in PWA: words with early AoA have faster recovery trajectories than words with late AoA following treatment (Zhou et al., 2009).

It has been suggested that words that are acquired early may be stored as a whole within the phonological lexicon, but words acquired later may have more fragmented representations (Brown & Watson, 1987). This would explain the slower processing of late-acquired words. Morrison and Ellis (1996) have suggested that the phonological lexicon could be conceptualized as a self-organizing neural network from which lexemes are retrieved in the act of speaking. Morrison (1993) found that when trained first with one set and only later with another set of words, the network results in a more fragmented learning of the late-acquired words, similar to Brown and Watson's proposition. As AoA and word frequency have been shown to be highly correlated, we can expect similar processes for less-frequent words as for late-acquired words.

Previous studies have shown that AoA and ***word frequency*** are highly correlated: words learned early tend to be more frequent (Brysbaert & Ellis, 2016). Both AoA and word frequency have been found to be predictors of naming accuracy in PWA, unlike other psycholinguistic variables: word density (number of phonologically similar words), word length, word imageability, and name agreement (Kittredge et al., 2008). Strong evidence for the link between AoA and frequency also comes from connectionist models. By the end of training new and old word pairs, the accuracy with which the model could convert input patterns into correct output patterns was influenced by the frequency of the training, and by the earliness/lateness of learning (Ellis & Lambon Ralph, 2000). If the network was damaged, the consequences were worse for the later-learned items. Goh et al. (2016) have also shown that AoA and imageability predicted naming accuracy for both object and action picture naming, whereas word frequency significantly influenced verb naming only.

In a review, Cuetos and Barbón (2006) argue that there are two components of the AoA effect: one is linked to word frequency, the other is not. Some tasks are influenced by AoA and word frequency to the same extent: these tasks include reading written words aloud quickly, lexical decision, and semantic categorization (making decisions based on the meanings of words). In Brysbaert and Ghyselink's (2006) terms, these tasks are "frequency-related." In other tasks, such as object picture naming, both AoA and frequency are present, but the size of AoA is larger. These tasks are "frequency-independent" (Brysbaert & Ghyselink, 2006). This view is supported by many findings in the literature. In picture naming in healthy adults, the AoA latency effect is more than 100 ms faster than expected on the basis of word frequency (Brysbaert & Ghyselink, 2006). The AoA effect is also larger than expected in word association generation (Brysbaert van Wijnendaele, & De Deyne, 2000), semantic categorization (Catling & Johnston, 2005), and retrieving a word to a definition (Navarrete Pastore, Valentini, & Peressotti, 2015). Thus, there seems to be another source of the AoA effect that plays a stronger role when verbal responses must be given based on semantic information. It has been argued that this is due to either the organization of the semantic system, making the early acquired meanings richer, more accessible, and robust, or due to how semantic information is transformed into verbal output (Brysbaert & Ellis, 2016).

Kay and Ellis (1987) have also found that word frequency is a predictor of naming performance. In a later reanalysis of the data, however, Ellis (2006) showed that both frequency and AoA were significant predictors of naming. Picture naming, which is a "frequency-independent" task, has been extensively used in AoA research, which may be reflected in research results claiming a stronger predictive power for AoA compared to word frequency. According to Brysbaert & Ellis (2016), our understanding of the mediating nature of psycholinguistic variables on naming performance would be greater, if we used more varied tasks (frequency-dependent vs. frequency-independent tasks). Such improvements in methodology are also expected to improve our understanding of the performance of PWA.

Articulatory-motor stage

Word length is typically operationalized by the number of letters, phonemes, or syllables, and it is considered to affect the articulatory-motor stage of the picture naming process

(Alario et al., 2004; Graves et al., 2007). It is assumed that the phonological encoding of a word has to do with filling a word frame with different segments or syllables making up the word (Fromkin, 1971). This is supported by evidence from speech errors (Alario et al., 2004). It is also proposed that longer words take more time to be encoded than shorter words.

Cognitive control and lexical-semantic access in aphasia

Different language production models suggest that lexical access from the mental lexicon is a competitive process (Caramazza, 1997; Dell, 1986; Levelt et al., 1999). The target word is selected among coactivated, competing words. Thus, we can assume that cognitive control is important in lexical access. Although there is a growing body of evidence that cognitive control deficits accompany language impairments in PWA (Kendrick et al., 2019), the relationship between cognitive control and language impairments is still unclear. Kendrick and colleagues (2019) have shown that the extent of verbal load did not influence PWA's executive control task performance. The same has been found in healthy controls. Given these findings, Kendrick et al. concluded that language processing was not essential for performance on the cognitive control tasks.

