Sustained Attention in Language Production

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Sustained Attention in Language Production

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Chapter 1

Introduction

Language production is a task we perform every day. An adult speaker produces 20.000 words a day on average, which can add up to 2.5 hours of non-stop talking. Considering it is such a highly practiced skill, it is perhaps surprising that our speech is susceptible to errors and disfluencies. Yet, more and more evidence is provided that language production is not a fully automatic process. Instead, to successfully and fluently produce words, attention is required. Already in the initial models of language production, concepts such as control and automaticity are touched upon. For instance, in his seminal book *Speaking: From Intention to Articulation* (1989) Levelt writes: "Given the existences of central or executive control, an important question is to what degree the various processing components are subject to such control." One might think that twenty years onwards we know the answer to this question, but there are still many open questions. One main aim of this thesis is to see if only some processes of production call upon attention or if all stages require control. Levelt, amongst others, argued that the early process of word production, message generation, requires a speaker's continuous attention. The stages that follow were assumed to be automatic. Since then, several studies have investigated this question and shown that even stages beyond message generation are subject to attention (Cook & Meyer, 2008; Ferreira & Pashler, 2002; Roelofs, 2008a). However, it still remains unclear at which point exactly in the production process the need for control ends and automaticity starts.

What do I actually mean by attention? Attention is a concept we regularly use and encounter in our daily lives, and if asked what we mean by attention we would likely describe it in a way as James did (although probably less eloquently): "Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration, of consciousness are of its essence." (1890). However, since then attention has been heavily researched and attention does not seem to be a unitary function. Attention can in fact refer to several different, cognitive capacities. This is often overlooked by psycholinguists; studies tend to only look at the distinction between automaticity versus non-automaticity. Only recently researchers have started to make a distinction between different types of attention and relating them to language production (Piai & Roelofs, 2013; Shao, Roelofs, & Meyer, 2012). Does production rely on all these types of attention or only on a few? Do different subcomponents of attention target the same stages of word production or are they involved in different stages?

In this thesis, I focused on one aspect of attention, namely sustained attention. Sustained attention denotes the ability to maintain attention over a longer period of time. This has been a largely understudied component of attention in language production even though there is reason to believe it could play a significant role. This evidence comes from a clinical population, children with specific language impairment to be exact. These children not only struggle with language production but also with sustaining their attention. This raises the possibility that the latter problem (partly) underlies the first. Imagine what could happen if you lose your attention somewhere halfway through the process of producing a word or phrase. You might have to completely start over, resulting in incoherent and slow speech. You might even forget what it was you wanted to say and make an error, or say nothing at all. It seems conceivable that a problem with sustained attention can have serious consequences for language production, but this has received very little attention (pun intended).

Using a range of methods and samples I have tried to investigate whether sustained attention is required for fast and accurate language production. Is sustained attention always necessary or only in certain situations? Does sustained attention play a role in all individuals, or only in clinical populations? Are all processes of word production affected by sustained attention, or only a few? How is sustained attention related to different types of attention? Can a lapse of attention be predicted? These are some of the questions I have tried to answer in my thesis. In the remainder of this chapter I first describe which processes are involved in language production. Second, I give a brief summary of the different aspects of attention, with sustained attention explained in more detail. Next, what is already known about language production and attention is discussed. Finally, I provide an outline of my thesis.

Language Production

Language production research first started over a century ago with the examination of speech errors and reaction times (RTs), see Levelt (2013) for a historical description. The first modern language production models, developed in the 1970s and 1980s, were based on the distribution of different error types (i.e., Dell, 1986; Fromkin, 1971; Garrett, 1980), whereas later production models put more emphasis on error-free speech production (i.e., Caramazza, 1997; Levelt, 1989; Levelt, Roelofs, & Meyer, 1999). Although these models differ considerably, there is some general consensus on which processes are necessary for production. In this thesis, I follow the word production model developed by Levelt, Roelofs, and Meyer (1999). They have proposed that word production comprises different subsequent stages, the first being conceptual preparation. At this initial stage the target concept is decided upon. Suppose someone has to name a picture of a dog: depending on the situation, this picture not only can be referred to as 'dog' but also as 'animal'. The current context determines which of these concepts is most appropriate. Semantically related concepts, such as cat, also become active at this stage of processing. All concepts, not just the target, send activation to the next level.

This next level is called the lexical selection stage where the concepts activate their corresponding lemmas. A lemma specifies syntactic information including grammatical class, and parameters for tense, number and person features. The activated lemmas are in competition with each other for selection. The third stage is word-form encoding. The phonological code is retrieved per morpheme, after which the syllable structure of the utterance is created. Then, the created syllables need to be phonetically encoded: the syllables are specified for the successive articulatory targets. The final step of production is the execution of the speech movements (articulation). Another component of the production model is the process of self-monitoring. This monitoring not only occurs after a word has been articulated by listening to ones own overt speech, but also during planning. This latter monitoring of "inner speech" is thought to occur after phonological encoding.

Producing words in isolation rarely occurs in natural situations, so a model of language production must also be able to explain multiple word utterances. Eye tracking has been used to examine the temporal alignment of processing stages in producing a multiple word utterance. Eye tracking studies are based on the finding of Deubel and Schneider (Deubel & Schneider, 1996) that saccades, or gaze shifts, and visual attention are tightly coupled, both temporally and spatially. When a subject makes a saccade to a new location, his or her visual attention will also be at this new location: gaze shifts indicate attention shifts. Meyer, Sleiderink, and Levelt (1998) used this knowledge about gaze shifts to investigate attention allocation during noun phrase production. By targeting specific stages in the production model using different manipulations, the authors showed that a saccade from the first to the second to-be-named object occurs only after completion of phonological encoding of the first. This suggests that during articulation of the first phrase, a speaker will already phonologically encode the next.

Attention

As evident from the earlier quote by James, attention was already a topic of interest in the 19th century. Since then it has been shown that attention is a broad term that encompasses several subcomponents. An influential model was developed by Posner and colleagues (Petersen & Posner, 2012; Posner & Petersen, 1990; Posner & Rothbart, 2007). The proposed attention system consists of three networks termed alerting, orienting and executive control. Alerting is the ability to maintain alertness over prolonged periods of time during task performance (tonic alertness), referred to as *sustained attention*, and to become alert in response to a warning signal (phasic alertness). Orienting refers to the ability to shift the focus of processing towards a source of information (i.e., spatial position), either with or without eye movements (i.e., overtly or covertly). Finally, executive control is the ability to remain goal-directed in the face of distraction. Different anatomical regions have been indicated for the three attentional networks (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Fan, McCandliss, Sommer, Raz, & Posner, 2002). Posner and colleagues (e.g., Petersen & Posner, 2012, for a review) showed that alerting depends on fronto-parietal cortical activation together with locus coeruleus and the thalamus, whereas orienting depends on the superior parietal lobes, frontal eye fields, and superior colliculus. Finally, the executive control network includes the anterior cingulate cortex and lateral frontal areas as well as the basal ganglia. This indicates that these three attention networks are functionally and anatomically distinct from one another.

The executive attention network has been further decomposed into three functions, namely updating, inhibiting and shifting. Miyake and colleagues showed that updating and monitoring of working memory representations, inhibition of dominant or prepotent responses, and shifting between tasks or mental sets are largely separable functions (Miyake et al., 2000). All in all, it has become clear that attention is not a unitary phenomenon, and that several cognitive capacities contribute to the state of mind that James described.

Sustained Attention

Sustained attention is part of the alerting system, one of the three attention networks described in the previous section. It refers to the ability to maintain alertness over a longer period. Interest in sustained attention heightened during the second world war, when radar operators had to monitor for very infrequent signals during a long shift. This proved to be difficult, with far-reaching consequences, as they sometimes missed a signal indicating enemy presence. Mackworth (1948) showed that alertness becomes increasingly difficult to maintain as time on task increases.

Since then, many studies have looked at the variables that influence sustained attention. Sustained attention ability is typically assessed using a continuous performance task (CPT). A CPT requires participants to monitor a series of stimuli for a specific, infrequent target (for reviews see Ballard, 2001; Langner & Eickhoff, 2013; Oken, Salinsky, & Elsas, 2006; Robertson & O'Connell, 2010; Sarter, Givens, & Bruno, 2001). When sustaining attention is taxed, individuals tend to miss targets, respond incorrectly to non-targets (false alarms), and respond more slowly. Moreover, as time during a task passes performance deteriorates; this is referred to as the performance decrement.

It has been shown that sustained attention can be affected by three types of factors. First, certain task parameters can influence sustained attention. Performance on a sustained attention task deteriorates the more infrequent the target signal, when stimuli are degraded, when it is uncertain where in space a stimulus will appear, and when stimuli are presented at a high speed (McFarland & Halcomb, 1970; Mouloua & Parasuraman, 1995; Parasuraman, 1979; Parasuraman, Nestor, & Greenwood, 1989). Second, individuals' characteristics can play a role in sustained attention performance. For instance, older participants tend to perform worse than younger adults (Parasuraman et al. 1989). Moreover, individuals with ADHD or schizophrenia exhibit deficits in sustained attention (Epstein, Johnson, Varia, & Conners, 2001; Liu et al., 2002). Third, environmental factors such as noise can affect sustained attention performance (Broadbent & Gregory, 1965).

Language Production and Attention

Evidence is accumulating that language production requires some form of attention, even in simple single word production. This evidence comes from a range of studies using different methods. One line of research has used neuro-imaging to identify brain areas involved in language production (for a meta-analysis see Indefrey & Levelt, 2004). Some of these studies have shown activation of areas associated with the attention networks (for a review see Roelofs, 2008b). For instance, Kan and Thompson-Schill (2004) found higher activation in prefrontal areas when a picture had several naming options (low name agreement) than when a picture could only be described with one word, suggesting frontal areas related to attentional processes are involved in word selection. A similar finding was obtained using electro-encephalography (EEG) when looking at the N2, an event-related potential component related to inhibitory processes. Shao, Roelofs, Acheson, and Meyer (2014) showed that pictures with low name agreement showed larger N2 amplitudes than high name agreement pictures, suggesting inhibitory mechanisms are called upon when choosing between several alternative names.

A second line of evidence comes from dual-task experiments. The dual-task procedure is a widely used method to test attention demands (i.e., Pashler, 1994; Szameitat, Schubert, Müller, & Von Cramon, 2002; Welford, 1952). It is assumed that when both tasks interfere, evident from slower RTs, both tasks call upon the same central, limited pool of attentional resources. This provides evidence that these tasks cannot be performed fully automatically, otherwise no interference effect should be present. Several dual-task experiments have shown that word production causes interference on a simultaneous, unrelated task (Becic et al., 2010; Kubose et al., 2006). It seems word production also taps into this shared attentional resource. However, there is still disagreement about which stages require attention and which are automatic, with the tipping point suggested to be either before or after phonological encoding (Ferreira & Pashler, 2002 vs. Cook & Meyer, 2008; Roelofs, 2008a).

Third, studies taking an individual differences approach have suggested that language production needs attention. Shao, Roelofs, and Meyer (2012) examined whether individual differences in executive control could explain variation in language production. They found that individuals with better updating and inhibiting skills were faster in naming pictures. Updating skills were correlated to picture naming RT in a study by Piai and Roelofs

(2013) as well. Executive control therefore seems to play a role in production. Shao et al. found no relationship between shifting and picture naming RT, which shows that not all attentional components are necessarily involved in language production. However, in a study that involved switching between phrase types in picture description, Sikora, Roelofs, Hermans, and Knoors (2015) obtained correlations between updating, inhibiting, and shifting abilities and production performance.

Finally, impaired language performance can be associated with deficits in attention capacities. One example is specific language impairment (SLI). Children with SLI are characterized by IQ levels similar to typically developing (TD) children, but their language abilities are far below average. The most common problems are word-finding difficulties and morpho-syntactic problems, especially the comprehension and production of grammatical morphemes (Leonard, 2014). In recent years, the idea that SLI is a purely linguistic deficit is disappearing as many studies report difficulties in non-linguistic tasks as well. Several studies have shown deficits in updating and inhibition (Henry, Messer, & Nash, 2012; Im-Bolter, Johnson, & Pascual-Leone, 2006; Marton, Kelmenson, & Pinkhasova, 2007).

Language Production and Sustained Attention

The previous section shows there is ample evidence that attention is involved during language production. However, this is limited to one of the attention networks, namely executive control. Less is known about the other two attention networks: alerting and orienting. There is a hint of evidence that sustained attention, part of the alerting network, also plays a role during production. Sustained attention has repeatedly been shown to be impaired in children with SLI as compared to typically developing (TD) children (for a meta-analysis see Ebert & Kohnert, 2011).

As far as I know, only two studies have tried to relate sustained attention ability directly to linguistic abilities in children with SLI. Montgomery and colleagues observed that sustained attention accounted for variance in performance on a sentence comprehension task for the SLI group, but not for the TD group (Montgomery, 2008; Montgomery, Evans, & Gillam, 2009). For production, the only evidence comes from Duinmeijer, De Jong, and Scheper (2012). Sustained attention ability in children with SLI correlated with the generation of plot elements when telling a picture story: children with better sustained attention generated more plot elements. These two studies provide evidence for some role of sustained attention in the language performance of children with SLI. As updating and inhibition seem to be involved in language production both in children with SLI as in healthy adults, the same could be true for sustained attention.

Overview of the thesis

The main goal of this thesis is to find out whether sustained attention is involved in language production. Is sustained attention required at all times, or only under certain conditions? Are certain stages of production more susceptible to a lapse of attention than others? Does sustained attention play a role in language production in all speakers, or only certain populations? These questions I have tried to answer in this thesis, using a variety of methods.

In Chapter 2, I have used the individual differences approach to find out whether healthy adult individuals with good sustained attention perform better at describing pictures than individuals with poor sustained attention. If this is true, then it would suggest that sustained attention is required for successful production. Moreover, this study investigated where in the process of production sustained attention played a role, by measuring gaze durations. Is sustained attention called upon during the early stages of production or can we also find evidence that later stages need attention?

In Chapter 3, I have investigated under which circumstances sustained attention plays a role. Is sustained attention only involved in difficult task settings, or is it also essential in more natural language production? The individual differences approach was taken just as in Chapter 2. Again, besides measuring speech onset, gaze durations were included to localize the effect of sustained attention.

In Chapter 4, I compared children with SLI with TD children while specifically investigating a possible difference in the relationship between sustained attention performance and picture naming in development. I investigated whether sustained attention correlated with picture naming performance, and whether this relationship was stronger for the SLI group than for the TD group. If correlations are obtained, this would provide evidence for the hypothesis that sustained attention underlies the production problem in children with SLI.

Chapter 5 set out to tax sustained attention in a simple word production task: can sustaining attention be made increasingly difficult and if so, does this subsequently affect production performance? A variable that has previously shown to tax sustained attention was used in a picture naming task to see if it would also tax language production.

Chapter 6 uses EEG to see whether there are electrophysiological signatures for failures to become or remain alert, which in turn predict poorer performance on a picture naming task. This would suggest that the attentional state before the onset of a trial is important in determining how well an individual can initiate and complete word production.

Finally, Chapter 7 summarizes the findings and discusses what we now know about the role of sustained attention in language production.

Chapter 2

Sustained Attention in Language Production: An Individual Differences Investigation

Whereas it has long been assumed that most linguistic processes underlying language production happen automatically, accumulating evidence suggests that these processes do require some form of attention. Here we investigated the contribution of sustained attention: the ability to maintain alertness over time. In Experiment 1, participants' sustained attention ability was measured using auditory and visual continuous performance tasks. Subsequently, employing a dual-task procedure, participants described pictures using simple noun phrases and performed an arrow-discrimination task while their vocal and manual response times (RTs) and the durations of their gazes to the pictures were measured. Earlier research has demonstrated that gaze duration reflects language planning processes up to and including phonological encoding. The speakers' sustained attention ability correlated with the magnitude of the tail of vocal RT distribution, reflecting the proportion of very slow responses, but not with individual differences in gaze duration. This suggests that sustained attention was most important after phonological encoding. Experiment 2 showed that the involvement of sustained attention was significantly stronger in a dual-task situation (picture naming and arrow discrimination) than in simple naming. Thus, individual differences in maintaining attention on the production processes become especially apparent when a simultaneous second task also requires attentional resources.

Jongman, S. R., Roelofs, A., & Meyer, A. S. (2015). Sustained attention in language production: An individual differences investigation. *The Quarterly Journal of Experimental Psychology, 68*(4), 710-730.

Introduction

Language production is a highly practiced skill that seems to happen effortlessly. However, it has been shown that speaking can have detrimental effects on unrelated tasks such as driving (Kubose et al., 2006) and vice versa (see Roelofs & Piai, 2011, for a recent review). This suggests that the production process is not completely automatic but requires some form of attention. The question arises what type of attention and how much of it is needed for error-free and fluent language production, and whether certain aspects of the production process require more attention than others.

An essential component of phrase and sentence production is the planning of words. Several accounts of word planning have been proposed (e.g., Caramazza, 1997; Dell, 1986; Levelt, Roelofs, & Meyer, 1999). Here we follow Levelt et al. (1999) and assume that the production of a single word consists of the following processes: conceptual preparation, lemma retrieval, and word-form encoding, which includes morphological, phonological, and phonetic encoding. To produce a word, a speaker must first select a concept that conveys the intended message. The target concept sends activation to the next level. This is the lemma retrieval stage, where the corresponding lemma is activated and selected, together with its syntactic properties such as grammatical class. This is followed by morpho-phonological encoding, where the phonological segments of each morpheme are retrieved and combined into syllables. During phonetic encoding the successive articulatory targets are specified, which are then executed to result in articulation. Speakers continuously monitor their utterances for errors. This self-monitoring not only occurs after a word has been articulated by listening to the speech output, but also during planning. This latter monitoring of "inner speech" is thought to be based on phonological word representations, created during phonological encoding.

