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Functional and time-course changes in single word production from childhood to adulthood

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ABSTRACT

Picture naming tasks are widely used both in children and adults to investigate language production for research and for assessment purposes. The main theoretical models of single word production based on the investigation of picture naming in adults provide a detailed account of the principal mental operations involved in the transformation of an abstract concept into articulated speech and their temporal dynamics. These models and in particular their time-course do not apply directly to children who display much longer production latencies than adults. Here we investigate the functional processes and the temporal dynamics of word encoding in school-age children and adults. ERPs were analysed from picture onset to the onset of articulation in 32 children and 32 adults performing the same overt picture naming task. Waveform analyses were not informative since differences appeared throughout the entire period, due to an early shift of waveform morphology and to larger amplitudes in children. However, when the sequences of periods of topographic stability were considered, different patterns of electric fields at scalp only appeared in approximately the first third of the analysed period, corresponding to the P1–N1 complex. From about 200 ms in adults and from 300 ms in children to articulation onset similar patterns of global topography were observed across groups but with a different time distribution. These results indicate qualitative changes in an early time-window, likely corresponding to pre-linguistic processes, and only quantitative changes in later time-windows, suggesting similar mental operations underlying lexical processes between age-school children and adults, with temporal dynamic changes during development.

Introduction

Both adults and children can produce a familiar word corresponding to the concept they wish to communicate fluently and effortlessly. Such a transformation of a pre-linguistic concept into articulated speech sounds requires a series of cognitive and neurophysiological processes which have been investigated widely with picture naming tasks in psycholinguistic (Levelt et al., 1999; Dell, 1986) and neuroimaging studies (Indefrey and Levelt, 2004; Price et al., 2005) on (young) adult speakers. Although the sequential or parallel nature of the processes underlying word production is still under debate, there is a general agreement on the necessity and existence of a minimal set of mental operations involved in such tasks. When speakers produce a word corresponding to a depicted object, they first analyse the picture visually and recognize it before beginning linguistic planning. Word encoding then entails lexical–semantic processes, that is, the lexical selection or the retrieval of the word – the lemma – in the mental lexicon and lexical–phonological processes or the encoding of the phonological form – lexeme – , which constitutes the input to the preparation of motor plans (phonetic encoding) for articulation. The time-course of these processes has been estimated in a meta-analysis of behavioural and event-related potential (ERP) studies by Indefrey and Levelt (2004), and then updated on the basis of more recent evidence (Indefrey, 2011). In picture naming tasks, visual and conceptual processes are estimated to take place during the first 190–200 ms after picture presentation, followed by lexical–semantic processes (lemma retrieval) until about 275 ms. Word form (lexeme) retrieval and phonological encoding processes are thought to be engaged until 400–500 ms followed by phonetic encoding and motor execution.

These estimates of the timing of the different cognitive processes have been made for adult word production. They provide a general framework for studying the dynamics of word production in adults, although mean production latencies vary considerably across experiments, raising the question of rescaling the duration of processing stages. Indefrey (2011) suggested that linear rescaling in the case of faster or longer response latencies is probably not the correct approach as, depending on the experimental conditions, specific processes may take less or more time. Laganaro et al. (2012) suggested that variation in object naming speed in a group of young adults is attributable to a single underlying electrophysiological process starting around 200 ms that lasts longer in slower participants. The question of rescaling the durations of processing stages is all the more relevant when populations

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with longer response times are considered, such as children. Here, the core question we are interested in is how these encoding processes and their timing change during development. School-age children have a vocabulary of approximately 10,000 words (Clark, 1993), and they are able to name the picture of many objects (Cycowicz et al., 1997; D'amico et al., 2001). However, even on items they can correctly name, children show longer production latencies than adults (e.g., 7 year-olds are 330 ms slower than adults in D'amico et al., 2001), and picture naming latencies speed up considerably during school-age (e.g., from ~1860 ms in 7 year-olds to ~1500 ms in 12 year-olds in Bragard et al., 2010).

Despite lower accuracy and longer production latencies (RTs) in children relative to adults, most behavioural studies point to the fact that globally the same psycholinguistic variables predict accuracy (Cycowicz et al., 1997) and production speed (D'amico et al., 2001; Bragard et al., 2010) in school-age children and adults. Other studies focusing on specific task manipulations known to influence word planning in adults (e.g., semantic interference and phonological facilitation) also observed the same effects on RTs in school-age children (Brooks and McWhinney, 2000; Jerger et al., 2002). Adult models also seem to account for picture naming errors in school-age children. Budd et al. (2011) fitted picture naming errors produced by children with a model previously used to simulate errors produced by aphasic adults and reported a good fit after the age of eight. Taken together, these behavioural studies suggest that, at least after the age of seven years, the same encoding processes underlie single word production in children and adults despite fairly different production latencies (see also Brooks and McWhinney, 2000, for differences on a rhyme phonological priming task in younger children).