However, several studies have shown significant relationships between language comprehension, for example, and different facets of cognitive control, such as working memory (Ivanova et al., 2017) and inhibition (Kuzmina & Weekes, 2016; Martin & Allen, 2008). Ivanova and colleagues (2017) have shown that performance on a modified listening span task was linked to language comprehension abilities, although only in people with nonfluent aphasia, and not for people with fluent aphasia. Kuzmina and Weekes (2016) found inhibition deficits in both fluent and non-fluent aphasia, although they were more prominent in the latter type. In non-fluent aphasia, there were cognitive deficits assessed by the Flanker and Stroop task. The authors also found significant associations between larger Flanker interferences and language comprehension scores in both types of aphasia.

Carpenter et al. (2020) have shown that compared to healthy bilinguals, bilingual PWA are more sensitive to the effects of increased cognitive control on lexical access. In single-language and dual-language contexts, bilingual PWA produced a lower proportion of correct responses compared to healthy bilinguals. However, in a self-switch condition between two languages, which is assumed to place lower cognitive control demands during lexical access, the bilingual PWA performed similarly to the healthy bilinguals. Both PWA and healthy adults had lower proportions of correct responses in the forced-switch condition, however, which Bose and Schafer (2017) expected, as this condition places higher cognitive control demands on lexical selection (see also, Green & Abutalebi, 2013).

The present study

Our aim is to investigate whether cognitive control mediates the effects of name agreement, AoA, and word frequency on the accuracy of object naming in PWA. Based on the outlined literature, the following research questions were formed:

1. *Is there an interaction between cognitive control and name agreement in the accuracy of object naming?* Bose & Schafer (2017) speculated that cognitive control abilities can mediate the role of name agreement in naming in PWA. In particular, they proposed that lower name agreement would lead to worse naming, since more competitors should be eliminated for the selection of the target. Thus, for the first research question, we hypothesize that cognitive control would mediate the main effect of name agreement (i.e., lower naming accuracy for words with lower name agreement compared to the higher name agreement words), in a way that the effect of name agreement is more pronounced in PWA with lower cognitive control.

2. *Is there an interaction between cognitive control and word frequency in the accuracy of object naming?* Given that high frequent words are typically more extensively used, and consequently, we assume that they are more accessible, we expect that less cognitive control is needed to retrieve these words compared to low-frequency words. Therefore, for the second research question, we hypothesize that cognitive control would mediate the main effect of word frequency (i.e., low frequent words are named less accurately than higher frequent words), in a way that this effect is stronger in PWA with lower cognitive control.

3. *Is there an interaction between cognitive control and AoA in the accuracy of object naming?* As it has been shown that word frequency and AoA are highly related (Brysbaert & Ellis, 2016), we hypothesize that cognitive control may mediate the AoA effect on naming accuracy in PWA in a similar fashion as word frequency.

Methodology

Participants

Thirty-one participants (32% female) with poststroke aphasia ranging in age from 40 to 70 (mean = 59.5, *SD* = 8.6), in lesion onset time from 4 to 120 months (mean = 23.9, *SD* = 23.6), and in the number of formal education years from 8 to 19 years (mean = 14.5, *SD* = 2.7) volunteered to participate in the present study. Performance on the scores of the Quantitative Aphasia Battery (QASA) varied from 35% to 94% (mean = 72%, *SD* = 14%). The participants were tested at the Center for Speech Pathology and Neurorehabilitation in Moscow. They did not have visual and hearing impairments documented in their clinical notes. As the data were collected as part of Author 2's (Ekaterina Kuzmina) PhD Thesis at the University of Hong Kong, the study protocol was approved by the Human Research Ethics Committee at the University of Hong Kong. Data from some of the participants included in the current study were partially used in another study (Kuzmina & Weekes, 2017). Table 2 summarizes participants' clinico-demographic details as well as their performances on the tasks used in the current study.

Procedure

Naming task

The object picture naming task included 229 colorized pictures (Snodgrass & Vanderwart, 1980). All pictures were standardized for Russian based on their psycholinguistic variables (Tsaparina et al., 2011). Several pictures from the original set were excluded from the

Table 2. Participants' clinico-demographic details and performance scores on the tasks.