In this paper we examine whether attention is required for successful word and phrase production. Attention is an umbrella term, comprising several different types of abilities. According to an influential theoretical proposal by Posner and colleagues (Petersen & Posner, 2012; Posner & Petersen, 1990; Posner & Rothbart, 2007), attention consists of executive control, orienting, and alerting. Executive control is the ability to remain goal-directed in the face of distraction. According to Miyake and colleagues (Miyake et al., 2000), executive control can be decomposed into updating (the ability to maintain or actively manipulate the contents of working memory and monitor incoming information), inhibiting (the ability to resolve conflict or lower activation of unwanted information), and shifting (the ability to rapidly switch back and forth between tasks or mental sets). Orienting concerns the ability to shift the locus of processing towards a source of information (i.e., a particular spatial position), either with or without corresponding eye movements (i.e., overtly or covertly, respectively). Alerting is the ability to achieve and maintain alertness, either briefly (e.g., in response to a warning signal) or prolonged over extended periods of time. The latter type of attention is often referred to as vigilance or sustained attention (Sarter, Givens, & Bruno, 2001). It is the focus of our two experiments.

The different stages of word production outlined above could require these different attentional abilities to different extents. According to Garrod and Pickering (2007), the early stages of the language production processes (i.e., conceptual preparation and lemma retrieval) require more attention than the later stages (e.g., word-form encoding and articulation). This view is supported by evidence from Ferreira and Pashler (2002), who asked participants to name pictures while simultaneously performing an unrelated tone discrimination task with manual responses. This dual-task procedure is a widely used method to test whether or not two tasks draw upon a shared pool of processing resources (e.g., Pashler, 1994; Szameitat, Schubert, Müller, & Von Cramon, 2002; Welford, 1952). When the time interval between the stimuli determining the responses becomes shorter, response time (RT) for the second task increases (the psychological refractory period or PRP effect), even in cases of tasks that do not share input or output modalities. Such interference is commonly taken as evidence for central capacity sharing between the two tasks.

In the dual-task experiment conducted by Ferreira and Pashler (2002), the durations of early and late word planning stages were manipulated by presenting written distractor words superimposed onto the pictures. The distractor words could be semantically related to the target, affecting the early stage of lemma retrieval relative to unrelated distractors, or they could be phonologically related, affecting the later stage of phonological encoding. Usually, semantically related words increase picture naming RTs relative to unrelated words, whereas phonologically related distractors decrease RTs (e.g., Damian & Martin, 1999; Schriefers, Meyer, & Levelt, 1990). In Ferreira and Pashler's study, the semantic effect on picture naming RTs was propagated onto the tone discrimination RTs, but the phonological effect was not. This suggests that the early stage of lemma retrieval requires attention, thereby delaying the performance of another task (i.e., tone discrimination), whereas the later stage of phonological encoding requires no attention. However, Cook and Meyer (2008) and Roelofs (2008a) found that, under certain circumstances, phonological effects on picture naming RTs may be propagated onto the RTs of performing unrelated manual tasks, suggesting that phonological encoding may require attention as well. Moreover, although these studies suggest that early and late stages of word production may require some form of attention, it is unclear which of the attentional abilities mentioned above are needed.

More recent research has examined which of the attentional abilities contribute to the speed of spoken word production. In an individual differences study, Shao, Roelofs, and Meyer (2012) examined the contributions of the three components of executive control (updating, inhibiting, and shifting) distinguished by Miyake et al. (2000) to picture naming performance. Their results showed that participants with better updating and inhibiting abilities were faster in naming pictures than participants with poorer updating and inhibiting. However, shifting showed no correlation, which suggests that this ability does not contribute to simple picture naming.

To examine whether updating and inhibiting consistently contribute to picture naming speed or only to a subset of the responses, Shao et al. (2012) performed ex-Gaussian analyses of the RT distributions. Analyses based on mean RTs assume a symmetric distribution around the mean, but RT distributions are typically positively skewed. Ex-Gaussian analysis provides estimates of parameters that characterize the shape of an RT distribution and gives much more information than just changes in mean RT performance (e.g., Balota & Yap, 2011; Balota, Yap, Cortese, & Watson, 2008; Heathcote, Popiel, & Mewhort, 1991; McAuley, Yap, Christ, & White, 2006). An ex-Gaussian analysis decomposes the mean RT into a parameter (μ) characterizing the normal (Gaussian) part of the underlying RT distribution and a parameter (τ) reflecting the tail end (i.e., RTs that are “abnormally” long, deviating from the normal part).

Using this analysis, Shao et al. observed that updating ability was correlated with τ characterizing the distribution tail but not μ, the normal distributional part of both action and object naming RTs. In other words, poorer updating did not result in overall slowing of naming responses but increased the number of very slow responses. Inhibiting capacity was correlated with the normal part of the RT distribution in action naming and the tail in object naming. This suggests that inhibition was regularly needed for action naming, but only on some of the trials in object naming. This could be explained by the fact that the action pictures were more complex and might have evoked more alternative responses than the object pictures. Therefore action naming required inhibition more regularly than object naming.

In the study by Shao et al. (2012), updating ability did not correlate with the mean RT of object naming but only with the distribution tail. This finding suggests that the contribution of updating ability to word planning is especially evident on difficult trials. This conclusion was further supported by evidence from Piai and Roelofs (2013), who made object naming more difficult by embedding it in a dual-task setting and superimposing written distractor words upon the object pictures. The dual-task situation was similar to the task used by Ferreira and Pashler (2002) except that tone discrimination responses had to precede rather than follow object naming responses. The distractor words were semantically related or unrelated to the targets. Piai and Roelofs observed a correlation between updating ability and the mean RT of object naming, suggesting that such a correlation with mean RT may be obtained when the naming situation is difficult (which was not the case in the study by Shao et al.). Moreover, updating ability correlated with the magnitude of dual-task interference of tone discrimination on object naming. However, there was no correlation between updating ability and the magnitude of the semantic interference effect of the distractor words. This suggests that the contribution of updating is especially evident before lemma retrieval, the production stage targeted by the semantic interference effect.

The studies by Shao et al. (2012) and Piai and Roelofs (2013) suggest that the executive control functions of updating and inhibiting, but not shifting, contribute to picture naming by adult speakers. Interestingly, evidence suggests that these same attentional functions are affected in children with specific language impairment (SLI). Until recently, it was thought that SLI reflects a pure linguistic deficit, mostly in the language production domain. Children with SLI are characterized by IQ levels similar to typically developing (TD) children, but their language abilities are far below the average level. The most common problems are word-finding difficulties and morpho-syntactic problems (Leonard, 2014). However several studies have reported deficits in attentional abilities in SLI compared with TD children (Henry, Messer, & Nash, 2012; Im-Bolter, Johnson, & Pascual-Leone, 2006; Marton, Kelmenson, & Pinkhasova, 2007; for a review see Montgomery, Magimairaj, &

Finney, 2010). Im-Bolter et al. (2006) and Henry et al. (2012) observed that children with SLI have deficits in updating and inhibiting but not in shifting. This provides additional evidence that updating and inhibiting play a role in language production, whereas shifting does not (at least when shifting is not explicitly required), as suggested by the individual differences studies of Shao et al. (2012) and Piai and Roelofs (2013).

The studies discussed above concerned components of executive control (i.e., updating, inhibiting, shifting), but these are not the only attentional abilities that may contribute to language production performance. Evidence from studies of SLI suggests that sustained attention also plays an important role. Sustained attention, the ability to maintain alertness for a longer time period, also seems to be deficient in children with SLI (for a meta-analysis see Ebert & Kohnert, 2011). For example, Montgomery and colleagues observed that children with SLI performed worse than TD children on an auditory sustained attention task. Moreover, in the SLI group but not the TD group, sustained attention accounted for 45% of unique variance in the performance on a sentence processing task (Montgomery, 2008; Montgomery, Evans, & Gillam, 2009). Evidence from Duinmeijer, de Jong, and Scheper (2012) suggests that sustained attention is important for successful language production as well: Within a group of children with SLI, sustained attention ability correlated with the successful generation of plot elements when telling a story. These studies provide evidence for a role of sustained attention in the language performance of children. However, it is unclear whether sustained attention also contributes to language production performance of adult speakers, and if so, which language planning stages are most sensitive to individual differences in sustained attention ability.

The aim of the present research was to investigate the contribution of sustained attention to language production in healthy adults. We used the individual differences approach applied previously when investigating executive control processes in relation to language performance. Sustained attention ability is typically assessed using a continuous performance task (CPT), which measures vigilance by requiring participants to monitor a series of stimuli for a specific target. The stimuli can be presented auditorily or visually. Sustaining attention becomes increasingly difficult when a task is very boring or highly repetitive (for reviews see Ballard, 2001; Langner & Eickhoff, 2013; Sarter et al., 2001). In two experiments, sustained attention performance was correlated with a performance in a language production task, either picture description (Experiment 1) or picture naming

(Experiment 2). In Experiment 1, participants were presented with colored objects, which they either described using determiner-noun or determiner-adjective-noun phrases. The picture description task was performed in a dual-task situation with spatially separated task stimuli: The participants first described a picture shown on the left side of the screen and then categorized an arrow shown on the right side. Different phrase types were used to determine whether longer phrases require more sustained attention than shorter phrases. In Experiment 2, participants were asked to name objects using single nouns, either as their only task or in a dual-task setting. This comparison was used to find out whether sustained attention is consistently needed for language production or whether it is required only, or to a larger extent, when attention has to be divided between production and a second unrelated task.

For both experiments, we did not only examine mean RTs but also performed ex-Gaussian analyses to decompose the RT distributions into the μ component reflecting the normal part and τ reflecting the right tail of the RT distribution. We expected that an effect of sustained attention would most likely be found in the τ parameter of the RT distribution of the language production tasks because this parameter has been most strongly associated with sustained attention in previous research (Unsworth, Redick, Lakey, & Young, 2010).

Experiment 1

The language production task in the first experiment was a picture description task. On each trial one of four pictures appeared in one of four colors. On half the trials, participants were asked to describe the colored object by producing determiner-noun phrases referring to the object but not its color, such as “de fiets” (the bike), henceforth “short phrases”. On the other half of the trials, participants not only had to refer to the object but also to its color by producing determiner-adjective-noun phrases, such as “de groene fiets” (the green bike), henceforth “long phrases”. We expected that the correlation of naming RTs with sustained attention would be stronger for the long phrases than for the short phrases. This is because more information needs to be accessed and encoded for long phrases, putting higher demands on the production system and possibly also on the sustained attention system. We used a small set of pictures and colors in order to make the task rather boring so that maintaining alertness would be a challenge. By doing this we hoped to increase the chance that individual differences in sustained attention would be reflected in the picture description latencies.

To localize the effect of sustained attention within the language production process, we exploited the fact that in picture naming and description tasks, speakers tend to maintain their eye gaze on the relevant objects until the process of phonological encoding is completed, and then, shortly before speech onset, shift their gaze to the next target (i.e., Korvorst, Roelofs, & Levelt, 2006; Meyer & Van der Meulen, 2000). This has been shown for multiple object naming and for tasks where participants first name an object and then shift their gaze to categorize a symbol (Griffin, 2001; Roelofs, 2008a). In both types of tasks, gaze durations are related to the length (measured in number of syllables or segments) and frequency of the object names (Meyer, Roelofs, & Levelt, 2003; Meyer, Sleiderink, & Levelt, 1998). In the present study we combined picture description with symbol categorization. We presented a picture on the left side of the screen and an arrow, pointing left or right, on the right side. The participants were asked to describe the picture and then indicate the direction of the arrow by pressing a left or right button. The object and arrow were presented simultaneously on the screen. Thus, we used a dual-task situation with a stimulus onset asynchrony of 0 ms. For an illustration of the visual display, see Figure 1A.

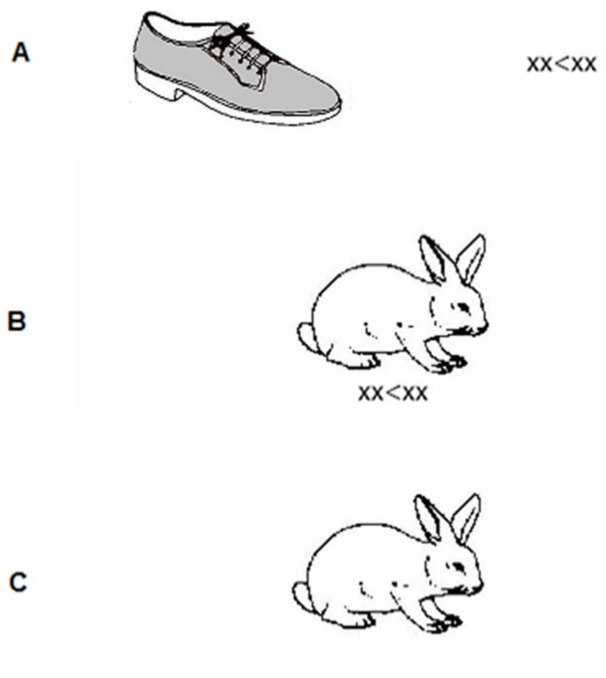

Figure 1. Illustration of the visual stimulus displays used in Experiment 1 (A) and Experiment 2, separately for the dual-task condition (B) and the single-task condition (C).

As noted, earlier studies have shown that speakers typically look at each object they name until they have generated the phonological representation of the corresponding utterance fragment. If a high level of sustained attention is invariably needed for all word production stages, and processes up to phonological encoding are critically sensitive to sustained attention, individual differences in sustained attention ability should correlate with the gaze durations as well as with picture description latencies. This would be consistent with findings suggesting that the early stages of word production demand attention (Ferreira & Pashler, 2002; Garrod & Pickering, 2007; Piai & Roelofs, 2013). In contrast, if only processes following phonological encoding (i.e., phonetic encoding and self-monitoring based on phonological representations) are critically sensitive to sustained attention, the correlation should be found for the picture description latencies, but not for the gaze durations. Note that in our task, a correlation with only the picture description latencies could also reflect that a high level of sustained attention is not constantly needed but is only required in more demanding situations. This is because a shift of gaze reflects a shift of the focus of attention away from the object towards the arrow discrimination task. Thus the arrow discrimination task then overlaps in time with the final steps of preparing an object names. This overlap of the processes of the two tasks could place greater demands on sustained attention ability than the preceding production stages would do. In all cases (i.e., critical sensitivity of all production stages to sustained attention or sensitivity only when attentional capacity is shared), correlations are expected to be strongest for the τ parameter of the latency distributions as revealed by ex-Gaussian analyses.

A second aim of this experiment was to examine whether or not adults would show a dissociation between performance on sustained attention tasks that differ in stimulus modality. Noterdaeme, Amorosa, Mildenberger, Sitter, and Minow (2001) found that children with SLI did less well than typically developing children on auditory CPTs but performed equally well on visual CPTs. This led Spaulding, Plante, and Vance (2008) to postulate separate sustained attention abilities for different stimulus modalities. However, opposing evidence was obtained by Finneran, Francis, and Leonard (2009), who found a sustained attention deficit for children with SLI on a visual CPT. The conflicting findings could be due to differences in task parameters, as suggested by Ebert and Kohnert (2011), who performed a meta-analysis on the available literature on sustained attention and SLI. They showed that studies that failed to find a deficit in the visual modality for children with

SLI used longer stimulus durations than studies that did report such deficits. Corkum and Siegel (1993) suggested that longer stimulus durations place less of a demand on attentional capacities. Therefore it is possible that the attention system of children with SLI was not taxed enough in those studies that failed to find deficit in the visual modality.

For Experiment 1, we created two CPTs that differed only in modality, modeled after the task used by Finneran et al. (2009) which is closest to CPTs used in adult research. We correlated the participants' performance in the two tasks, and we determined how well performance on each task correlated with their performance in the picture description task. A subset of participants returned for a second session in order to assess task reliability.

In summary, Experiment 1 examined whether sustained attention plays a role in language production using an individual differences approach. Whereas sustained attention ability has been found to correlate with language comprehension and production performance in children, we examined such correlations in adults. We expected to find a correlation between sustained attention ability and the τ parameter of object description latencies, as τ has previously been associated with sustained attention. Moreover, if processes up to phonological encoding are critically sensitive to sustained attention, individual differences in sustained attention ability should also correlate with the durations of the gazes to the objects. However, if only processes after phonological encoding are critically sensitive to sustained attention, or if sustained attention is required only when task demands increase, no such correlation with gaze durations should be obtained. Finally, we examined how well performance on visual and auditory sustained attention tasks correlated with each other and whether the tasks differed in how well they predicted performance in object description tasks.

Method

Participants

Eighty-one students of the Radboud University Nijmegen or the Hogeschool van Arnhem en Nijmegen took part in the first session of the study. All participants were native speakers of Dutch and had normal or corrected-to-normal vision. The average age was 21.0 years (range: 18-29) with 56 participants being female. Twenty-two participants returned for a second session (see below). Participants were paid for taking part in the study. Ethical approval was granted by the Ethics Board of the Faculty of Social Sciences of the Radboud University Nijmegen.

General Procedure

During the first session, participants performed the auditory and visual CPTs. The order of tasks was counterbalanced across participants. Thereafter, participants carried out the picture description task. In the second session, which took place approximately two weeks after the first session, the CPTs were repeated to assess their test-retest reliability.

Continuous Performance Tasks

Materials and design. The target stimulus for the visual CPT (VCPT) was a red circle, and the non-target was a red square. Stimuli were 3.2 by 3.2 cm, shown on a 20 inch screen (Acer TCO03). The red stimuli in the VCPT were presented on a white background using Presentation Software (Version 16.2, www.neurobs.com). The auditory CPT (ACPT) used a high tone (800 Hz) as the target and a low tone (300 Hz) as the non-target stimulus. The tones were played through headphones (Sennheiser HD201).