Neuroimaging studies using functional magnetic resonance to compare language production in children and adults have shown largely overlapping activated brain regions between these two groups but also areas with higher haemodynamic response in children than in adults as well as the opposite (Brown et al., 2005; Krishnan et al., 2014). These differences in the activation patterns observed in children and adults may reflect qualitative changes in underlying processes (as for instance differences in task monitoring as suggested by Krishnan et al., 2014) and/or quantitative changes across age groups related to the cognitive demand affecting the duration and strength of the activation of specific brain regions. Qualitative and timing differences between children and adults have been tracked with magnetoencephalographic (MEG) or electroencephalographic (EEG) evoked potential studies. Most ERP studies on language development have focused on speech perception and comprehension in infants and on written word processing in school-age children. Perception studies have shown that already very early in their development children display the same electrophysiological components as adults; changes are mainly in timing, with later peaks in children than in adults (Friederici, 2006). The very few ERP studies investigating language production with picture naming tasks in school-age children have led essentially to the same conclusions. For instance, Budd et al. (2013) reported ERP latency shifts in 12 year-old children relative to adults in a verb production (conjugation) task. Greenham and Stelmack (2001) used a picture naming task in the context of a reading study with 9 to 13 year-old children and adults and reported similar waveforms in children and adults with enhanced amplitudes in children.

In sum, most behavioural and neuroimaging studies suggest that the cognitive processes and ERP components underlying language processing are similar for children and adults. Indeed, it seems that it is the time-course of the underlying processes rather than the processes themselves that are subject to developmental changes. The former changes are suggested in particular by longer latencies of waveform components in children's ERPs. Such shifts have been reported on both early ERP components associated with auditory or visual perception (e.g., at P50 and P100 peaks for auditory and visual stimuli respectively, Holcomb et al., 1992) and on later components associated with language processing (prolonged N400 in a semantic task in Friedrich and Friederici, 2005; shifted component at 300–550 ms in the verb conjugation task in Budd et al., 2013). Given that these results focused on specific ERP components in various experimental paradigms and ages, it is not possible to conclude whether only specific word planning processes speed up from childhood to adulthood or if the increases in processing speed are distributed across all processing stages.

In the present study we take advantage of local waveform analyses combined with global topographic analyses to investigate the functional and temporal dynamics of changes in word production from childhood to adulthood. We will analyse periods of stable electric field (topographies) in the ERP signal, which can be associated with specific periods of information processing (Changeux and Michel, 2004; Koukou and Lehmann, 1987), from picture onset to the individual onset of articulation in children and adults. The combination of stimulus-aligned and response-aligned ERPs enables to cover the entire planning period for each participant and to account for differences in production latencies across individuals and groups (Laganaro and Perret, 2011, see Laganaro, 2014 for the rationale and the description of the method). The analysis of periods of stable electric fields (topographic analysis) allows us to disentangle functional changes (different topographies) between age-groups from changes in the temporal dynamics (same periods of stable electric field which are differently distributed). If only processing speed increases from children to adults, the same functional microstates should be observed in the two groups but with different durations. Such changes in the duration of processing stages may be distributed throughout the processes underlying word production in picture naming (simple rescaling) or be limited to specific time-windows, corresponding to specific encoding processes.

Method

Participants

Thirty-three school-age children and 32 adults (undergraduate students) participated in the study. The data of one child was removed from the data set due to excessive noise in the EEG signal. The children were recruited from two age-groups, namely “7–8 year-old” children (16 participants, age range: 7–8 year-old, average: 7.2, 8 females) and “10–12 year-old” children (16 participants, age range: 10–12 year-old, average: 11.6, 5 females). Adults were recruited among undergraduate students (aged 20–30) and were divided a posteriori into two subgroups: 16 adults aged 20 to 22 (average: 20.8, 13 females) and 16 adults aged 24–29 (average: 26, 12 females). They were all right-handed but one ambidextrous in each children group and native French speakers without diagnosed reading impairment or neurological disease. Adults were recruited through announcements posted at the university whereas children were recruited through Geneva public schools. This study was approved by the local ethics committee; adults gave their written informed consent and parents' approvals were collected for their children. Children were offered a small present and a voucher whereas adults were paid for their participation.

Stimuli

120 black and white drawings and their corresponding modal names were selected from two French databases (Alario and Ferrand, 1999; Bonin et al., 2003). The stimuli corresponded to words with an age of acquisition range of 1.19–3.55 on a five-point scale (1: learned between 0 and 3 years; 4: learned between 9 and 12 years) and high name agreement (mean = 92.5%) to ensure that participants give the same name for a same picture. A preliminary test carried out with two 7-year-old children without previous familiarisation allowed to make sure that the majority of the words were named correctly by the