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The origins of age of acquisition and typicality effects: Semantic processing in aphasia and the ageing brain

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ABSTRACT

Age of acquisition (AOA) has frequently been shown to influence response times and accuracy rates in word processing and constitutes a meaningful variable in aphasic language processing, while its origin in the language processing system is still under debate. To find out where AOA originates and whether and how it is related to another important psycholinguistic variable, namely semantic typicality (TYP), we studied healthy, elderly controls and semantically impaired individuals using semantic priming. For this purpose, we collected reaction times and accuracy rates as well as event-related potential data in an auditory category-member-verification task. The present results confirm a semantic origin of TYP, but question the same for AOA while favouring its origin at the phonology-semantics interface. The data are further interpreted in consideration of recent theories of ageing.

1. Introduction

Various linguistic variables influence word processing in healthy individuals, as well as in individuals with aphasia (IWA). In IWA, those variables often indicate the specific underlying deficit during language assessment (critical-variable approach; Shallice, 1988). Increased effects of variables such as concreteness or typicality in aphasic speech perception or production often point to a semantic deficit, while word frequency effects indicate lexical-phonological impairments (Nickels and Howard, 1995). Age of acquisition (AOA) has been described as one of the most important variables in aphasic speech production (Brysbaert and Ellis, 2015). However, its actual role at stages of speech perception in IWA has not been investigated so far.

Age of acquisition (AOA) characterises the point in time when a word has first been learned and produced in language acquisition (for reviews, see Juhasz, 2005; Johnston and Barry, 2006). The influence of AOA in word processing was first differentiated from word frequency by Carroll and White (Carroll and White, 1973) in a picture naming task. Early acquired words are processed faster and more accurately than late acquired words, that is generally referred to as the AOA effect. To date, numerous behavioural studies in healthy young participants investigated the influence of AOA on a wide range of psycholinguistic tasks. Aside from written picture naming (Bonin et al., 2006), increased AOA effect sizes have been found in tasks requiring spoken output processes, such as word reading (Bonin et al., 2004; Gerhand and Barry, 1998; Monaghan and Ellis, 2010; Morrison and Ellis, 2000) and picture naming (Catling and Johnston, 2009; Belke et al., 2005; Cuetos et al., 1999; Holmes and Ellis, 2006). Further, AOA effects have also been described in tasks related to the perception of words and pictures, albeit with smaller effect sizes than in the studies above: in lexical decision tasks (Smith et al., 2006; Ghyselinck et al., 2004b; Menenti and Burani, 2007), semantic categorisation tasks (Ghyselinck et al., 2004a; Brysbaert et al., 2000), and particularly in animacy decision tasks (Catling and Johnston, 2006; De Deyne and Storms, 2007; Räling et al., in preparation). However, others have been unsuccessful in finding AOA effects in semantic processing (e.g., Morrison et al., 1992; Holmes and Ellis, 2006).

To date, a consensus on the origin of AOA effects in cognitive models of language processing has not yet been achieved. The range of AOA effects in language processing tasks that involve input and output levels casts doubts on accounts that pinpoint effects of AOA at speech production levels only (e.g., at the phonological output level, Brown and Watson, 1987; Gerhand and Barry, 1998; Laganaro and Perret, 2011; Perret et al., 2014). For this purpose, an origin of AOA effects at the semantic processing level that accounts for AOA effects occurring in tasks that involve input as well as output modalities has been discussed (Brysbaert et al.,

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2000; Ghyselinck et al., 2004a; Steyvers and Tenenbaum, 2005; van Loon-Vervoorn, 1985). To account for varying of AOA effects sizes, some authors also discuss an origin of AOA effects at multiple levels of language processing: Belke et al. (2005; see also Brysbaert and Ghyselinck, 2006) suppose a distinction between frequency-related and frequency-independent AOA effects. Frequency-related AOA effects have been shown to be highly yoked with (cumulative) frequency effects (Lewis, 1999) and might occur wherever learning plays a role. Thus, effects of frequency-related effects are supposed to appear independently from modality and processing stage. They are assumed to be disseminated in the connection strengths between representations within the entire cognitive system and occur whenever access to learned information is mandatory (as has been proposed by Ellis and Lambon Ralph, 2000, in a connectionist model). Frequency-independent effects enable explanations of increased AOA effect sizes which are not related to word frequency and have been reported in tasks that require spoken output subsequent to a semantic analysis (i.e., in picture naming). Accordingly, Brysbaert and Ghyselinck (Brysbaert and Ghyselinck, 2006) propose the origin of frequency-independent AOA effects to be located either at the conceptual/semantic level or, more likely, at the semantics-phonology interface at output stages (lemma level) (see also Belke et al., 2005). These accounts refer to speech production (i.e., output level). Another account that postulates AOA effects at multiple levels is the accumulative account of Catling and Johnston (Catling and Johnston, 2006; Catling and Johnston, 2009). The authors assume additive AOA effects, the more levels of language representation are involved in task-relevant processing. Accordingly, tasks requiring additional spoken output result in increased AOA effect sizes as compared to lexical decision or semantic categorisation tasks. Catling and Johnston (Catling and Johnston, 2009) set the origins of AOA effects on early perceptual/structural, phonological and/or semantic-phonological-mapping representation levels. Here, we aim at evaluating frequency-independent AOA effects at the auditory input level by using a category-member verification task.