Targets, circles or high tones, were presented with a probability of 20%. In each task, there were 300 trials, divided into two blocks for analysis purposes. Each block therefore consisted of 30 targets and 120 non-targets, presented randomly.

Procedure. The procedure for the two CPTs was identical. Stimuli were presented for 400 ms each. Participants responded to the target stimuli with a button press using their dominant hand. The inter-stimulus interval ranged from 1500 to 2500 ms. Each sustained attention tasks took approximately 12 minutes.

Analyses. RTs were measured and errors were divided into misses and false alarms with the former being failures to respond to targets and the latter being responses to non-targets. The visual and auditory CPTs were analyzed using R (R Core Team, 2012) and the R packages *lme4* (Bates, Maechler, & Bolker, 2013) and *languageR* (Baayen, 2011). The data were analyzed with a linear mixed effect model including modality and block and the interaction as fixed effects. Factors were mean-centered and the RTs were log transformed because of positive skewing. Participant was included as a random effect (Baayen, Davidson, & Bates, 2008). Random slopes were included for modality and block and for their interaction to capture additional variability at the subject level (Barr, Levy, Scheepers, & Tily, 2013). The model provides estimates, standard errors and *t*-values for each coefficient; factors with *t* greater than the absolute value of 2 were considered to significantly contribute to explaining the dependent variable (Baayen, 2008).

Picture Description Task

Materials and design. Four common objects, *vis* (fish), *kast* (cupboard), *fiets* (bicycle), and *schoen* (shoe), were selected from a database of normed pictures (Severens, Van Lommel, Ratinckx, & Hartsuiker, 2005). The object names have high frequency (mean lemma frequency: 59 tokens per million; CELEX database, Baayen, Piepenbrock, & Gulikers, 1995) and high name agreement (98% in the norming study by Severens et al.) They are monosyllabic, of non-neuter gender, and from different semantic categories.

On each trial, one object was presented in one of four colors, *rood* (red), *blauw* (blue), *geel* (yellow), or *groen* (green). The color words had a mean frequency of 95 tokens per million occurrences in CELEX. No color name shared the beginning phoneme with any of the object names. Each of the objects occurred in each of the four colors in natural situations.

The colored pictures were presented in the center of the left half of the computer screen, fit into a virtual frame of 4 by 4 cm. On the right side of the screen an arrow flanked by rows of x on both sides was presented (font Times New Roman, size 20). There were four objects with four possible colors thus resulting in 16 stimuli. These objects could either be accompanied by a left arrow or a right arrow, which yielded 32 displays. These 32 displays were presented in a randomized order in ten blocks, so that there were 320 trials in total.

In half of the blocks, participants described the colored objects by producing determiner-noun phrases, such as “de fiets” (the bike). In the remaining blocks, they named the object color as well by producing determiner-adjective-noun phrases. The determiner was always “de”, and in the long phrases, all color adjectives ended in schwa, as in "de rode kast" (the red cupboard). Blocks with short phrases alternated with blocks with long phrases. Block order was counterbalanced across participants.

Procedure. Participants were tested individually in a dimly illuminated room. They were seated in front of a 20 inch screen (Acer TCO03) with their chin on a chin rest, approximately 1 m away from the screen. The movements of each participant's right eye were recorded with an Eyelink 1000 Tower Mount eye tracker sampling at 1000 Hz. After object description, participants indicated the direction of the arrow by pressing either the left or right arrow on the keyboard (HP KB0316). One second after the button press, the next trial was presented. Spoken utterances were recorded with a Sennheiser ME64 microphone.

Analyses*.* Vocal responses were recorded and RTs were determined manually using the program Praat (Boersma & Weenink, 2012). Description errors and hesitations were coded offline and discarded from the analyses of RTs and gaze durations, as were button press errors. Using the algorithm provided by the Eyelink software, gaze duration was defined as the time interval between the beginning of the first fixation on the picture and the end of the last fixation before the first shift of gaze was initiated to the arrow. Log-transformed latencies were analyzed with a linear mixed effect model with phrase type and block as fixed effects including their interaction. Fixed effects were centered and the dependent measures were log transformed because of positive skewing. Participant and item were treated as random effects, with both intercepts and random slopes included for all factors.

Analyses of Individual Differences

Ex-Gaussian analyses were performed to characterize each participant's latency distributions for the gaze durations and naming responses. The ex-Gaussian function consists of a convolution of a normal (Gaussian) and an exponential distribution and can be used to decompose the latency distribution into three parameters: μ, σ, and τ. The parameters μ and σ reflect the mean and standard deviation of the normal portion, respectively, and τ reflects the mean and standard deviation of the exponential portion. The sum of μ and τ equals the mean latency, with μ reflecting the normal part and τ the tail of the underlying latency distribution.

The ex-Gaussian parameters μ, σ, and τ were estimated from the naming latencies and gaze durations using the continuous maximum-likelihood method proposed by Van Zandt (2000). In contrast to the linear mixed effect analyses, latencies were not log-transformed for the ex-Gaussian analysis. The parameters were estimated separately for the short and long phrases and for each participant individually using the program QMPE (Heathcote, Brown, & Cousineau, 2004). The parameters μ and τ were then correlated, using Pearson's product-moment correlations, with individuals' mean RTs for the CPTs. The parameter σ was not included in these analyses because it was not of interest in the present study and to limit the number of comparisons. Both the visual and auditory CPTs were administered again in a second session after approximately two weeks for a subset of participants, and correlations were computed to test reliability.

Results

Data from thirteen participants had to be excluded for the following reasons. To allow for ex-Gaussian analysis using continuous maximum-likelihood fitting, at least 100 trials per condition are necessary. For seven participants, too few eye fixations were recorded in the picture description task due to tracker loss. Three participants were excluded because they misunderstood the task instructions. Finally, three participants were considered to be outliers based on their performance in the two CPTs as calculated using the Mahalanobis distance. A multivariate outlier was defined as having a probability of equal or less than .001. This left data from 68 participants.

Continuous Performance Tasks

Very few errors were made, in total only 0.5% false alarms and 0.3% misses, precluding any further analysis. Table 1 shows the results of the linear mixed effect model analyses performed on the RTs. The table reveals that no main effect of modality or block was obtained, but the interaction reached significance. Whereas RTs increased across blocks for the VCPT from 445 to 456 ms, a decrease from 450 to 444 ms was found for the ACPT.

Table 1. Results of mixed effect model analyses of the log-transformed reaction times for the two continuous performance tasks in Experiment 1. The estimated coefficient (ß), standard error (SE) and t-value (*t*) are presented.

Fixed effects	*ß*	SE	*t*
Intercept	6.07	0.02	326.60*
Modality	0.02	0.02	1.24
Block	0.00	0.01	0.51
Modality*Block	0.03	0.01	3.30*

*A coefficient is a significant predictor at $p < .05$ using the criterion that $|t| > 2$

Picture Description Task

The participants made naming errors on 2.2% of the trials, hesitated on 2.7% of the trials, and chose the incorrect arrow direction on 1.0% of the trials. All of these trials were eliminated from the following analyses. As expected, the participants usually (on 90% of the trials) first looked at the object and then at the arrow. On most of the remaining trials, they briefly looked at the arrow, then at the object, and then again at the arrow. On 97% of the trials, articulation was initiated before the button press, indicating participants followed task instructions to describe the object first and then categorize the arrow. The trials where arrow discrimination preceded picture description have been removed from the analyses.

For the correct trials, the linear mixed effect models for the different dependent measures (gaze durations, picture description latencies and key presses) all showed a block effect in that latencies decreased over time. We refer to Table 2 for the mean latencies, standard errors, and error rates and to Table 3 for the results of the model analyses. Only the gaze durations and the key presses showed a main effect of phrase type (short vs. long), with gaze shifts and key presses being initiated earlier for the short utterance than the long utterances. This effect of phrase type was absent for the vocal latencies.

Individual Differences

The correlation between the RTs of the two CPTs reached significance, $r = .66$, $p < .001$. Thus, participants who performed well on the visual CPT also performed well on the auditory CPT confirming the hypothesis that these two tasks tap into a modality-independent sustained attention ability. Performance was stable over time as reflected by

Table 2. Mean latencies (ms), standard error (SE) and error percentages (E%) per phrase condition for the gaze durations, the vocal responses and the manual responses in the picture description task in Experiment 1.

	Gaze		Vocal			Manual		
Phrase Type	M	SE	M	SE	E%	M	SE	E%
Short	499	3.1	752	2.3	1.51	1199	3.9	1.41
Long	646	3.8	761	2.3	2.83	1451	4.3	0.68

Table 3. Results of mixed effect model analyses of the log-transformed latencies for the gaze durations, vocal responses and manual responses in Experiment 1. The estimated coefficient (*ß*), standard error (SE) and *t*-value (*t*) are presented.

	Gaze			Vocal			Manual		
Fixed	*ß*	SE	*t*	*ß*	SE	*t*	*ß*	SE	*t*
Intercept	6.16	0.04	139.82*	6.59	0.02	329.34*	7.14	0.02	316.31*
Phrase	0.26	0.02	14.93*	-0.00	0.01	-0.04	0.19	0.01	18.98*
Block	-0.06	0.01	-5.29*	-0.03	0.00	-9.02*	-0.05	0.00	-10.61*
Phr*Bl	0.00	0.01	0.13	-0.00	0.01	-0.81	0.00	0.01	0.26

*A coefficient is a significant predictor at $p < .05$ using the criterion that $|t| > 2$

the high correlations between the two sessions (22 participants; $r = .88$, $p < .001$, for the visual CPT, and $r = .95$, $p < .001$, for the auditory CPT).

The estimates of the ex-Gaussian parameters of the picture description task are presented in Table 4. The correlations between the mean latency and the parameters μ and τ, on the one hand, and the CPT RTs, on the other hand are given in Table 5. Note that the latencies for the CPTs, gaze shifts and vocal responses, were not log transformed in these analyses of correlations. Scatterplots are shown in Figure 2. There were significant correlations between the CPTs and the picture description latencies, specifically for the slow vocal responses. The VCPT and the τ parameter of the long phrases showed a correlation of $r = .31$, $p < .05$, whereas the ACPT showed a correlation with τ for both the short and long phrases, $r = .26$, $p <.05$, and $r = .32$, $p <.01$, respectively. There were no significant correlations with the μ parameter of the vocal latencies (all *r* values below .11). There were no significant correlations between the CPTs and the gaze durations, with all *r* values being below .16 for the μ parameter and below .06 for τ.

We compared the correlations of the CPTs with the τ parameter of the vocal latencies for short phrases versus long phrases using Steiger's *z* test. We found that the correlation of τ with VCPT was significantly stronger for the long phrases than for the short phrases, $z = 2.27$, $p = .02$. The correlations of τ with ACPT did not differ significantly between the long and short phrases ($z = 0.67$, $p = .51$).

Table 4. Mean values of ex-Gaussian parameters mu (µ), sigma (σ) and tau (τ) per phrase condition for the gaze durations and vocal responses in Experiment 1.

	Gaze			Vocal		
Phrase Type	µ	σ	τ	µ	σ	τ
Short	293	91	203	601	71	157
Long	428	142	216	611	75	149

Table 5. Correlations between the mean reaction times of the two continuous performance tasks and the mean latencies (*M*) and the mu (µ) and yau (τ) parameter for gaze durations and vocal responses in Experiment 1. Pearson's *r* (*r*) and *p*-values (*p*) are presented.

			Short Phrase			Long Phrase		
Task			*M*	µ	τ	*M*	µ	τ
Gaze	VCPT	*r*	.142	.160	.005	.085	.095	-.031
		p	.247	.193	.970	.492	.443	.804
	ACPT	*r*	.143	.122	.060	.155	.130	.036
		p	.246	.321	.628	.208	.289	.768
Vocal	VCPT	*r*	.088	.042	.096	.190	.057	.309*
		p	.475	.735	.438	.120	.642	.010
	ACPT	*r*	.228	.103	.256*	.232	.107	.317**
		p	.061	.405	.035	.057	.384	.008

Correlation significant at *.05 level, **.01 level.

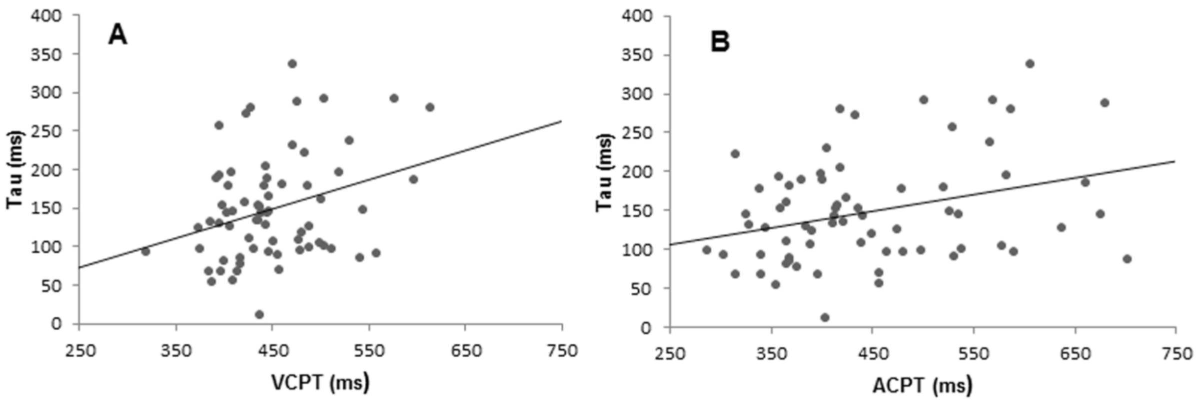

Figure 2. Scatterplots of the relationship between the tau of the vocal reaction time for the long phrases and the visual continuous performance task (VCPT, panel A) and auditory continuous performance task (ACPT, panel B) in Experiment 1.

The results described above, specifically the presence of correlations of the CPTs with the vocal latencies, and the absence of correlations with gaze durations, point to a critical sensitivity of language production to sustained attention only after phonological encoding, as indexed by the end of gaze durations. That gaze shifts depend on phonological encoding was corroborated by the length effect (short vs. long phrases). However, Meyer, Wheeldon, Van der Meulen, and Konopka (2012) showed that gaze durations do not always reflect the processes up to and including phonological encoding. With increased practice, the eye-speech lag (the time interval between shift of gaze away from the object and the onset of speech) became shorter, indicating that participants can deviate from the default coordination of gaze and speech. To test for a practice effect in the present data, we ran a linear mixed effect model for the eye-speech lags with phrase type and block as fixed effects including their interaction, and participant and item as random effects. The phrase effect was significant (ß = -73.66, SE = 20.09, t = -3.67). Importantly, the effect of block was not significant, nor was its interaction with phrase type (ß = -1.32, SE = 9.72, t = -0.14; ß = 10.95, SE = 6.81, t = 1.61, respectively). Therefore, there was no practice effect and we can assume that the gaze durations indeed reflected the processes up to and including phonological encoding.

As the correlation between the τ parameter and production latencies was found for both the auditory and visual CPTs and performance in the two tasks highly correlated with one another, there is evidence that they tap into the same domain-general sustained attention ability. Thus one can view the two successive CPTs used here as being one CPT divided into two blocks. We examined whether there was a difference in performance going from the first to the second block, independent of the modality the block was presented in. In the sustained attention literature it is often found that performance decreases over time. If this holds for the present study, the second CPT should tax the sustained attention system to a greater extent and correlate more strongly with the τ parameter of the vocal latencies. We correlated performance on the first administered CPT, independent of whether it was in the visual or auditory modality, with performance on the second administered CPT. This yielded a correlation of r = .56, p <.001. Correlating each of these two CPT blocks with vocal latencies revealed that the correlations were mainly driven by the second sustained attention block. Block 1 did not correlate with τ for either the short or long phrases, r = .06 and r = .15 respectively. By contrast, Block 2 correlated with r = .32, p < .01 for the short

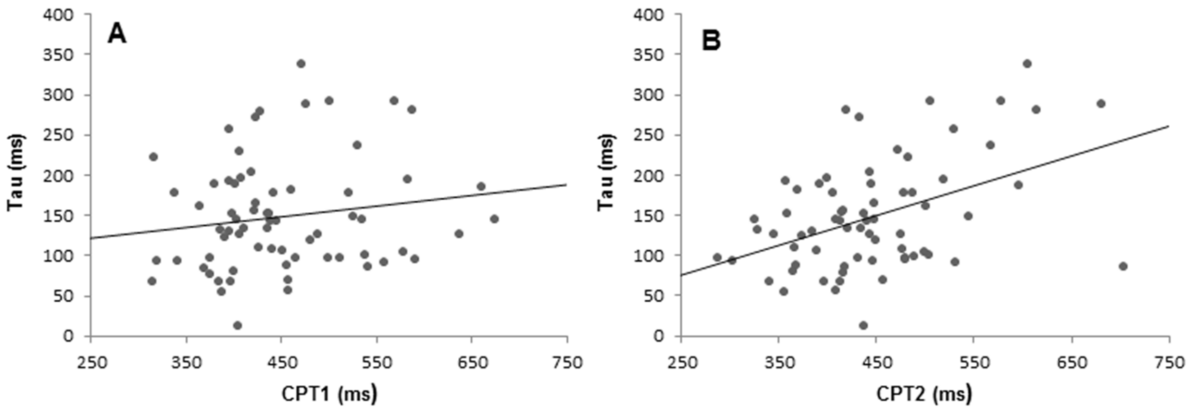

Figure 3. Scatterplots of the relationship between the tau of the vocal reaction time for the long phrases and the first administered continuous performance task (CPT1, panel A) and second administered continuous performance task (CPT2, panel B) in Experiment 1.

phrases and *r* = .45, *p* <.001 for the long phrases. Scatter plots are shown in Figure 3. This suggests that the CPTs administered last better reflected sustained attention ability and therefore correlated to a higher extent with the picture description task.