Number	Gender	Age	Education	Fluency	MPO	Hand	Lesion site	QASA score	Picture naming, accuracy	Picture naming, %	Auditory attention, accuracy	Rule finding, accuracy	AQ
1	m	65	8	NF	55	r	L CVA	35%	69	30%	30	2	105.6
2	m	54	14	F	12	r	L CVA & L frontal	48%	205	90%	46	14	143.5
3	f	64	19	NF	23	r	L fronto-parietal	51%	128	56%	0	4	154
4	m	43	10	NF	30	r	L CVA	56%	198	86%	0	12	167
5	m	51	15	NF	17	r	L temporo-occipital & R frontal & R temporo-occipital	56%	149	65%	0	8	167.5
6	f	56	13	F	18	r	L parieto-temporal	57%	111	48%	52	1	172
7	m	59	18	F	6	r	L CVA	61%	140	75%	46	11	182
8	f	64	13	NF	26	r	L fronto-parietal & R fronto-parietal	62%	200	87%	49	3	187
9	m	45	16	NF	52	r	L fronto-parietal & R cerebellum	63%	190	83%	49	12	187.5
10	m	62	19	NF	11	r	L parieto-temporal	64%	199	87%	46	5	192
11	m	66	14	F	52	amb	L temporal	66%	217	95%	54	10	197
12	m	68	15	F	11	r	L CVA	67%	225	98%	54	10	200
13	f	66	15	F	39	r	L temporal	67%	179	78%	44	8	201.5
14	f	70	14	F	16	r	L temporo-occipital & R temporal osteoma	71%	185	81%	38	7	213
15	m	55	12	NF	18	r	L fronto-temporal	72%	181	79%	47	12	214.5
16	m	58	17	F	12	r	L temporo-occipital & R frontal angioma	72%	60	41%	54	10	215
17	m	54	15	NF	23	r	L fronto-temporal	73%	228	100%	54	14	220
18	m	68	11	F	50	r	L VCA	77%	219	96%	52	13	230
19	f	67	13	NF	12	r	L temporal hemorrhage + L thalamus	79%	190	83%	34	0	237
20	f	70	15	NF	8	r	L occipital & L fronto-parietal & R fronto-parietal	79%	207	90%	43	6	
21	m	59	17	F	5	r	L CVA	80%	221	97%	54	12	240
22	m	40	15	NF	120	r	L fronto-temporal & L thalamus	80%	162	71%	38	1	240.5
23	m	50	13	F	4	r	Brainstem	83%	220	96%	53	5	249
24	m	58	13	NF	10	r	L CVA	84%	207	90%	47	8	250.5
25	f	70	18	F	6	r	L fronto-parietal	84%	209	91%	53	11	250.5

(*Continued*)

Table 2. (Continued).

Number	Gender	Age	Education	Fluency	MPO	Hand	Lesion site	QASA score	Picture naming, accuracy	Picture naming, %	Auditory attention, accuracy	Rule finding, accuracy	AQ
26	m	57	11	NF	4	r	L frontal	84%	214	93%	37	9	253
27	m	44	13	NF	9	r	L CVA	86%	224	98%	45	10	259
28	m	62	16	F	19	r	L temporal	88%	214	93%	50	7	264
29	m	62	14	NF	4	amb	L CVA	90%	200	87%	43	9	269
30	m	67	15	F	36	r	L frontal	92%	191	83%	42	13	276
31	f	69	19	F	33	r	L temporal hemorrhage	94%	217	95%	54	13	282

Note. NF = nonfluent; F = fluent; MPO = months post onset; AQ = aphasia quotient according to QASA (max. total score is 300).

analysis because (1) they had no specific Russian names (i.e., *thumb, toe*) or (2) they were not familiar to Russian speakers (i.e., *artichoke, toaster, peanut, asparagus, baseball bat, celery, barn, church, football, garbage can, roller skate*) or (3) they were complex words in Russian (i.e., *kite/vozdushny zmey, ironing board/gladilnaya doska, lamp/nastolnaya lampa, leaf/klenovy list, rocking chair/kreslo-kachalka, seahorse/morskoy konek*) or (4) they had extreme values in psycholinguistic variables (i.e., *lion* had an extreme value in visual complexity, 212). Participants were instructed to name pictures as fast and as accurately as possible. Once a participant responded, the experimenter pressed a key and the next picture was shown on the screen after 500 ms. Pictures in the naming task were presented in a random order for each participant. Normative data as presented in Tsaparina et al. (2011), were used to judge PWA's response accuracy. Nondominant names produced by PWA were judged as correct if at least two healthy Russian speakers had used this name as stated in the normative data (supplementary material from Tsaparina et al., 2011).