When determining the origin of AOA effects, it seems useful to consider not only behavioural data such as reaction times and accuracy rates in young healthy adults, but to expand the data by means of electrophysiological measures and different populations. So far, event-related potential (ERP) studies exclusively evaluating the AOA variable are very rare, and present rather inconsistent findings. For silent word reading, Cuetos, Barbon, Urrutia, and Dominguez (Cuetos et al., 2009) report an influence of AOA on the N400 component – a negative ERP wave peaking at about 400 ms post-stimulus onset, which is associated with semantic processing and varies with the effort of the preceding context alignment (Federmeier and Laszlo, 2009; Kutas and Federmeier, 2011; Kutas and Hillyard, 1984). In contrast, other ERP studies instead found no evidence for a semantic origin (at input stages: lexical decision: Tainturier et al., 2005; category-member-verification: Räling et al., 2015; or at output stages: object naming: Laganaro and Perret, 2011; Perret et al., 2014).

Investigating word processing in IWA is supposed to provide additional significant insights into the language processing system and may help to verify or modify existing cognitive models. With regard to AOA, its influence on impaired language processing has been examined to predict naming performance and vocabulary loss in various studies, including individuals suffering from Alzheimer's disease, semantic dementia, acquired dyslexia and aphasia (see Brysbaert and Ellis, 2015; Ellis, 2011 for reviews), indicating its significant impact on speech production following semantic analyses. Studies investigating aphasic language processing were not aimed at pinpointing the origin of AOA effects but at determining AOA as a significant predictor of picture naming accuracy only and mostly neglected a possible influence of AOA on speech perception. From today's perspective, drawing conclusions about the origin of AOA on the basis of previous studies on aphasia is hardly possible since a) the focus was primarily on picture naming and b) IWA were not selected with respect to their specific underlying language deficit, but based on the presence of general word-finding difficulties, which might occur on various levels in word production. This could explain why, in these studies, AOA was a predictor of semantic as well as phonological errors in aphasic picture naming (semantic errors: Cuetos et al., 2002; Nickels and Howard, 1995; phonological errors: Cuetos et al., 2002; Kittredge et al., 2008).

AOA intercorrelates very highly with semantic variables such as imageability or concreteness, and to a lesser extent with lexical variables such as word frequency (e.g., Morrison et al., 1997; Ramey et al., 2013; Rubin, 1980)[1]. Thus, systematically analysing further relationships of AOA with semantic variables such as semantic typicality (TYP) while controlling for word frequency might provide further insight into the origin of AOA effects (Brysbaert et al., 2000). TYP has been described as a category member's representativeness of a superordinate, semantic category. The underlying theory of prototypes (Rosch and Mervis, 1975; Osherson and Smith, 1981; Rosch, 1973; Rosch, 1975) assumes that typical members (e.g., *sparrow* for BIRDS) share many semantic features with a mental, idealised prototype of a category. More recent accounts consider TYP to be represented in the semantic system by the typicality of features in connectionist models (McRae et al., 1999). Thus, typical members possess features which are highly intercorrelated with the features of other typical members (e.g., having feathers and wings as typical intercorrelated features for the category BIRDS), while atypical members are represented by rather distinct and less intercorrelated features (McClelland and Rogers, 2003; Rogers et al., 2004). Numerous behavioural studies on TYP (see Räling et al., 2015, for a summary) demonstrated a processing advantage for typical vs. atypical words during semantic processing, stressing its semantic origin (see also Woollams, 2012 for a discussion on the semantic origin of TYP). Typical words are processed faster and with greater accuracy than atypical words in semantic tasks without speech production, such as category-member-verification (e.g., Holmes and Ellis, 2006; Kiran et al., 2007) and animacy decisions (Morrison and Gibbons, 2006; Räling et al., in preparation). TYP effects have also been found in tasks requiring verbal output, such as picture naming (Dell'Acqua et al., 2000), word reading (Garrod and Sanford, 1977), or category-member-generation (Hernández-Muñoz et al., 2006). ERP studies on the N400 component support a semantic origin of TYP. Studies report a more negative N400 for atypical compared to typical words in visual and auditory category-member-verification tasks (e.g., Fujihara et al., 1998; Heinze et al., 1998; Pritchard et al., 1991; Räling et al., 2015; Stuss et al., 1988).

Analogous to AOA, TYP also significantly influences language processing in aphasia, in that typical items are better preserved than atypical ones, as reflected in reaction times and accuracy rates. TYP effects in aphasia have mainly been studied at input stages with semantic category-member-verification tasks (Sandberg et al., 2012; Grober et al., 1980; Kiran et al., 2007; Kiran and Thompson, 2003; Riley and Thompson, 2010), but also in tasks requiring speech production, such as picture naming (Rossiter and Best, 2013) or category-exemplar generation (Grossman, 1981; Hough, 1993). The majority of studies did not select the participating IWA with respect to their specific underlying language

[1] But, see Schröder, Gemballa, Ruppin, and Wartenburger (Schröder et al., 2012) for comparable correlation coefficients of AOA and word frequency ($r = -.57$), AOA and concept familiarity ($r = -.58$), and AOA and TYP ($r = .50$).