Discussion

Two continuous performance tasks were used to determine the contribution of sustained attention to performance in a picture description task where participants produced determiner-noun phrases or determiner-adjective-noun phrases to refer to colored objects. The question was whether an individual's ability to sustain attention would correlate with their response times in the description tasks. As predicted, this relation was found for the τ parameter of the production latencies. Participants with worse performance on the continuous performance tasks showed a higher proportion of slow vocal responses than participants with better performance on the continuous performance tasks.

In addition to production latencies, we measured gaze durations to the objects. Earlier research has suggested that gaze duration typically reflects language planning processes up to and including phonological encoding (i.e., Griffin, 2001; Korvorst, Roelofs, & Levelt, 2006; Meyer, Sleiderink, & Levelt, 1998; Meyer & Van der Meulen, 2000). In line with these findings, we found that the gaze durations were longer for determiner-adjective-noun phrases than for determiner-noun phrases. This was expected as phonological encoding should take longer for long than for shorter phrases. We did not find an effect of phrase type for the vocal latencies. Most likely this is because speakers did not fully plan the phrases before speech onset, but initiated articulation earlier, perhaps as soon as the phonetic encoding of the determiner had been completed, and planned the remainder of the utterances after speech onset (cf. Korvorst et al., 2006; Meyer, Roelofs, & Levelt, 2003).

We used gaze durations to localize the effect of sustained attention within the language production process. If processes up to phonological encoding are critically sensitive to sustained attention, individual differences in sustained attention ability should correlate with gaze durations. However, we observed that individual differences in sustained attention ability did not correlate with individual differences in the magnitude of the tail of the distribution of gaze durations, but only with the tail of the RT distribution. This suggests a late effect of sustained attention, which could either reflect a critical sensitivity of the processes after phonological encoding to sustained attention or a need for sustained attention when distracting information from another task comes into play. After the gaze shift, phonetic encoding of the phrase overlapped in time with performing the arrow discrimination task. That is, participants were already looking at and processing the arrow while they were phonetically encoding the phrases. If phonetic encoding and the processing of the arrow both require attentional capacity, then the combination of these tasks may bring individual differences in sustained attention capacity to light. To address this possibility, we conducted a second experiment, where we compared the role of sustained attention in picture naming as the only task and in picture naming in a dual-task situation.

Experiment 2

To answer the question whether a high level of sustained attention is consistently needed for phonetic encoding or only when processes of two tasks overlap, participants named pictures in a single and in a dual-task condition. In both conditions, participants named pictures presented in the middle of the screen, using simple nouns (e.g., “fles”, bottle). In the single-task condition (half of the trial blocks), picture naming was the only task to be performed. In the dual-task condition (the other half of the trial blocks), an arrow was shown below the picture and participants were instructed to indicate the direction of the arrow after naming the picture. Figures 1B and 1C illustrate the visual displays used in these conditions.

If individual differences in sustained attention ability consistently affect all word production stages, performance in a sustained attention task should correlate with naming RTs in both conditions. By contrast, if individual differences in sustained attention ability only affect naming RTs when there is a overlap with performing a concurrent second task, performance in a sustained attention task should only correlate with naming RTs in the dual-task but not in the single-task condition. Correlations were expected to be strongest for the τ parameter of the naming latencies. Eye gazes were not measured as there was no reason for participants to move their eyes away from the object in the single-task condition.

A different sustained attention task was used than in Experiment 1, namely the visual digit discrimination task (DDT). This was done for two reasons. First, there was no evidence for the involvement of separate attentional systems for the auditory and visual modality in Experiment 1. Therefore we tested just one modality to save time. Second, in Experiment 1, CPT analyses were based on mean RTs, as we did not find a performance decrement for the CPTs. However, a performance decrement, as reflected by an increase in error rates or RTs over time, is one of the key findings in the sustained attention literature (Davies & Parasuraman, 1982; See, Howe, Warm, & Dember, 1995). The DDT is a visual continuous performance task that consistently causes performance decrements over time in adults (i.e., Matthews & Davies, 2001; Parasuraman, Nestor, & Greenwood, 1989; Sepede et al., 2012). It has been shown that tasks with faster event rates result in more errors and larger performance decrements (Ballard, 1996; Parasuraman, 1979). The DDT might therefore be more taxing than the CPTs and might show individual differences in sustained attention more clearly.

Method

Participants

Forty-five students of the Radboud University Nijmegen or the Hogeschool van Arnhem en Nijmegen took part in the experiment. All participants were native speakers of Dutch and had normal or corrected-to-normal vision. The average age was 22.7 years (range: 18-29 years). 38 participants were female. Participants were paid for taking part in the study.

General Procedure

Participants first performed the picture naming task, with alternating single and dual-task blocks and then they performed the digit discrimination task used to measure sustained attention ability.

Picture Naming Task

Materials and design. Thirty common objects were presented to the participants, each eight times. The pictures were selected for high name agreement (all higher than 94%, mean 99%; (Severens, Van Lommel, Ratinckx, & Hartsuiker, 2005). The object names were highly frequent (mean lemma frequency: 107 tokens per million; CELEX database, Baayen, Piepenbrock, & Gulikers, 1995) and consisted of one to three syllables. An effort was made to minimize overlap in the initial phonemes of the object names. In the set of names no more than three names began with the same phoneme (see Appendix A for all object names).

The pictures were presented in the center of the computer screen, fit to a virtual frame of 8 by 8 cm. In half of the trial blocks (the dual-task blocks), an arrow flanked by xx on both sides was presented (font Arial, size 20) below the picture. In the remaining trial blocks (the single-task blocks), the displays featured only the pictures. In each block, the 30 pictures were presented in a randomized order. Single-task and dual-task blocks alternated, and block order was counterbalanced across participants.

Procedure. Participants were tested individually in a dimly illuminated room. They were seated in front of a 17 inch (Iiyama LM704UT) screen. Before the experiment, participants were familiarized with the pictures and the corresponding names. A trial started with a blank screen shown for 500 ms, followed by a fixation cross shown for 500 ms and another blank screen shown for 250 ms. Then the picture was shown. In the single-task condition, the picture disappeared 250 ms after the voicekey (Sennheiser ME64) was triggered, or after 3 seconds. In the dual-task condition, participants first named the picture and then indicated the direction of the arrow by pressing either the left or right arrow on the keyboard. After the button press, the next trial was presented.

Analyses*.* Vocal responses were analyzed similarly to the preceding experiment. The linear mixed effect model included task (single vs. dual) and block as fixed effects as well as their interaction. Participant and item were treated as random effects, with both intercepts and random slopes included for all factors.

Digit Discrimination Task

Materials and design. Single digits in white (font Arial, size 40) were presented on a black background using Presentation Software (Version 16.2, www.neurobs.com). The digit 0 was the target digit, and all other digits (1 through 9) were non-targets. Targets were presented with a probability of 25%. Stimuli were presented in a pseudorandom sequence with the restriction that identical targets never directly followed one another and that targets were preceded by each non-target an equal number of times. A total of 72 practice trials and 576 experimental trials were presented. The experimental trials were divided into four blocks for analysis purposes. Each block thus consisted of 36 targets and 108 non-targets.

Procedure. Digits were presented for 100 ms each, with an inter-stimulus-interval of 900 ms. Participants responded to the target stimuli with a button press using their dominant hand. Task duration was 10.8 minutes.

Analysis. The data were analyzed in a similar fashion to the sustained attention tasks in Experiment 1. However, since there was only one sustained attention task there was no effect of modality to be assessed. The linear mixed effect model therefore only contained the effect of block and its random slope, and participant was included as a random effect.

Analyses of Individual Differences

Ex-Gaussian analyses were performed to characterize each participant's naming latencies, as in Experiment 1. The parameters were estimated separately for the single and dual-task and for each participant individually. The parameters μ and τ were then correlated with performance on the DDT.

Results

Data from five participants were excluded from the analyses. One participant failed to complete the DDT, and one participant's phone rang during the picture naming task. Three participants completed the arrow discrimination task before naming the picture on a large number of trials in the dual-task condition, leaving too few correct trials for the ex-Gaussian analysis. This left data from forty participants.

Picture Naming Task

Naming errors were made in 0.4% of all trials, hesitations occurred on 0.2% of the trials. In the dual-task condition, the wrong arrow direction was chosen in 0.2% of the trials in the dual-task condition, and on 1% of the trials participants indicated the arrow direction before naming the picture, contrary to instructions. All of these trials were removed from the following analyses.

The linear mixed effect model for the correct naming latencies (see Table 6) showed that RTs were significantly different for the two task situations such that participants were faster to name the pictures in the single-task condition compared to the dual-task situation (single: 618 ms, SE = 1.9; dual: 712 ms, SE = 2.8). The main effect of block reached significance, as did the interaction with task. Separate analyses of linear mixed effect models for each task revealed that this interaction was due to a significant decrease in naming latencies in the dual-task condition (ß = -0.02, SE = 0.00, *t* = -4.77), but not in the single-task condition (ß = 0.00, SE = 0.00, *t* = 0.23). Key presses in the dual-task condition showed a similar block effect as the naming latencies (ß = -0.04, SE = 0.01, *t* = -6.31).

Digit Discrimination Task

Mean RT for the DDT was 400 ms (SE = 1.1). Very few errors were made, in total only 0.3% false alarms and 0.6% misses, precluding any further analysis. The linear mixed effect model performed on the RTs showed a significant main effect of block (ß = 0.02, SE = 0.00, *t* = 5.83). As expected, performance deteriorated over time, with an average RT of 387 ms for the first block compared to 413 ms for the final block.

Table 6. Results of mixed effect model analyses of the log-transformed latencies for the vocal responses in Experiment 2. The estimated coefficient (*ß*), standard error (SE) and *t*-value (*t*) are presented.

Fixed effects	ß	SE	T
Intercept	6.47	0.02	306.64*
Task	0.13	0.01	9.50*
Block	-0.01	0.00	-2.74*
Task*Block	-0.02	0.00	-7.71*

*A coefficient is a significant predictor at $p < .05$ using the criterion that $|t| > 2$

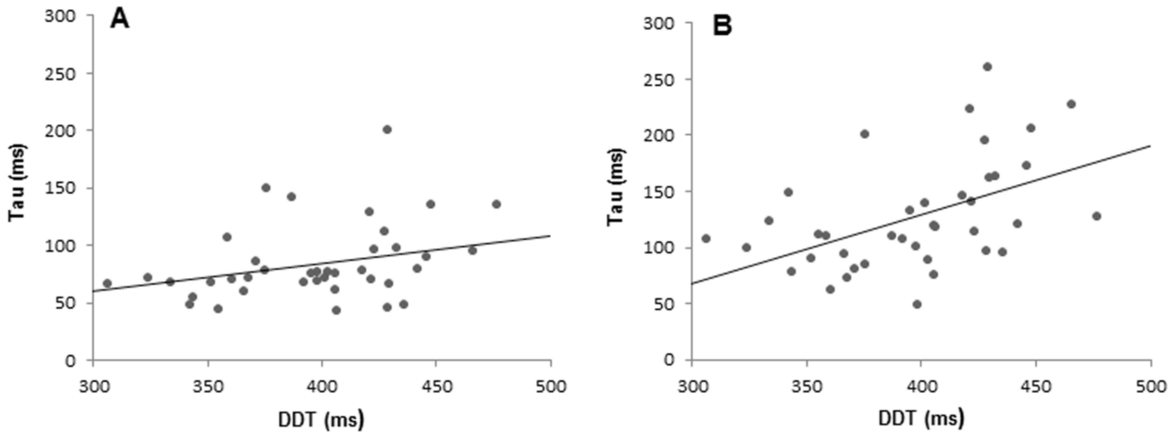

Figure 4. Scatterplots of the relationship between sustained attention as measured by the digit discrimination task (DDT) and the tau of the naming latencies in the single-task condition (panel A) and the dual-task condition (panel B) in Experiment 2.

Individual Differences

For both the single-task and dual-task conditions, the mean naming RT correlated significantly with the mean RT for the DDT, $r = .35$, $p < .05$ and $r = .48$, $p < .01$, respectively. When the mean naming RT was split up in μ and τ, the τ parameter correlated significantly with DDT performance with $r = .33$, $p < .05$ (single-task) and $r = .55$, $p < .001$ (dual-task). The μ parameter did not correlate significantly with DDT ($r = .24$, $p = .14$) for the single-task condition, but the correlation approached significance for the dual-task condition ($r = .30$, $p = .06$).

The relationship between sustained attention as measured by the DDT and object naming was stronger in the dual-task condition than in the single-task condition (see Figure 4 for scatterplots). This difference reached significance when comparing the correlations between DDT and the τ parameter for naming in the single-task compared to the dual-task condition using Steiger's *z*, $z = 1.78$, $p < .05$ (one-sided).

Discussion

The aim of the second experiment was to examine whether sustained attention ability is important only when attention needs to be divided between tasks or whether sustained attention is regularly important for speech production. The correlation between the sustained attention task and the τ parameter of the naming latencies was significant for both tasks, with the correlation being significantly higher in dual-task than single-task performance. This suggests that sustained attention is consistently needed in naming, but becomes especially important in situations where attention is divided between two tasks.

Sustained attention ability was measured differently than in the previous experiment, namely by DDT rather than CPT performance. The use of a different sustained attention task could explain why the correlations with the ex-Gaussian parameters of the production tasks in Experiment 2 are higher than in Experiment 1. Moreover, the correlations with the μ parameter were higher in the second experiment than in the first experiment, although they still did not reach significance. The DDT could be a more sensitive measure of sustained attention than the CPTs used in Experiment 1, due to its shorter stimulus duration and inter-stimulus-interval. The DDT might therefore be better at characterizing each participant's sustained attention ability.

Another possibility is that the DDT also measures general speed of processing, more so than the CPTs. This could explain the increased correlation between the mean RT scores on the DDT and the μ parameter for object naming. However, the correlations with μ did not reach significance, which favors the view that the correlation with naming reflects sustained attention rather than general processing speed. We used the DDT, because we hoped we could use performance decrement as a measure of individual differences, but our analysis was again based on the mean RTs in the task. We expected that the DDT would reveal worse sustained attention performance, reflected in more errors and a larger performance decrement across trials, compared to the CPTs. However, the number of errors was again very low and the performance decrement was significant but small with an average of 26 ms. We correlated the participants' performance decrement (mean RT Block 4 - mean RT Block 1) with the parameters of picture naming, but none of these correlations reached significance. It has been suggested that in addition to mean RT and accuracy, performance variability is a good indicator of sustained attention ability (Betts, Mckay, Maruff, & Anderson, 2006; Loher & Roebers, 2013; van Zomeren & Brouwer, 1992). In line with this proposal, we found that the participants' standard deviation of their RT in the DDT task showed a significant correlation with the τ parameter of object naming in the dual-task situation (r = .50, p = .001). This correlation approaches significance for the simple naming (r = .27, p = .09). This suggests that individuals with greater fluctuations in sustained attention have a larger variability in the slow responses in naming objects. This provides additional evidence that the DDT captured sustained attention rather than merely general speed of processing.

General Discussion

In two experiments, we investigated the involvement of sustained attention in language production. Both experiments showed that sustained attention ability correlated with the τ parameter of the production latencies, such that individuals with poorer sustained attention had a larger number of slow responses than those with relatively good sustained attention. Given this correlation, we suggest that the slow trials reflect instances where a participant failed to sufficiently sustain attention, in line with the proposal made by Unsworth, Redick, Lakey, and Young. (2010) that τ reflects lapses of attention (cf. Roelofs, 2012).

The absence of a correlation between the CPTs and the gaze durations to the object pictures and the presence of such a correlation with the production latencies in Experiment 1 suggests a need of a high level of sustained attention for the final stages of the language production process. Individual differences in sustained attention did not become apparent significantly in the processes indexed by the gaze durations, which are the processes up to and including phonological encoding, but only for the remaining processes of phonetic encoding and initiation of articulation. Experiment 2 revealed that the need for sustained attention for the last stages of production was higher in the dual-task setting compared to simple naming. If production is the only task, it is relatively easy for all speakers to keep a high level of sustained attention on the task at hand and individual differences in sustained attention ability are minimally reflected in the RTs. The dual-task situation is more challenging, as individuals already shift gaze away from the object before articulation to process the arrow, thus attentional capacity needs to be divided between the two tasks. Individuals seem to differ especially in their ability to maintain a high level of sustained attention for the last stages of production when attention is also required by the arrow discrimination task. Taken together, the findings of Experiments 1 and 2 challenge the idea that the last stages of language production are the most automatic ones (Ferreira & Pashler, 2002; Garrod & Pickering, 2007).

The late language production processes, which occur after phonological encoding, include the generation of the phonetic code of the utterance and internal self-monitoring processes. Sustained attention may be needed for each of them or for carrying them out simultaneously as these processes are tightly linked and overlap in time. According to Levelt, Roelofs, and Meyer (1999), self-monitoring based on phonological presentations occurs in parallel with phonetic encoding, which may involve dividing sustained attention capacity between these two processes, taxing the attention system. This could explain why we found a significant correlation between sustained attention ability and the naming latencies not only in the dual-task situation but also in the simple naming task. If this demand on sustained attention is further increased by another unrelated task, the arrow discrimination task in our experiments, individual differences in sustained attention ability become increasingly apparent.