Cognitive control tasks

To measure cognitive control, two tasks from the Russian version of the Birmingham Cognitive Screen (Rus-BCoS; Kuzmina et al., 2018) were used and administered together in one session: *Auditory Control* and *Rule Finding tasks*. In the *Auditory Control task*, participants were instructed to listen to audio-recorded word sequences and tap when they heard target words (e.g., "hello," "yes," "thanks") while ignoring semantically related distractors (e.g., "goodbye," "no," "please"). Accuracy calculated as the sum of responses to targets and no-responses to distractors was taken as a measure of selective attention. The *Rule Finding task* including three practice and 19 test trials is comparable to the Brixton Spatial Anticipation Test (Burgess & Shallice, 1997) and measures the ability to detect and follow a rule. Cognitive control ability was measured as an average between standardized performance scores for *Rus-BCoS Auditory Control* and *Rule Finding tasks.*

Data analysis

As Brysbaert and Ellis (2016) have suggested, mixed-effect linear regression was used to test whether cognitive control mediates the effects of psycholinguistic variables on naming accuracy in aphasia. To identify multicollinearity, the Spearman correlation coefficients between the eight psycholinguistic variables of interest were checked: the correlation coefficients varied from $\rho = -.03$ to $\rho = .82$ (see Table 3). Following recommendations from Field, and colleagues (2012), the correlation between imageability and conceptual familiarity, $\rho = .82$, was defined as very high and potentially problematic for the multiple regression analysis. As rating

Table 3. Spearman correlation coefficients between the psycholinguistic variables.

	NA	CF	AOA	IM	NS
CF	.04				
AOA	−.21**	−.51***			
IM	.13*	.82***	−.48***		
NS	−.06	−.05	.20**	−.03	
WF	.09	.45***	−.42***	.38***	−.23***

Note. NA = name agreement, CF = conceptual familiarity, AOA = age of acquisition, IM = imageability, NS = number of syllables, WF = word frequency.

imageability was deemed to be easier than rating conceptual familiarity, the latter was excluded from further analysis. Thus, the maximal model of binary naming accuracy included the following predictors:

(1) three clinico-demographic variables: months post onset, age, education;
(2) five psycholinguistic variables: name agreement, AoA, log-transformed word frequency, imageability, number of syllables;
(3) one cognitive control measure;
(4) five interactions between the above-listed psycholinguistic variables and cognitive control;
(5) random slopes for each participant.

All variables were scaled and standardized before being used in mixed-effect linear regression. The backward elimination stepwise procedure was applied for model selection: at each step, a variable with the highest *p*-value in the model was excluded and the new model was compared to the previous one through a likelihood ratio test. If there was no significant difference between the models, the simpler one (i.e., containing less variables) was chosen for further analysis.

The variance inflation factors (VIF) of the main effects were found for the predictors to identify strong linear relationships among them. VIF values varied from 1.06 to 1.42; therefore, all variables were kept for further analysis. The whole analysis was performed in R (R Core Team, 2013) (for the analysis script, see Appendix).

Results

Details of the model selection process can be found in ***Appendix 1***. In the final model (see Table 4), the following effects appeared to be significant predictors of naming accuracy in PWA:

(1) main effect of log-transformed word frequency: pictures of more frequent words were named more accurately;
(2) main effect of AoA: pictures of earlier acquired words were named more accurately;
(3) main effect of cognitive control: PWA with better preserved cognitive control named pictures more accurately;
(4) interaction between log-transformed word frequency and cognitive control: frequency effect in naming accuracy was more prominent in PWA with lower performance on the cognitive control tasks.

Table 4. Summary of the final mixed-effect linear regression model of oral picture-naming accuracy in PWA.

Effects	Estimate	Std. Error	z-value	*p-value*
(Intercept)	2.12	0.20	10.46	0.000
Age of acquisition	−0.28	0.04	−7.68	0.000
Word frequency, log	0.59	0.04	13.07	0.000
Cognitive control	1.05	0.26	4.06	0.000
Word frequency, log * Cognitive control	0.16	0.05	3.56	0.000
sd_(Intercept).patient	1.09	NA	NA	NA

Discussion

The aim of this study was to examine whether cognitive control mediates the effects of psycholinguistic variables, more specifically name agreement, AoA, and word frequency, on accuracy in object naming in aphasia. The following research questions were posed:

(1) Is there an interaction between cognitive control and name agreement in the accuracy of object naming?
(2) Is there an interaction between cognitive control and word frequency in the accuracy of object naming?
(3) Is there an interaction between cognitive control and AoA in the accuracy of object naming?

Looking at all the three research questions, there was a significant main effect of cognitive control, meaning that participants with lower performance on the cognitive control tasks were less accurate at object naming. For research question 1, the answer is negative. We expected that cognitive control abilities would mediate the role of name agreement in naming in PWA, as suggested by Bose and Schafer (2017). However, our results do not show any effect of name agreement in naming, although Bose and Schafer have shown that the effect of name agreement is more pronounced in PWA compared to healthy adults. Our results are, however, in line with previous research where no significant effect of name agreement in naming was found (Kittredge et al., 2008).

The answer to research question 2 is, as expected, yes. We found a significant main effect for log-transformed word frequency: pictures depicting more frequent words were produced more accurately. In addition, a significant interaction between word frequency and cognitive control was evident. Thus, our results point to a stronger frequency effect in naming accuracy in PWA with weaker cognitive control compared to PWA with better preserved cognitive control. As high-frequency words are typically used more than less frequent words, we assume that they are more accessible, and less cognitive control is needed to retrieve low-frequency words than high-frequency words.

Finally, for research question 3, the answer is somewhat mixed. No significant interaction between cognitive control and AoA was found. This is interesting as an interaction was found between cognitive control and word frequency. AoA and word frequency have been shown to be highly correlated (Brysbaert & Ellis, 2016), and it could be assumed that cognitive control would mediate the AoA effect on naming accuracy in PWA in a similar fashion to word frequency. As there was no interaction between AoA and cognitive control, we speculate that the frequency effect is more to do with exposure and use of language, whereas AoA may be more about the maturation of the brain: as PWA have suffered brain injury in their adult age, AoA is not as affected by their cognitive control as word frequency. However, it has to be taken into account that we used a “frequency-independent” task, according to Brysbaert and Ghyselink’s (2006) terminology, namely picture naming. This can explain our findings. Thus, it seems that the pure AoA effect does not seem to be mediated by cognitive control in naming in aphasia. In the future, it would be important to study the possible mediating effects of cognitive control on AoA by using “frequency-related” AoA measures, such as reading written words aloud quickly and lexical decision, as suggested by Cuetos and Barbón (2006). Although we did not find significant interactions between cognitive control and AoA, it was still important to include both AoA and word frequency in the analysis as including both psychological variables is of great theoretical interest to examine their interactions (see also, Brysbaert & Ellis, 2016).

What do our results tell us about the effect of cognitive control on the different stages of spoken picture naming? Based on our results, PWA named pictures with low AoA more accurately compared to pictures with high AoA. As expected, the accuracy of naming was also higher for high-frequency words than for low-frequency words. However, the only significant interaction was found between cognitive control and word frequency. In this study, then, cognitive control seems to have mediated word frequency in naming in aphasia. Based on the models of language production (Levelt, 1999; Levelt et al., 1999; Dell, 1986; Dell et al., 1997; Indefrey, 2011), it can further be proposed that PWA may have difficulty with lexical access, which is mediated by cognitive control. Thus, the lower the PWA's cognitive control abilities are, the less accurately they are able to access lexemes and produce the accurate name for a picture depicting a low-frequency word. Through the lens of psycholinguistic variables, more frequent words, and hypothetically also words acquired earlier, would have fewer competitors at the lexical level of word retrieval, making them easier to retrieve, as they do not require as much inhibition, as less frequent words, or earlier acquired words. Thus, we suggest that the performance of PWA is not consistent with the view that they are losing their lexical presentations, but that the impairment may lie in the access to words. More active lexical elements can be more easily retrieved and require less inhibition than less active lexical elements.

Conclusions

To conclude, our findings suggest that cognitive control does in fact mediate word frequency in naming in aphasia. PWA with weaker cognitive control name pictures depicting less frequent words less accurately than more frequent words. However, even though it has been shown that AoA and word frequency are highly correlated, no such interaction was found between cognitive control and AoA in this study. This may be due to the fact that the task used in this study was a “frequency-independent” task (Brysbaert & Ghyselink, 2006).

The psycholinguistic variables reflect different stages of language production depicted in several models (Levelt, 1999; Levelt et al., 1999; Dell, 1986; Dell 1997; Indefrey, 2011). Based on our findings, it seems that within language production, PWA has the greatest difficulty with lexical access. The implications of this study are that word frequency is important for language production, and it is even more important when people have impaired cognitive control. When a person has more severe deficits in cognitive control, communication can be enhanced by using highly frequent words and structures. In aphasia rehabilitation, the focus should be on very frequent structures and words as these are usually more preserved in PWA with weaker cognitive control. The present study contributes to a better understanding of factors – both external attributes of testing materials and internal cognitive processes of patients – that mediate oral naming in aphasia. Understanding these factors will, in turn, inform theories of oral lexical-semantic retrieval, and should be of importance for developers of language assessment materials, as well as rehabilitation, in aphasia.

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No potential conflict of interest was reported by the author(s).

ORCID

Leena Maria Heikkola http://orcid.org/0000-0002-1795-7656

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