As noted in the Introduction, it has been suggested that children with SLI only deviate from typically developing children in auditory but not in visual sustained attention ability (Noterdaeme, Amorosa, Mildenberger, Sitter, & Minow, 2001; Spaulding, Plante, & Vance, 2008). Our results from Experiment 1, where matched visual and auditory CPTs were used, argue against a strict distinction between two sustained attention systems in adults. This is because the participants' performance in the two CPTs was highly correlated, and both the auditory and visual CPTs showed a significant correlation with the production latencies for the long phrases. However, the correlation between the two CPTs was not perfect. Moreover, only performance on the auditory CPT, but not performance on the visual CPT, was correlated with the production latencies for short phrases. Thus, consistent with the child literature, the auditory CPT was a slightly more powerful predictor of language production performance than the visual CPT. Overall, our results suggest that the auditory and visual CPTs we used tapped both shared and unique attentional abilities.

Whether children with SLI have a specific deficit concerning auditory sustained attention or a more general sustained attention deficit needs to be investigated in further research. The contrasting findings in the SLI literature may in part be due to the choice of task parameters, rather than the modality tested. Corkum and Siegel (1993) reviewed the use of CPTs to diagnose children with ADHD and showed that studies using longer stimulus duration tended to find smaller differences between children with ADHD and control groups. The same might hold for children with SLI and control groups. To assess whether or not both visual and auditory sustained attention are deficient in children with SLI, both visual and auditory CPTs with short stimulus durations should be administered to the same group of individuals, as done in the present study with adult speakers.

Summary and Conclusions

We investigated the contribution of sustained attention to language production using an individual differences approach. In Experiment 1, sustained attention ability correlated with picture description latencies, such that individuals with poorer sustained attention showed an increased number of slow responses compared to individuals with relatively good sustained attention. This relationship between sustained attention ability and phrase production was not found for gaze durations, suggesting that a high level of sustained attention is especially required after phonological encoding. This finding challenges the common assumption that the final stages of language production proceed automatically. In Experiment 2, the correlation was replicated and shown to be significantly higher when object naming took place in a dual-task situation (as in Experiment 1) than in simple naming. It seems that individual differences in the ability to maintain sustained attention to the production processes become increasingly apparent when an overlapping second task also requires attentional resources.

Acknowledgements

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Appendix A

Target names of pictures used in Experiment 2, with English translation.

appel (apple), bed (bed), blad (leaf), brood (bread), deur (door), doos (box), ei (egg), emmer (bucket), fles (bottle), glas (glass), hoed (hat), huis (house), kerk (church), konijn (rabbit), kruis (cross), leeuw (lion), maan (moon), mes (knife), neus (nose), paard (horse), pijp (pipe), radio (radio), ring (ring), spiegel (mirror), telefoon (telephone), tent (tent), vliegtuig (airplane), voet (foot), wiel (wheel), wortel (carrot).

Chapter 3

The Role of Sustained Attention in the Production of Conjoined Noun Phrases: An Individual Differences Study

It has previously been shown that language production, performed simultaneously with a nonlinguistic task, involves sustained attention. Sustained attention concerns the ability to maintain alertness over time. Here, we aimed to replicate the previous finding by showing that individuals call upon sustained attention when they plan single noun phrases (e.g., "the carrot") and perform a manual arrow categorization task. In addition, we investigated whether speakers also recruit sustained attention when they produce conjoined noun phrases (e.g., "the carrot and the bucket") describing two pictures, that is, when both the first and second task are linguistic. We found that sustained attention correlated with the proportion of abnormally slow phrase-production responses. Individuals with poor sustained attention displayed a greater number of very slow responses than individuals with better sustained attention. Importantly, this relationship was obtained both for the production of single phrases while performing a nonlinguistic manual task, and the production of noun phrase conjunctions in referring to two spatially separated objects. Inhibition and updating abilities were also measured. These scores did not correlate with our measure of sustained attention, suggesting that sustained attention and executive control are distinct. Overall, the results suggest that planning conjoined noun phrases involves sustained attention, and that language production happens less automatically than has often been assumed.

Jongman, S. R., Meyer, A. S., & Roelofs, A. (2015). The role of sustained attention in the production of conjoined noun phrases: An individual differences study. PLoS One, 10(9): e0137557.

Introduction

We talk every day, for years on end. Speaking is such a highly practiced skill that one would think that it must have become a highly automatic process. Yet there are several studies showing that even single word production requires some form of attention (Cook & Meyer, 2008; Ferreira & Pashler, 2002; Roelofs, 2008a). Both word production and attention consist of a number of components. Word production involves conceptualizing, lemma retrieval, word-form encoding, and articulation (Levelt, Roelofs, & Meyer, 1999), whereas attention includes alertness, orienting, and executive control (Petersen & Posner, 2012; Posner & Petersen, 1990), with the latter comprising updating, inhibiting, and shifting (Miyake et al., 2000). An important question is which production component requires which component of attention. Below, we first briefly describe the major components of word production and attention in more detail. Next, we discuss the scarcity of evidence regarding the attentional demands of the different components of production. The present article concerns the sustained attention demands of phrase production. We report an individual differences study examining the role of sustained attention in the production of complex noun phrases.

Word production consists of several planning stages that a speaker must go through before reaching articulation. There have been several proposals regarding the planning stages (Caramazza, 1997; Dell, 1986), but here we follow Levelt et al. (1999). Their word production model assumes three planning stages: conceptualizing, lemma retrieval, and word-form encoding, with the word-form encoding incorporating morphological, phonological, and phonetic encoding. First, the concept that best matches the intended message is chosen. The target concept activates the corresponding lemma with its syntactic properties. Then the word form is encoded, which means that the phonological segments of each morpheme are selected and combined into syllables. Finally, the articulatory program is specified (phonetic encoding), which is followed by articulation.

In the present study, we examined how phrase production time depends on sustained attention, which is the ability to maintain alertness over a prolonged period of time (Langner & Eickhoff, 2013; Oken, Salinsky, & Elsas, 2006; Sarter, Givens, & Bruno, 2001). Sustained attention research started in the 1940s with Mackworth, who showed radar operators monitoring for rare events tended to increasingly fail to detect such events towards the end of their watch (Mackworth, 1948). Since then many studies have shown that people find it hard to stay focused on a task for a long time, even though it is such an essential cognitive capacity, see Sarter et al. (2001) for a review. Sustained attention is part of the alerting network, one of three anatomically and functionally separate attention networks postulated by Posner and colleagues (Petersen & Posner, 2012; Posner & Petersen, 1990; Posner & Rothbart, 2007). Besides the alerting network, attention consists of orienting and executive control. Orienting denotes the ability to shift the focus of processing to a new spatial source of information, either with eye movement (overtly) or without (covertly). Executive control refers to the ability to remain goal-directed when distracted. Executive control has been decomposed by Miyake and colleagues (2000) into updating and monitoring of working memory (updating), inhibiting of prepotent responses (inhibiting), and mental set or task shifting (shifting).

These subcomponents of executive control have previously been linked to language production. Shao, Roelofs, and Meyer (2012) showed that individuals with better updating and inhibiting skills were faster at naming pictures than individuals with poorer updating and inhibiting, whereas there was no relationship between shifting ability and word production latency. A correlation between updating ability and picture naming latency was also found by Piai and Roelofs (2013).

The orienting of attention during language production has been examined by tracking people's eye gaze (i.e., overt orienting). Saccades and visual attention are tightly coupled, both temporally and spatially (Deubel & Schneider, 1996). Thus when a person makes a saccade to a new location, his or her visual attention will also be at this new location: Gaze shifts indicate attention shifts. During object naming, people tend to look at the relevant object until they have retrieved the phonological code of the object name, then they shift their gaze towards the next target. For instance, gaze durations are affected by word frequency manipulations (Meyer, Sleiderink, & Levelt, 1998), phonological priming (Meyer & Van der Meulen, 2000) and word length (Meyer, Roelofs, & Levelt, 2003). These effects are all assumed to occur at the level of phonological encoding. Gaze is held at the target until phonological encoding is complete regardless of whether the next target is linguistic (i.e., another object that needs to be named; Griffin, 2001) or nonlinguistic (i.e., an arrow that needs to be categorized; Roelofs, 2008a). These findings suggest that orienting of attention is dependent on phonological encoding.

Shifting attention after phonological encoding, but before speech onset, suggests that the final stages of word production, phonetic encoding and the initiation of articulation, can occur in parallel with processes subserving other tasks. This is consistent with the view that late stages in planning a word do not require attention. For instance, Garrod and Pickering (2007) argued that the early stages of language production require attention, whereas subsequent processes are automatic. This was corroborated by evidence obtained by Ferreira and Pashler (2002), who showed that a semantic manipulation (targeting the early stage of lemma retrieval) influenced performance on a concurrent unrelated task, whereas a phonological manipulation (targeting the later stage of phonological encoding) did not. They concluded that semantic processing could not co-occur with another task, because both tasks tapped into the same central processing resource. In contrast, phonological encoding does not require attention and can therefore proceed in parallel with a second process (but see Cook & Meyer, 2008; Roelofs, 2008a).

However, in a previous study (Jongman, Roelofs, & Meyer, 2015) we found evidence that sustained attention does play a role during these last stages of word planning. In this earlier study, we used an individual differences approach to assess the effects of sustained attention ability on early versus late processes of word production. In a first experiment we exploited the finding that gaze durations (i.e., the time from stimulus onset until the overt orienting of attention) reflect the planning processes up to phonological encoding of a word, whereas naming latencies reflect the entire process of word production. Using a dual-task procedure with picture description as Task 1 (e.g., production of the noun phrase "the carrot") and arrow categorization using manual responses as Task 2, we found that naming latencies, but not gaze durations, correlated with sustained attention ability. This suggests that sustained attention is needed for the stages following the gaze shift, namely phonetic encoding and the initiation of articulation. Thus, these final stages do not proceed fully automatically, in contrast to Ferreira and Pashler's (2002) conclusion. In a second experiment, we compared picture naming in a dual-task setting (as in the first experiment) to picture naming as the only task. We found significant correlations between naming latencies and sustained attention ability in both tasks. The correlation was, however, significantly stronger in the dual-task than in the single-task setting (r = .48 compared to r = .35, respectively). Thus, the involvement of sustained attention in naming becomes most evident when sustained attention capacity is shared between picture naming and performing another task.

In the present study we wished to see whether we could increase the need for sustained attention during these final stages of word production without introducing an unrelated, artificial second task. The stronger correlation between naming and sustained attention ability in the dual-task setting in our previous study could have been due to the attention demands of task switching (Braver, Reynolds, & Donaldson, 2003; De Jong, Berendsen, & Cools, 1999; Meiran & Chorev, 2005; Pashler, 2000). The role of sustained attention could be much diminished when the entire task is linguistic in nature and no task switching is required. This is important to assess, because speakers regularly produce multi-phrase utterances. In the present study we compared the impact of sustained attention on word planning in two dual-task conditions: One task (single object naming hereafter) was identical to the task in the earlier study and required participants to name a picture (e.g., produce the noun phrase "the carrot") and then categorize an arrow as pointing to the left or right. This dual-task situation required switching between a linguistic and a nonlinguistic task. The second task (double object naming) was to name two pictures shown next to each other (e.g., produce the conjoined noun phrase "the carrot and the bucket"). This is also a dual task (with the two naming responses being the two tasks that need to be coordinated), but it does not require switching between a linguistic and a nonlinguistic task. We examined whether strong correlations are observed between sustained attention ability and naming latencies for the first (or only) object name in the switch task only or in both tasks. Should strong correlations be observed only in the switch task we would conclude that sustained attention is only implicated when naming is combined with a nonlinguistic task. However, should strong correlations be observed in both tasks then we would conclude that sustained attention is also involved when participants combine two linguistic tasks, planning two words or phrases in succession, as is required in connected speech.

For each task, half of the blocks contained monosyllabic words and the other blocks consisted of disyllabic words. We expected to replicate Meyer et al. (2003), who found a word length effect in pure blocks (i.e., blocks where all words had the same number of syllables) in gaze durations. Finding this effect would allow us to confidently interpret gaze durations as reflecting the processes up to and including phonological encoding. As mentioned previously, in Jongman et al. (2015), we observed that sustained attention ability correlated with naming latencies but not with gaze durations. We interpreted this as a late effect of sustained attention, after phonological encoding. Replicating the correlation between sustained attention and naming latencies but not gaze durations, would provide corroborating evidence for our interpretation that sustained attention plays a role especially after phonological encoding, contrary to what is commonly assumed in the literature (Ferreira & Pashler, 2002; Garrod & Pickering, 2007).

The literature suggests that although sustained attention and other components of attention are separable, they are also related to some extent. Unsworth, Redick, Lakey, and Young (2010) provided evidence that sustained attention ability is related to the updating and inhibiting components of executive control. Moreover, dual-task performance involving picture naming is influenced by individual differences in updating ability (Piai & Roelofs, 2013). Furthermore, inhibiting ability is engaged in task switching (Koch, Gade, Schuch, & Philipp, 2010), which was required in the dual-task condition of Jongman et al. (2015). To make sure that any correlations between sustained attention ability and language production latency reflected sustained attention rather than updating and inhibiting abilities, we also measured these executive control subcomponents to examine their relationship to sustained attention.

Specifically, we measured updating ability using the operation span task (ospan) and inhibiting ability using the flanker task (Miyake et al, 2000; Unsworth et al., 2010). The operation span task requires participants to solve mathematical equations while having to keep a set of words in working memory. In the flanker task, participants respond to the direction of an arrow, flanked by arrows pointing in the same direction (congruent condition) or in the opposite direction (incongruent condition). Use of the operation span task and the flanker task allowed us to investigate whether sustained attention and these two executive control abilities correlate and therefore whether correlations between sustained attention and language production can be interpreted as purely reflecting sustained attention or also as reflecting executive control. Sustained attention was measured with a digit discrimination task (DDT; Jongman et al., 2015; Matthews & Davies, 2001; Parasuraman, Nestor, & Greenwood, 1989; Sepede et al., 2012). Sustained attention is typically measured with a continuous performance task, where participants monitor a series of stimuli for a specific, infrequent target (in our experiment the target was presented in 25% of trials). In the DDT, the digit zero is the target amongst the foils zero to nine. Sustaining attention during such a task becomes increasingly difficult due to its repetitive and dull nature.

When investigating the contribution of sustained attention, we did not only look at the mean RTs but also divided the RT distribution into separate components to see whether attention affected a subset of the responses. Using ex-Gaussian analysis one can decompose the underlying RT distribution into two parameters, the μ parameter that reflects the normal part of the distribution and τ which reflects the tail end of the distribution. RT distributions are typically not normally distributed but positively skewed. The τ parameter is an index of skewness. It reflects the proportion of “abnormally” slow responses. Using ex-Gaussian analysis therefore provides much more information than just analyzing the mean RT (Balota & Yap, 2011; Heathcote, Popiel, & Mewhort, 1991; McAuley, Yap, Christ, & White, 2006).

Jongman et al. (2015) found sustained attention ability to correlate only with the τ parameter of the picture description latencies, not μ. In other words, individuals with poorer sustained attention had a greater number of very slow responses when describing a picture compared to individuals with improved sustained attention. We interpreted τ as reflecting lapses of attention as suggested by Unsworth et al. (2010). Similarly, in the object naming study by Shao et al. (2012), updating correlated only with the τ parameter of naming latencies, again not with μ. Attention, whether it is alerting or executive control, might be required more for difficult than for easy trials. For the current experiment, we predicted that the correlation between phrase production latency and sustained attention will be found for the τ parameter for both the single and double object conditions.

To summarize, the present study investigated the relationship between sustained attention and the production of conjoined noun phrases as compared to production of a single noun phrase combined with a nonlinguistic manual task. We assessed whether sustained attention ability correlated with the proportion of abnormally slow naming responses for a purely linguistic task (double object naming) and a switch task, or only for the switch task. We expected no correlations between sustained attention and gaze durations in either task, as we hypothesize that the effect of sustained attention is less evident because the early stages of word planning occur without any concurrent competing processing. Finally, we not only measured the participants' sustained attention, but also their updating and inhibiting abilities to test the extent to which the sustained attention task purely reflects sustained attention or also measures executive control.

Method

Participants

Sixty-two students of Radboud University Nijmegen or the Hogeschool van Arnhem en Nijmegen took part. All participants were native speakers of Dutch and had normal or corrected-to-normal vision. The average age was 21.4 years (range: 18-28 years) with forty participants being female. Participants were paid for taking part in the study. The current study is part of the approved research program 'Psychology of Language' of Antje Meyer, ethical approval was granted by the Ethics Board of the Faculty of Social Sciences of the Radboud University, Nijmegen. Participants provided written informed consent before the start of the experiment.

General Procedure

Participants first carried out the picture description tasks. The order of the single and double object tasks was counterbalanced across participants. After a break and moving to a different lab, participants performed the flanker task measuring inhibiting ability, then the ospan task measuring updating ability, and finally the digit discrimination task measuring sustained attention ability. The entire session for a single participant lasted one and a half hours.

Picture Description Tasks

Materials and design. The same materials were used for the single and double object tasks. Participants were presented with 120 black-and-white line drawings selected from a database of normed pictures (Severens, Van Lommel, Ratinckx, & Hartsuiker, 2005). Sixty of these pictures had monosyllabic names, the others had disyllabic names. Monosyllabic and disyllabic words were matched for name agreement (which was above 75% for all pictures), frequency, AOA, and visual complexity as measured by file size of the pictures (Székely & Bates, 2000). Initial phoneme was matched pair-wise. Common gender nouns are preceded by the determiner *de,* neuter nouns by *het*. Each set contained the same number of neuter gender nouns (13 out of 60). See Appendix A for the set of pictures and their characteristics.

In the double object description task two pictures were presented simultaneously, one in the center of the left half of the computer screen and the other in the center of the right half. Each picture fit into a virtual frame of 5 by 5 cm. In the single object description task, the right picture was replaced by an arrow flanked by xx on each side (font Times New Roman, size 20), yielding xx>xx and xx<xx as stimuli. Each task consisted of four blocks, two blocks containing only monosyllabic words, the other two blocks consisting solely of disyllabic words. Monosyllabic blocks alternated with disyllabic blocks, and the first block was counterbalanced across participants. In the single object task each picture was presented twice, once in each block. In each block of the double object task, each picture was shown twice, once as the initial object, once as the second object. Note that each object was thus named four times, twice in the utterance-initial position and twice in the utterance-final position. For both tasks, pictures were presented in a pseudorandom order, such that participants never named two objects with the same phoneme or from the same semantic category in a row. Each participant had a different order of object presentation.

Participants first described the left object and, depending on the task, either indicated the direction of the arrow by a button press or continued by describing the second object (see Figure 1 for an illustration of the displays used). Participants were asked to include the determiner and in the double object task to use the conjunction "en" between the two object descriptions to create conjoined noun phrases such as "de wortel en de emmer" (the carrot and the bucket). Task order was counterbalanced across participants.

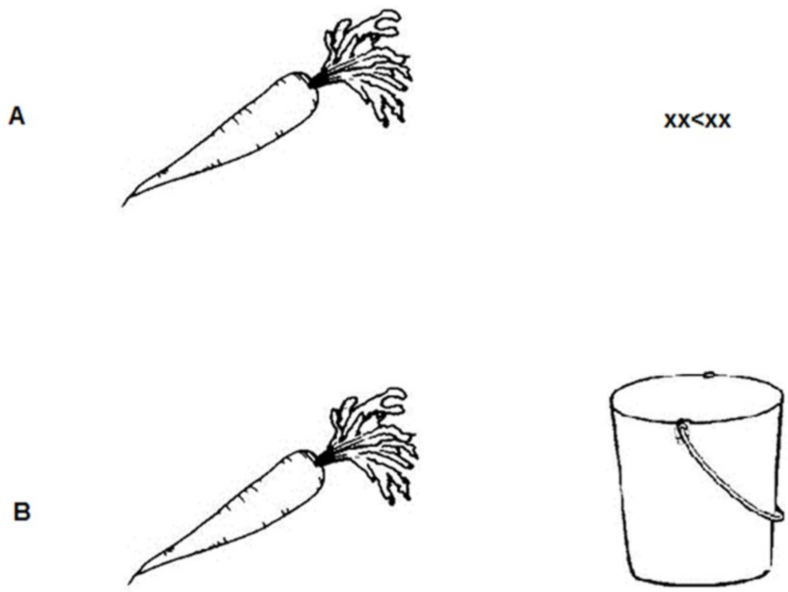

Figure 1. Illustration of the visual stimulus displays used in the single object task (A) and in the double object task (B).

Procedure. Participants were tested individually in a dimly illuminated room. They were seated in front of a 20 inch screen (Acer TCO03) with their chin on a chin rest, approximately 1 m away from the screen. The movements of each participant's right eye were recorded with an Eyelink 1000 Tower Mount eye tracker sampling at 1000 Hz.

On each trial, a fixation cross was presented for 250 ms in the center of the screen, followed by a blank screen for 150 ms. The stimuli were presented for 3.5 seconds. In the single object task, participants indicated the direction of the arrow by pressing either the left or right arrow on the keyboard (HP KB0316). Spoken utterances were recorded with a Sennheiser ME64 microphone.

Analyses*.* Vocal responses were recorded and RTs were determined manually using the program Praat (Boersma & Weenink, 2012). Naming errors and hesitations were coded offline and error trials were discarded from the analyses of RTs and gaze durations, as were trials with button press errors. Gaze duration was defined as the time interval between the beginning of the first fixation on the left picture (interest area of 5 by 5 cm) and the end of the last fixation before the first shift of gaze was initiated to the arrow or the second object. The data were analyzed using R (R Core Team, 2012) and the R packages *lme4* (Bates, Maechler, & Bolker, 2013) and *languageR* (Baayen, 2011). Gaze durations and naming latencies were both analyzed with a linear mixed effects model with task and word length as fixed effects including their interaction. Fixed effects were centered and the dependent measures were log transformed to eliminate positive skewing. Participant and item were included as random effects (Baayen, Davidson, & Bates, 2008). Random slopes were included for all fixed effects to capture additional variability at the subject and item level (Barr, Levy, Scheepers, & Tily, 2013). The model provides estimates, standard errors and *t*-values for each coefficient; factors with absolute values of *t* greater than 2 were considered to significantly contribute to explaining the dependent variable (Baayen, 2008).

Flanker Task

Materials and design. The target stimulus, an arrow, was presented in the middle of the screen flanked by two symbols on each side. In the congruent condition, the flankers consisted of arrows pointing in the same direction (e.g., <<<<<) whereas in the incongruent condition the arrows pointed in the opposite direction to the target (e.g., >><>>). In the neutral condition the target was surrounded by xx (e.g., xx<xx). Stimuli were presented in

white on a black background (font Arial, size 20) using Presentation Software (Version 16.2, www.neurobs.com). A total of 144 trials were presented separated into two blocks for analysis purposes. Each block contained 24 trials for each of the three conditions, presented in a randomized order.

Procedure. Participants were seated in a dimly lit room, facing a 17 inch (Iiyama LM704UT) screen. They were instructed to indicate the direction of the middle arrow as fast and as accurately as possible by pressing either the left or right arrow on the keyboard (HP KB0316). A trial started with a blank screen presented for 1000 ms, this was followed by a fixation cross in the middle of the screen for 250 ms. After another blank screen displayed for 1000 ms, the stimulus was presented. The next trial started after a button press or after 1500 ms. Participants were given a short practice block containing each possible combination of arrow and flankers (6 trials). The task lasted in total approximately 8 minutes.

Analyses. RTs were measured and incorrect responses were removed. The correct responses were log transformed to eliminate positive skewing and were analyzed with a linear mixed effects model with condition, block and their interactions as fixed effects. Fixed effects were centered. As condition had three levels, contrast coding was chosen such that the neutral condition was compared to the congruent and incongruent conditions. Participant was included as a random effect. Random slopes for all fixed effects were included.

Operation Span Task

Materials and design. The equations were taken from Tokowicz, Michael, and Kroll (2004). Sixty mathematical equations were paired with 60 newly chosen Dutch words. All Dutch words were monosyllabic, see Appendix B for a list. Each mathematical equation was coupled with a Dutch word (i.e., (15 / 3) - 4 = 1? Pen), presented simultaneously and next to each other in black text on a white screen (font Arial, size 16). The 60 trials were divided into 15 blocks, consisting of 2 to 6 trials. Words within one block differed with respect to their initial phoneme and rhyme. Two practice blocks preceded the experiment. All participants received the same list.

Procedure. A trial started with a fixation cross shown in the middle of the screen for 800 ms, followed by a 100 ms blank screen. Then the mathematical equation and word appeared on screen. Participants were requested to first read aloud both the equation and word, then indicate whether the operation was correct or not by pressing either the "Z" or "M" key. After a key press, the next trial started. After a block of trials a recall cue was presented (*herinner "recall"*), and participants were requested to orally recall the words of that block, in the correct order. The experimenter wrote down their responses. The task was self-paced and took on average 15 minutes to complete.

Analyses. The operation span score was established using partial-credit unit scoring (Conway et al., 2005). For each block, the proportion of correctly recalled words (in the correct serial order) was calculated. Thus correctly recalling one word in a two-word block received the same weight as correctly remembering two words in a four-word block. A participant's ospan score thus reflected the mean proportion of correct items over all blocks and could range from 0 to 1.

Digit Discrimination Task (DDT)

Materials and design. Single digits in white (font Arial, size 40) were presented on a black background. The digit 0 was the target digit, and all other digits (1 through 9) were non-targets. Targets were presented with a probability of 25%. Stimuli were presented in a pseudorandom order with the restriction that identical targets never directly followed one another and that targets were preceded by each non-target an equal number of times. A total of 648 trials were presented, divided into a practice block of 72 trials, which was not included in the analysis, and four further blocks of 144 trials (36 targets) each.

Procedure. Digits were presented for 100 ms each, with an inter-stimulus-interval of 900 ms. Participants responded to the target stimuli with a button press using their dominant hand. Task duration was 10.8 minutes.

Analyses. RTs were measured and errors were divided into misses and false alarms with the former being failures to respond to targets and the latter being responses to non-targets. The RTs for correct responses were log transformed to correct for positive skewing. The linear mixed effects model contained the effect of block (centered) and its random slope, and participant was included as a random effect.

For the gaze durations and naming latencies, the ex-Gaussian parameters μ, σ, and τ were estimated using the continuous maximum-likelihood method proposed by Van Zandt (2000). The parameters μ and σ reflect the mean and standard deviation of the normal portion, respectively, and τ reflects the mean and standard deviation of the exponential portion of the distribution. In contrast to the linear mixed effects analyses, latencies were not log-transformed for the ex-Gaussian analyses. The parameters were estimated separately for the single and double object tasks. Moreover, separate analyses were run for monosyllabic and disyllabic words. Therefore, eight sets of parameters (dependent measure by task by syllable length) were estimated for each participant using the program QMPE (Heathcote, Brown, & Cousineau, 2004). We computed Pearson's product-moment coefficients, and tested for correlations between the parameters μ and τ, on the one hand, and the individuals' mean RT and performance decrement (mean RT second half minus mean RT first half) on the DDT, on the other hand. The parameter σ was not included in these analyses because it was not of interest in the present study and to limit the number of comparisons. To test for the relation between sustained attention and executive control, we assessed the correlations between performance on the DDT and individuals' flanker effect and operation span score. To keep the number of correlation tests to a minimum, we did not test for correlations between the flanker effect and ospan scores and the parameters μ and τ of the picture description task. In total, we tested 38 correlations, and applied the Benjamini-Hochberg correction for multiple comparisons. The Benjamini-Hochberg correction controls the false discovery rate instead of the familywise error rate, and as such has more power than Bonferroni-type procedures, especially when the number of tests is large as is the case in the present study (Bender & Lange, 2001; Benjamini & Hochberg, 1995; Benjamini & Yekutieli, 2001; Williams, Jones, & Tukey, 1999). The Benjamini-Hochberg procedure first sorts and ranks the *p*-values with the smallest value getting rank 1, the second rank 2 and the largest rank *N.* Then, each *p*-value is multiplied by *N* and divided by its assigned rank. In the present study, this resulted in the first seven correlations to be significant after the Benjamini-Hochberg correction, down to an uncorrected *p*-value of .009.

Results

Data from four participants were removed. Two participants were excluded because their number of correct math responses in the operation-span task was lower than 80%. This exclusion criterion was used to avoid a trade-off between processing the mathematical equations and storing the words. To allow for ex-Gaussian analyses of the picture

Table 1. Mean latencies (*M*), standard error (SE) and error percentages (E%) per task and per syllable length for the gaze durations and the vocal responses in the picture description tasks.

		Gaze		Vocal	
Task	*Length*	*M*	SE	*M*	SE
Single Object	Monosyllabic	779	4.9	918	3.7
	Disyllabic	828	5.2	947	3.8
Double Object	Monosyllabic	696	4.1	945	3.6
	Disyllabic	739	4.3	964	3.6

description latencies and gaze durations using continuous maximum-likelihood fitting, at least 100 trials per condition are necessary. For one participant, too few eye fixations were recorded due to tracker loss. One participant used the wrong determiner in 1/4th of the naming trials. This left data from 58 participants.

Picture Description Tasks

In the single object task, naming errors occurred on 4.5% of the trials. In the double object task, this was true for 8.8% of the trials (4.7% for the left object, 4.3% for the right object). In both tasks, error rates for monosyllabic and disyllabic items were very similar (single: 4.4% and 4.5%; double: 4.5% and 4.5%, respectively). Hesitations occurred on 0.6% of the trials. In the single object task, the wrong arrow direction was chosen on 0.4% of the trials, and on 0.4% of the trials participants indicated the arrow direction before describing the picture, contrary to instructions. All error trials were removed from the following analyses. Moreover, trials with gaze durations to the target below 80 ms or above 2500 ms and trials with production latencies below 400 ms and above 3000 ms were removed, together equating to an additional 0.5% of the data.

The linear mixed effects model for the gaze durations revealed significant main effects for both task (ß = -0.09, SE = 0.03, t = -2.68) and word length (ß = 0.06, SE = 0.02, t = 3.03). The interaction did not reach significance (ß = 0.01, SE = 0.02, t = 0.25). This indicates that gaze durations were significantly shorter for the double object task than for the single object task. Importantly, gaze durations were significantly shorter for monosyllabic words than for disyllabic words. This was true for both tasks, as the interaction between task and word length was not significant (see Table 1).

The linear mixed effects model for production latencies revealed no significant effects for task (ß = 0.02, SE = 0.02, t = 1.08) or word length (ß = 0.02, SE = 0.01, t = 1.76). The interaction did not reach significance (ß = 0.01, SE = 0.01, t = 1.21).

Flanker Task

On average, 2.7% of the trials were responded to incorrectly. The mean error rates in the incongruent, congruent, and neutral conditions were 7.1%, 0.3%, and 0.7%, respectively. Incorrect responses were removed from the RT analysis. The linear mixed effects model revealed a significant effect of condition. The first contrast, neutral versus congruent condition (445 ms vs. 450 ms), was not significant (ß = 0.01, SE = 0.01, t = 1.24). The second contrast, between the neutral and incongruent condition, did show a significant difference (445 ms vs. 556 ms; ß = 0.21, SE = 0.01, t = 23.93). Block and the interaction with condition did not reach significance, indicating that performance was stable over time.

Operation Span Task

The mean ospan score was 0.59, range 0.20 - 0.90 (SD = 0.18). The mean score was somewhat lower than reported in other studies using partial-credit unit scoring for the operation span task (e.g., Piai & Roelofs, 2013 [M = 0.76, range = 0.54 – 0.94]), although a large range has been shown previously (Lewandowsky, 2011 [M = 0.70, range = 0.31 – 0.92]).

Digit Discrimination Task

Mean RT for the DDT was 408 ms (SE = 0.9). Few errors were made, in total only 0.4% false alarms and 1.3% misses. The linear mixed effects model performed on the RTs showed a significant main effect of block (ß = 0.02, SE = 0.00, t = 5.83). As expected, performance speed decreased over time, with an average RT of 392 ms for the first block compared to 424 ms for the final block.

Analyses of Individual Differences

Neither of the two executive control measures, the flanker effect or the operation span score, correlated with the mean RTs on the DDT or with the performance decrement on the sustained attention task (flanker: r = -.10, p = .47 and r = .19, p = .15; ospan: r = -.10,

Table 2. Mean values of ex-Gaussian parameters mu (μ), sigma (σ) and tau (τ) per phrase condition for the gaze durations and vocal responses.

		Gaze			Vocal		
Task	*Length*	μ	σ	τ	μ	σ	τ
Single Object	Monosyllabic	563	159	217	692	63	228
	Disyllabic	584	163	248	704	72	247
Double Object	Monosyllabic	493	131	204	731	71	218
	Disyllabic	511	138	226	732	74	235

Table 3. Correlations between mean latency on the digit discrimination task (DDT) and performance decrement on DDT (Decr) and the mu (μ) and tau (τ) parameter for gaze durations and vocal responses for the picture description tasks. Pearson's *r* (*r*) and uncorrected *p*-values (p) are presented.

			Single Object				Double Object			
			Monosyllabic		Disyllabic		Monosyllabic		Disyllabic	
Measure	*Aspect*		μ	τ	μ	τ	μ	τ	μ	τ
Gaze	DDT	*r*	-.09	.24	-.07	.28	-.15	.42*	-.04	.24
		p	.48	.06	.58	.03	.28	.001	.78	.07
	Decr	*r*	-.02	.09	-.08	.29	.04	.18	.04	.22
		p	.91	.52	.54	.03	.76	.17	.76	.10
Vocal	DDT	*r*	.20	.46*	.24	.29	.25	.43*	.29	.37*
		p	.13	<.001	.08	.03	.06	<.001	.03	.004
	Decr	*r*	.17	.27	.19	.34*	-.01	.31	-.01	.37*
		p	.21	.04	.15	.009	.93	.02	.95	.004

*Correlation significant after Benjamini-Hochberg correction for multiple comparisons

p = .47; r = -.08, p = .54). Mean RTs on the DDT did correlate with individuals' performance decrement on that same task (r = .42, p = .001), such that participants who were slower in general also showed a larger performance decrement (mean RT second half minus mean RT first half). Note that this correlation remains significant after correcting for multiple comparisons using the Benjamini-Hochberg procedure.

The estimates of the ex-Gaussian parameters of both picture description tasks are presented in Table 2. The correlations between the μ and τ parameters and the two measures of sustained attention (i.e., mean RT and performance decrement on the DDT) are listed in Table 3.

DDT correlated significantly with only one of the four τ parameters estimated for the gaze durations, namely with the monosyllabic words in the double object task: $r = .42$, $p = .001$ (see Figure 2 for all four scatterplots). Individuals' performance decrement on the DDT did not correlate significantly with any of the parameters.

The relationship between DDT and naming latencies was far more stable. Three out of four correlations between the mean RT on the DDT and the τ parameter for the naming latencies were significant after correction for multiple comparisons (see Figure 3 for scatterplots). For the single object task, the monosyllabic word latencies showed a correlation of $r = .46$, $p < .001$. The double object task showed correlations of $r = .43$, $p = .001$ and $r = .37$, $p = .004$ for monosyllabic and disyllabic words, respectively. Moreover, the τ parameter significantly correlated with the performance decrement for the disyllabic words in both tasks, with correlations of $r = .34$ (single object task) and $r = .37$ (double object task). Thus, individuals with poorer sustained attention, as reflected both by overall slow responding on the DDT and by a larger performance decrement, had a larger number of slow picture description responses independent of task.

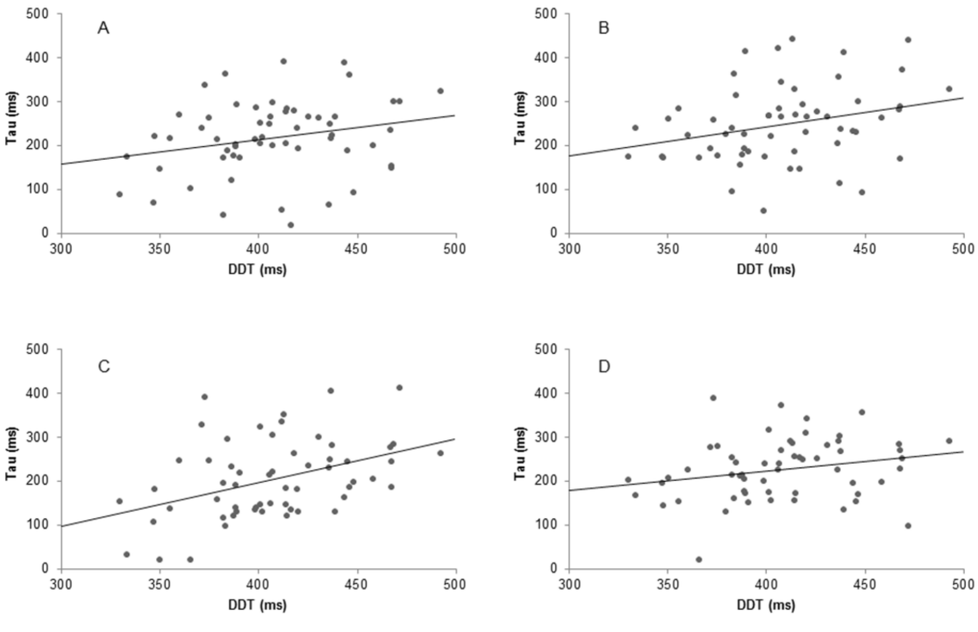

Figure 2. Scatterplots of the relationship between sustained attention as measured by the mean RT on the digit discrimination task (DDT) and the tau of gaze durations of monosyllabic and disyllabic words separately in the single object task (monosyllabic panel A, disyllabic panel B) and the double object task (monosyllabic panel C, disyllabic panel D).

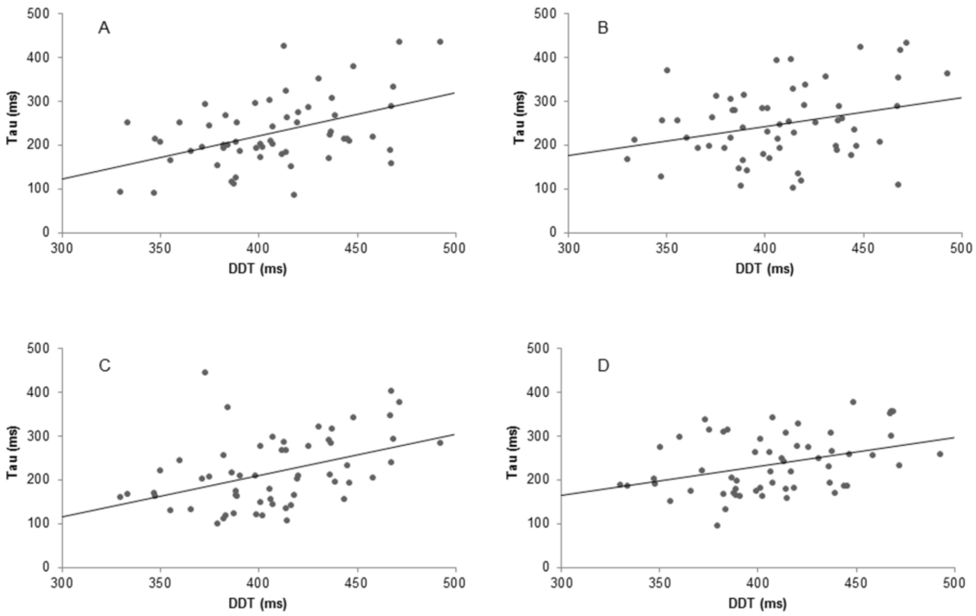

Figure 3. Scatterplots of the relationship between sustained attention as measured by the mean RT on the digit discrimination task (DDT) and the tau of the naming latencies of monosyllabic and disyllabic words separately in the single object task (monosyllabic panel A, disyllabic panel B) and the double object task (monosyllabic panel C, disyllabic panel D).

The results show a robust effect of DDT on naming latencies and a weaker effect on gaze durations. This is further supported by performing the linear mixed effects model analysis for the picture description data again, this time including the fixed effects flanker effect, operation span score and mean RT on the DDT. For gaze durations, we find again significant main effects of task and word length, with the three attentional measures not contributing to the model. By contrast when we run such a model for production latencies, DDT is the only significant effect (ß = 0.001, SE = 0.00, t = 3.16).

Discussion

The main aim of the current experiment was to test whether speech onset latencies for conjoined noun phrases such as "the carrot and the bucket" correlated with sustained attention ability. We hypothesized that describing two objects in succession would call upon sustained attention because the final processes of producing the first object name coincide with planning the correct phrase for the second object. This hypothesis was derived from results of a previous experiment, where we showed that description latencies for single objects embedded within a dual-task situation correlated with sustained attention ability for the final stages of word production (Jongman, Roelofs, & Meyer, 2015). However, it could be the case that this finding was driven by the switch from a linguistic to a nonlinguistic task. In that case language production in a purely linguistic context might occur without much need for sustained attention. In the present study, we obtained evidence that describing two objects in succession and describing a single object and then carrying out a nonlinguistic task both involved sustained attention to similar degrees.

For both the single and double object naming tasks, we found a correlation between sustained attention ability and the τ parameter of the naming latencies. Individuals with poor sustained attention ability showed a larger number of abnormally slow responses when describing pictures than those with good sustained attention, both when the pictures were followed by another picture to be described and when followed by an arrow categorization task. This suggests that a high level of alertness needs to be maintained to coordinate the production processes of describing an object and the initial processes of a second task regardless of its nature (i.e., linguistic or nonlinguistic). This is corroborated by the finding that performance decrement on the sustained attention task also correlated with production latencies (although after correcting for multiple comparisons this correlation only remained significant for the disyllabic words): Individuals who became increasingly worse in sustaining attention showed an increasing number of slow object description responses compared to individuals who showed no, or a small, performance decrement. Again, this suggests that speakers need to maintain attention when producing complex noun phrases.

The correlation between sustained attention and τ of the naming latencies was consistently present. We also found one out of four correlations (namely with the monosyllabic words in the double object task) to be significant for the mean RTs on the DDT and the τ parameter of gaze durations, contrary to our predictions. In our previous research we found no correlations with gaze durations, only with naming latencies, which we interpreted as an effect of sustained attention on the final processes of word production. Gaze durations have been taken to index the early processes of word planning up to and including phonological encoding (Griffin, 2001; Korvorst, Roelofs, & Levelt, 2006; Meyer, Roelofs, & Levelt, 2003; Meyer & Van der Meulen, 2000). The effect of sustained attention arose after the gaze shift, which left only phonetic encoding and initiation of articulation to be completed. When this occurred in combination with processing of a second unrelated task, individuals' ability to sustain attention influenced performance. Yet, in the current research we also found a significant correlation with gaze durations suggesting sustained attention is sometimes involved in the early processes of word planning.

The reason why the relationship between sustained attention and the early processes of production becomes evident in the current experiment could potentially be explained by increased task difficulty. A larger picture set was used in this study compared to that used in Jongman et al. (2015), with which the participants were not familiarized prior to the experiment, thus making object naming harder. This increased difficulty is reflected in the relatively long RTs. Yet our original conclusion that the relationship between sustained attention and language production becomes increasingly evident when attention needs to be shared with processing of another stimulus receives some support from the current data, as the relationship between sustained attention and the naming latencies was far more stable than for gaze duration. Five out of eight correlations between mean RT and performance decrement on the sustained attention task and the τ parameter of naming latencies reached significance after correcting for multiple comparisons, whereas only one passed the threshold for gaze durations. This suggests that especially the final stages of producing the first object name, phonetic encoding and articulation, are related to sustained attention in complex noun phrase production.

To be certain that indeed only these two processes (i.e., phonetic encoding and initiation of articulation) were left after gaze shifts in our experimental set-up, we included the contrast between monosyllabic and disyllabic words in the current experiment. Meyer et al. (2003) showed a word length effect for gaze durations, an effect that takes place at the phonological level. We replicated this result, with gaze durations being longer for disyllabic words than for monosyllabic words. Whether monosyllabic and disyllabic words differ in the amount of sustained attention involved in production cannot be answered by our data. The correlations were smaller for disyllabic words than for monosyllabic words in both the single object task and the double object task, although this difference was only significant for the single object task as calculated by Steiger's z ($z = 2.45$, $p = 0.02$). This pattern seems to point to a larger role for sustained attention when producing monosyllabic words. Yet individuals' performance decrement only correlated with the disyllabic words in both tasks, which would support the opposite conclusion that disyllabic words are more tightly linked to sustained attention. Further research is needed to investigate whether certain types of phrases relate differently to sustained attention than others.

In addition to measuring sustained attention, we also used an operation span task and a flanker task to examine the relationship between the updating and inhibiting subcomponents of executive control and sustained attention. Previous research (Unsworth, Redick, Lakey, & Young, 2010) provided evidence that sustained attention ability is related to updating and inhibiting abilities. However, neither updating nor inhibiting ability correlated with sustained attention in our study, which is consistent with the idea that sustained attention is distinct from executive control. This suggests that the observed correlations are instead due to sustained attention rather than being indirect influences of the executive control abilities. However, we must note that our conclusion that sustained attention is needed for language production is based on correlations, and as such we must be careful in interpreting our results. Yet, we favor the simplest explanation where sustained attention is needed for language production instead of a possible third mediating factor that we failed to test in this experiment. If a mediating factor was involved, for instance motivation, we would expect a correlation not just with τ as in the present study, but also with μ as it should affect all trials. To conclude, the present results indicate that sustained attention is involved during the production of conjoined noun phrases. This corroborates and extends earlier evidence that language production happens less automatically than has often been assumed.

Acknowledgements

We thank Luisa Solms for running part of the participants and Alastair Smith for his helpful comments.

Appendix A

Target names of pictures, with English translation.

Monosyllabic words:

arm (arm), aap (monkey), beer (bear), broek (trousers), baard (beard), bril (glasses), bord (plate), bijl (ax), doos (box), dak (roof), eend (duck), geit (goat), harp (harp), hert (deer), jas (coat), kaars (candle), kruis (cross), clown (clown), kok (chef), kers (cherry), knoop (button), leeuw (lion), lamp (lamp), mes (knife), mais (corn), neus (nose), nest (nest), pauw (peacock), pet (hat), peer (pear), pijl (arrow), pijp (pipe), pruik (wig), riem (belt), ring (ring), rits (zipper), roos (rose), rok (skirt), slot (lock), spook (ghost), slak (snail), slee (sled), stuur (steering wheel), spuit (needle), touw (rope), tol (spinning top), tent (tent), tang (pliers), taart (cake), tank (tank), vos (fox), vuur (fire), vlag (flag), vlot (raft), vork (fork), vaas (vase), worst (sausage), wiel (wheel), zaag (saw), zweep (whip).

Disyllabic words:

aardbei (strawberry), anker (anchor), banaan (banana), bureau (desk), beker (trophy), borstel (brush), ballon (balloon), baby (baby), dolfijn (dolphin), dokter (doctor), emmer (bucket), geweer (rifle), handdoek (towel), hamer (hammer), jojo (yoyo), konijn (rabbit), kasteel (castle), cactus (cactus), kanon (cannon), koning (king), ketting (chain), ladder (ladder), lepel (spoon), mixer (mixer), matroos (sailor), neushoorn (rhinoceros), nijlpaard (hippo), pinguin (penguin), pompoen (pumpkin), puzzel (puzzle), potlood (pencil), pleister (bandaid), pizza (pizza), radijs (radish), rugzak (backpack), robot (robot), rolstoel (wheelchair), regen (rain), schildpad (turtle), schouder (shoulder), scharnier (hinge), schommel (swing), springtouw (jumprope), soldaat (soldier), tomaat (tomato), trommel (drum), tafel (table), tandarts (dentist), tractor (tractor), tijger (tiger), varken (pig), vinger (finger), vlieger (kite), vliegtuig (airplane), vleugel (wing), vlinder (butterfly), wortel (carrot), weegschaal (scale), zebra (zebra), zadel (saddle).

Length	Frequency (per	Age of Acquisition	Name	Visual Complexity
Monosyllabic	27.3 (SD = 38.1)	5.8 (SD = 1.2)	92 (SD = 7.6)	34.5 (SD = 9.7)
Disyllabic	29.3 (SD = 49.6)	6.0 (SD = 1.1)	94 (SD = 6.5)	36.4 (SD = 11.6)

Appendix B

Words operation span task.

angst (fear), arts (doctor), band (tire), bloed (blood), brief (letter), brug (bridge), dienst (service), dorp (village), droom (dream), film (movie), gids (guide), grens (border), groep (group), hand (hand), huid (skin), hulp (help), inkt (ink), kaart (map), kans (chance), kleur (color), klok (clock), krant (newspaper), kunst (art), kust (coast), lamp (lamp), leeuw (lion), lijn (line), lucht (air), maan (moon), maand (month), mes (knife), mond (mouth), nacht (night), peer (pear), pen (pen), pijp (pipe), punt (point), raam (window), reis (journey), rok (skirt), school (school), slot (lock), soort (kind), stoel (chair), stof (fabric), straat (street), strand (beach), tand (tooth), traan (tear), vlag (flag), vloer (floor), voet (foot), volk (folk), vrouw (woman), vuur (fire), wens (wish), wet (law), wijn (wine), zaak (business), zeep (soap).

Chapter 4

Picture Naming in Typically Developing and Language Impaired Children: The Role of Sustained Attention

Children with specific language impairment (SLI) not only have problems with language performance but also with sustained attention, which is the ability to maintain alertness over an extended period of time. Although there is consensus that this ability is impaired with respect to processing stimuli in the auditory perceptual modality, conflicting evidence exists concerning the visual modality. Here, we asked groups of 7-9 year olds with SLI (N = 28) and typically developing (TD) children (N = 22) to perform a picture naming task and two sustained attention tasks, namely auditory and visual continuous performance tasks (CPTs). We observed that children with SLI performed worse than TD children on picture naming and on both the auditory and visual CPTs. Moreover, performance on both the CPTs correlated with picture naming latencies across developmental groups. These results provide evidence for a relationship between domain-general sustained attention and picture naming performance in both typically developing and language impaired children.

Jongman, S. R., Roelofs, A., Scheper, A., & Meyer, A. S. (under review). Picture naming in typically developing and language impaired children: The role of sustained attention.

Introduction

There has been increasing interest in the cognitive processes underlying specific language impairment (SLI). For a long time, SLI was considered to be a purely linguistic deficit as children with SLI are characterized by IQ levels similar to typically developing (TD) children, but their language abilities are far below the average level. Their linguistic problems range from phonology to syntax and semantics, both in language comprehension and production (for reviews see Leonard, 2014; Schwartz, 2009). This led many researchers to propose deficits in linguistic knowledge to explain SLI (i.e., Novogrodsky & Friedmann, 2006; Van der Lely, 1998; Wexler, Schütze, & Rice, 1998). However, several studies have reported deficits in other cognitive domains such as attention and memory ((Henry, Messer, & Nash, 2012; Im-Bolter, Johnson, & Pascual-Leone, 2006; Marton, Kelmenson, & Pinkhasova, 2007; Ullman & Pierpont, 2005; Vugs, Knoors, Cuperus, Hendriks, & Verhoeven, 2015). Some researchers have therefore suggested that domain-general deficits are the underlying cause of SLI (i.e., Bishop, 1992).

Sustained attention is an attentional component that has been put forward as one of the factors contributing to SLI. Sustained attention refers to the ability to maintain alertness for a prolonged period of time (e.g., Petersen & Posner, 2012; Sarter, Givens, & Bruno, 2001). It has repeatedly been shown to be impaired in children with SLI as compared to typically developing (TD) children (for a meta-analysis see Ebert & Kohnert, 2011). Sustained attention is typically measured with a continuous performance task (CPT) where a response has to be made to an infrequent target, whereas no response is required for non-targets. On CPTs, children with SLI tend to make more errors than TD children, either by missing targets or by incorrectly responding to non-targets (false alarms). This is sometimes accompanied by longer reaction times (RTs) to targets for the SLI group as compared to the TD group. Moreover, children with SLI tend to show a larger performance decrement over time, which refers to an increase in errors and RTs as time on task increases.

As of yet, only two studies have tried to relate sustained attention ability directly to linguistic abilities in children with SLI. Montgomery and colleagues observed that children with SLI performed worse than TD children on an auditory sustained attention task. Moreover, sustained attention accounted for variance in performance on a sentence comprehension task for the SLI group, but not for the TD group (Montgomery, 2008; Montgomery, Evans, & Gillam, 2009). Evidence from Duinmeijer, De Jong, and Scheper

(2012) suggests that sustained attention is not only important for successful language comprehension but for language production as well. Within a group of children with SLI, sustained attention ability correlated with the generation of plot elements when telling a picture story, such that children with better sustained attention generated more plot elements. These studies provide evidence for a role of sustained attention in the language performance of children with SLI.

The present study intends to contribute to this line of research by examining sustained attention in SLI and TD children in relation to their word production skills. Children with SLI tend to be slower than TD children in naming pictures (Lahey & Edwards, 1996). Moreover, they tend to make more errors, and proportionally more often these errors are semantically or phonologically related to the picture name (Lahey & Edwards, 1999). In adults, it has already been shown that picture naming and picture description require sustained attention (Jongman, Meyer, & Roelofs, 2015; Jongman, Roelofs, & Meyer, 2015). Correlations between sustained attention ability and picture naming in adults are observed for only a subset of the trials, namely for picture naming trials with long RTs only. Language skills are highly practiced in adults, but less so in children. We therefore suspected sustained attention ability to play an even more important role in picture naming by children than by adults. This was investigated by assessing SLI and TD children on picture naming performance and on their sustained attention ability, and by testing for correlations between picture naming and sustained attention performance. We expected to obtain correlations between sustained attention ability and picture naming for most of the naming trials rather than for trials with long RTs only, as we further explain below.

Sustained attention performance on CPTs can be characterized by several measures. In the present study, we used the following four measures to characterize individuals' performance, namely mean RT, hit rate (correctly identified targets), false alarm rate (incorrect responses to non-targets), and performance decrement (increase in RT over time). We expected that SLI children would show lower hit rates and more false alarms than TD children. Whether they would also show longer RTs was an open question. Children with SLI tend to be slower on a range of tasks, both linguistic and non-linguistic ones (Leonard et al., 2007; Miller, Kail, Leonard, & Tomblin, 2001). Yet, the meta-analysis on sustained attention in SLI by Ebert and Kohnert (2011) seems to indicate that RTs are not consistently affected. However, it must be noted that in general there are only very few responses required on sustained attention tasks, as targets are presented infrequently. If only 20% of the trials require a response, and children miss some of these targets, only few trials are left for calculating the mean RT. This could explain the lack of consistent RT differences between SLI and TD children. In the current study, 40% of the trials were targets, which allowed for a better estimation of mean RTs and RT performance decrement. We expected to find longer RTs for SLI than for TD children.

Picture naming performance can be characterized by mean naming RTs and error rates. We expected children with SLI to take longer in naming pictures and to make more naming errors than TD children. In assessing picture naming performance, we did not only look at mean naming RTs but examined entire RT distributions by performing ex-Gaussian analyses (e.g., Luce, 1986; Ratcliff, 1979). Picture naming RTs are typically not normally distributed but their distributions are positively skewed (i.e., the distribution tail is longer for the slow responses than for the fast responses). The ex-Gaussian consists of a convolution of a Gaussian and an exponential distribution, which captures both the normal part (parameter μ) and the longer right tail of a distribution (parameter τ). The mean RT is equal to μ plus τ. Ex-Gaussian analyses may be used to assess to what extent RT effects are present on most of the trials (reflected by μ) or on the trials with the slowest responses (reflected by τ). Effects in μ reflect distributional shifting and effects in τ reflect distributional skewing (Balota, Yap, Cortese, & Watson, 2008; Roelofs, 2008c; Shao, Roelofs, & Meyer, 2012).

In previous experiments with adults, we showed sustained attention to correlate with the τ parameter and not the μ parameter of picture naming and picture description RTs, i.e., word and phrase production (Jongman, Meyer, & Roelofs, 2015; Jongman, Roelofs, & Meyer, 2015). This reveals that adults with poorer sustained attention are not consistently slower in naming pictures than adults with better sustained attention, but they show a larger number of very slow responses. Here, we assessed whether the same pattern is obtained in children between the age of 7 and 9 years, or whether they needed to maintain attention more consistently during language production. During this stage of development, word production could be more effortful than it would be for adults, and children might depend on sustained attention more strongly. This would be revealed by a correlation between sustained attention performance and the μ parameter of picture naming RTs.

We also wanted to examine whether or not children with SLI show a dissociation between performance on sustained attention tasks that differ in stimulus modality. Impaired sustained attention performance in the auditory domain is well attested (Ebert & Kohnert, 2011). Whether sustained attention in the visual domain is impaired is unclear. Several studies showed impaired performance on auditory CPTs in children with SLI, but no difference in performance on visual CPTs between SLI and TD children was found (Dodwell & Bavin, 2008; Noterdaeme, Amorosa, Mildenberger, Sitter, & Minow, 2001; Spaulding, Plante, & Vance, 2008). This led Spaulding et al. to postulate separate sustained attention abilities for different perceptual modalities, that is, separate visual and auditory sustained attention systems. However, conflicting evidence was obtained by Finneran, Francis, and Leonard (2009), who found a sustained attention deficit for children with SLI on a visual CPT. The contradictory findings could be due to differences in task parameters, as suggested by Ebert and Kohnert (2011). They showed that studies that failed to find a deficit in the visual modality for children with SLI used longer stimulus durations than Finneran and colleagues. Corkum and Siegel (1993) suggested that longer stimulus durations placed less of a demand on attentional capacities. Therefore it is possible that a domain-general sustained attention system of children with SLI was not strained enough in those visual CPT studies that failed to find impaired performance, so that existing differences with TD children were not revealed.

In the present study, two CPTs were used that differed only in perceptual modality, modeled after the task used by Finneran et al. (2009). If a domain-general sustained attention system is impaired in children with SLI, we should replicate Finneran et al.'s results and find worse performance on the VCPT as well as the ACPT for SLI children as compared to TD children. If we fail to replicate this finding and only find a deficit for the ACPT, this would be in favor of separate attentional systems as proposed by Spaulding et al. (2008). Note, however, that different performance on VCPTs and ACPTs could also arise from different interactions between a domain-general sustained attention system and modality-specific processing systems (i.e., children with SLI are often reported to have impaired auditory processing, see Leonard, 2014).

In summary, we aimed to address four issues. First, do SLI children perform the same or worse than TD children on picture naming? Second, do SLI children perform the same or worse on sustained attention tasks than TD children? Third, if they do worse, is this true for both auditory and visual modalities, or only for the auditory domain? Fourth, does sustained attention ability correlate with picture naming performance, and are there differences in correlations between perceptual modalities or between SLI and TD groups?

Method

Participants

Fifty-five Dutch children between the ages of 7 and 9 years participated in the study. The children with SLI (N = 31, mean age = 8;4 years, nine female) were recruited from a special education school for children with speech and language disorders of Royal Dutch Kentalis in the east of the Netherlands. These children were previously diagnosed with SLI and receive special education. The control group (N = 24, mean age = 7;8 years, seventeen female) were selected from a primary school in the south-eastern part of The Netherlands. The TD children were selected for good reading skills and high scores on language tests, which are part of the regular curriculum of the primary school. IQ scores were available only for the SLI children, measured by the Snijders-Oomen Nonverbal Intelligence Test (Tellegen & Laros, 2011a, 2011b; Tellegen, Winkel, Wijnberg-Williams, & Laros, 1998), with a mean IQ score of 102 (range 87–117). In both groups, all children were monolingual speakers of Dutch, and none of the children were diagnosed with dyslexia, autism, or an attention deficit disorder. Ethical approval for the study was granted by the Ethics Board of the Faculty of Social Sciences of the Radboud University Nijmegen.

General Procedure

Children were individually tested in a quiet, empty room in their school. They were seated in front of a laptop (15.6 inch screen, HP EliteBook 8540P), next to the experimenter. The experimenter told the children they were going to play three games. Children first named pictures and then they performed the two sustained attention tasks. The order of the auditory and visual CPTs was counterbalanced across participants. Breaks were held between each task, the break duration was determined by the children. An entire session lasted between 40 and 60 minutes.

Picture Naming Task

Materials and design. Twenty common objects were selected from a database of normed pictures (Severens, Van Lommel, Ratinckx, & Hartsuiker, 2005). The object names were selected for an early age of acquisition (mean 4.7 years) and high frequency (mean lemma frequency: 108 tokens per million; CELEX database, Baayen, Piepenbrock, & Gulikers, 1995). Amongst adults, all pictures were named with high agreement (mean 96% in the norming study by Severens et al.). All words were monosyllabic and none started with a consonant cluster (see Appendix for a list of the words).

Pictures were presented as black line drawings on a white background, in the middle of the screen, 300 by 300 pixels. Each picture was presented five times, first once in a practice block and then once in each of four experimental blocks. During the practice block, the experimenter provided the name of the object if the child did not know the correct word after approximately 10 seconds. In each block, the twenty pictures were pseudorandomized such that participants never named two objects starting with the same phoneme or belonging to the same semantic category in a row.

Procedure. A trial started with the presentation of a fixation cross in the middle of the screen for 500 ms, followed by a blank screen of 250 ms. The picture would then be presented until the end of the trial. A trial ended when the experimenter pressed one of three buttons to indicate whether the response was correct, incorrect, or whether the child hesitated before giving the correct response (buttons "g", "f", and "h", respectively). Children were given maximally 10 seconds to respond. If no response was given the trial was coded as an incorrect response. A blank screen of 250 ms was shown before the next trial started. Spoken utterances were recorded with a Sennheiser ME64 microphone.

Analyses*.* Vocal responses were recorded and RTs were determined manually using the program Praat (Boersma & Weenink, 2012). Naming errors and hesitations were coded online and these trials were discarded from the analyses of RTs. Naming latencies were analyzed with a linear mixed-effects model using R (R Core Team, 2012) and the R packages *lme4 (*Bates, Maechler, & Bolker, 2013) and *languageR* (Baayen, 2011). Group and block were included as fixed effects including their interaction. Fixed effects were centered and the dependent measures were log transformed because of positive skewing. Participant and item were included as random effects ((Baayen, Davidson, & Bates, 2008). To capture additional variability random slopes for block were included at the subject level and for group, block, and their interaction at the item level (Barr, Levy, Scheepers, & Tily, 2013). The model provides estimates, standard errors, and *t*-values for each coefficient; factors with *t* greater than the absolute value of 2 were considered to significantly contribute to explaining the dependent variable (Baayen, 2008). Age and gender were added as factors to a first model, if they did not make a significant contribution, they were not included in the final model. Moreover, the effect of IQ was tested for SLI children only, as information on IQ was not available for the TD children. A similar model was run to the one just described, excluding the factor group as we could not compare the two groups of children but only look at the SLI group.

Continuous Performance Tasks

Materials and design. The target stimulus for the visual CPT (VCPT) was a red circle and the non-target was a red square. Stimuli were 150 by 150 pixels. The red stimuli in the VCPT were presented on a white background using Presentation Software (Version 16.2, www.neurobs.com). The auditory CPT (ACPT) used a high tone (800 Hz) as the target and a low tone (300 Hz) as the non-target stimulus. The tones were played through headphones (Sony MDR 301).

Before each task, the children were presented with the targets and non-targets twice each and the experimenter explained that the game was to press the button only when seeing the target. Then they performed two practice blocks (before the first task and before the second task). In the first, 4 targets and 4 non-targets were randomly presented and children received both visual feedback (a traffic light turning green when they correctly responded to a target and withheld a response to a non-target, light turning red for an incorrect response) and oral feedback from the experimenter. In a second practice block of 20 trials (8 targets), the children no longer received feedback. Before the start of the experimental trials, the experimenter repeated the instructions. Now targets were presented with a probability of 40%. In each task, there were 320 trials, divided into 8 blocks for analysis purposes. Each block therefore consisted of 16 targets and 24 non-targets, presented randomly.

Procedure. The procedure for the two CPTs was identical. Stimuli were presented for 400 ms each. Participants responded to the target stimuli with a button press using their dominant hand. The inter-stimulus interval ranged from 1100 to 1600 ms. Each experimental session took approximately 10 minutes.

Analyses. RTs were measured and errors were divided into misses and false alarms with the former being failures to respond to targets and the latter being responses to non-targets. A logit mixed model was conducted for both hits (i.e., correct responses to targets) and for false alarms (Jaeger, 2008). The models included group, modality, and block and their interactions as fixed effects. Factors were mean-centered. Participant was included as a random factor, with intercepts and slopes for modality and block. The interaction was also included in the model for hits, but not in the model for false alarms due to failure to converge. The models provide estimates, standard errors, *z*-values and *p*-values for each coefficient.

For the correct RTs to targets, a linear mixed-effects model was run with identical fixed and random effects as the logit mixed model for hits as just described. RTs were log-transformed to reduce the influence of positive skewing.

For all models, as with the picture naming model, age and gender were added as factors to a first model, but if they did not make a significant contribution, they were excluded from the final model. The effect of IQ was tested for SLI children only, with three models similar to the ones just described, but without the factor group.

Analyses of Individual Differences

We assessed whether children's mean naming latencies were correlated with their performance on the two sustained attention tasks by computing Pearson's product-moment coefficients. The two groups were analyzed together to increase power, but we also tested whether correlations were different between groups. The naming latencies were additionally characterized by two parameters, the μ parameter reflecting the normal part of the RT distribution and the τ parameter reflecting the tail end of the distribution. These ex-Gaussian parameters were estimated using quantile maximum likelihood estimation proposed by Heathcote, Brown and Mewhort (2002). In contrast to the linear mixed effect analyses, latencies were not log-transformed for the ex-Gaussian analysis. The parameters were estimated for each child individually using the program QMPE (Heathcote, Brown, & Cousineau, 2004). We tested whether the parameters μ and τ of the naming RTs were correlated with performance on the CPTs. These tests included mean RT, hit rate, false alarm rate and performance decrement (mean RT second half minus mean RT first half) for both CPTs.

Results

Data from five participants had to be excluded, three from the SLI group and two from the control group. One SLI child failed to finish the ACPT, another the VCPT. For the other three children the microphone failed to work. This left data from 28 SLI and 22 TD children.

Picture Naming Task

Very few naming errors were made, only 2.0% in the SLI group and 0.6% in the TD group. Hesitations occurred in 0.7% (SLI) and 0.9% (TD) of the trials. Due to the small number of errors, no error analysis was run. The error trials were removed from the naming latencies analysis. Naming latencies beyond 4 seconds were also removed (0.2%). The linear mixed-effects model revealed a significant effect of group ($ß = 0.19$, $SE = 0.05$, $t = 4.15$) and age ($ß = -0.07$, $SE = 0.03$, $t = -2.82$). Block or the interaction of block and group did not reach significance ($ß = 0.00$, $SE = 0.01$, $t = 0.29$ and $ß = -0.01$, $SE = 0.01$, $t = -0.43$, respectively). Children with SLI named pictures slower than TD children (978 ms vs. 789 ms, see Figure 1), and younger children had longer naming RTs than older children. Speed of naming remained consistent throughout an experimental session for both groups.

IQ was included as a factor in a model involving only the SLI children. However, IQ was not a significant predictor of naming latencies.

Continuous Performance Tasks

For none of the models, age or gender showed a significant effect in explaining variation in performance. These variables were therefore not included in the final models. For the SLI group only, analyses were run including IQ as a factor. IQ was not a significant predictor of hit rate, false alarm rate, or RTs of the CPTs.

The logit mixed model of hits showed a main effect of group and block, and a significant interaction between group and modality (see Table 1). Children with SLI had a lower hit rate than TD children, namely 0.91 versus 0.97. Moreover, SLI children performed better in the visual modality than in the auditory modality (VCPT: 0.93, ACPT: 0.89), whereas TD children showed the reverse pattern (VCPT: 0.96, ACPT: 0.98). Both groups showed a decrease in hit rate over time.

The logit mixed model of false alarms showed a main effect of group and modality. Moreover, there was an interaction between group and modality, as well as between modality and block. Table 1 lists the model parameters. The false alarm rate for children with SLI was 0.12, whereas it was 0.04 for the TD group. The number of false alarms was higher in the visual modality, and the difference between the two modalities was larger for the TD children (VCPT: 0.07 vs. ACPT: 0.02) as compared to the SLI children (VCPT: 0.13 vs. ACPT: 0.11). The interaction between block and modality showed a slightly larger decrease in false alarm rate for the auditory domain (0.09 to 0.06) than for the visual domain (0.11 to 0.09).

Table 1. Results of logit mixed model analyses of the hits and false alarms for the two continuous performance tasks. The estimated coefficient (*ß*), standard error (SE), *z*-value (*z*) and *p*-value (*p*) are presented.

Measure	*Fixed Effects*	*ß*	SE	*z*	*p*
Hits	Intercept	3.51	0.16	21.10	<.001*
	Group	-1.13	0.32	-3.45	<.001*
	Modality	-0.23	0.21	-1.07	.28
	Block	-0.18	0.03	-5.47	<.001*
	Group x Modality	1.09	0.41	2.69	.007*
	Group x Block	-0.00	0.06	-0.05	.96
	Modality x Block	0.02	0.07	0.38	.71
	Group x Mod x Block	-.15	.11	-1.36	.17
False alarms	Intercept	-2.97	0.13	-22.74	<.001*
	Group	1.20	0.26	4.57	<.001*
	Modality	0.75	0.18	4.08	<.001*
	Block	0.00	0.02	0.14	.89
	Group x Modality	-0.88	0.37	-2.37	.02*
	Group x Block	-0.07	0.04	-1.48	.14
	Modality x Block	-0.10	0.03	-3.32	<.001*
	Group x Mod x Block	0.01	0.06	0.23	.82

Table 2. Results of mixed effects model analyses of the log-transformed reaction times for the two continuous performance tasks. The estimated coefficient (*ß*), standard error (SE) and *t*-value (t) are presented.

Fixed Effects	*ß*	SE	*t*
Intercept	6.35	0.02	284.78*
Group	0.02	0.04	0.37
Modality	-0.15	0.02	-7.05*
Block	0.01	0.00	5.84*
Group x Modality	0.03	0.04	0.80
Group x Block	0.01	0.00	2.06*
Modality x Block	0.01	0.00	1.62
Group x Mod x Block	0.01	0.01	0.87

*A coefficient is a significant predictor at $p < .05$ using the criterion that $|t| > 2$

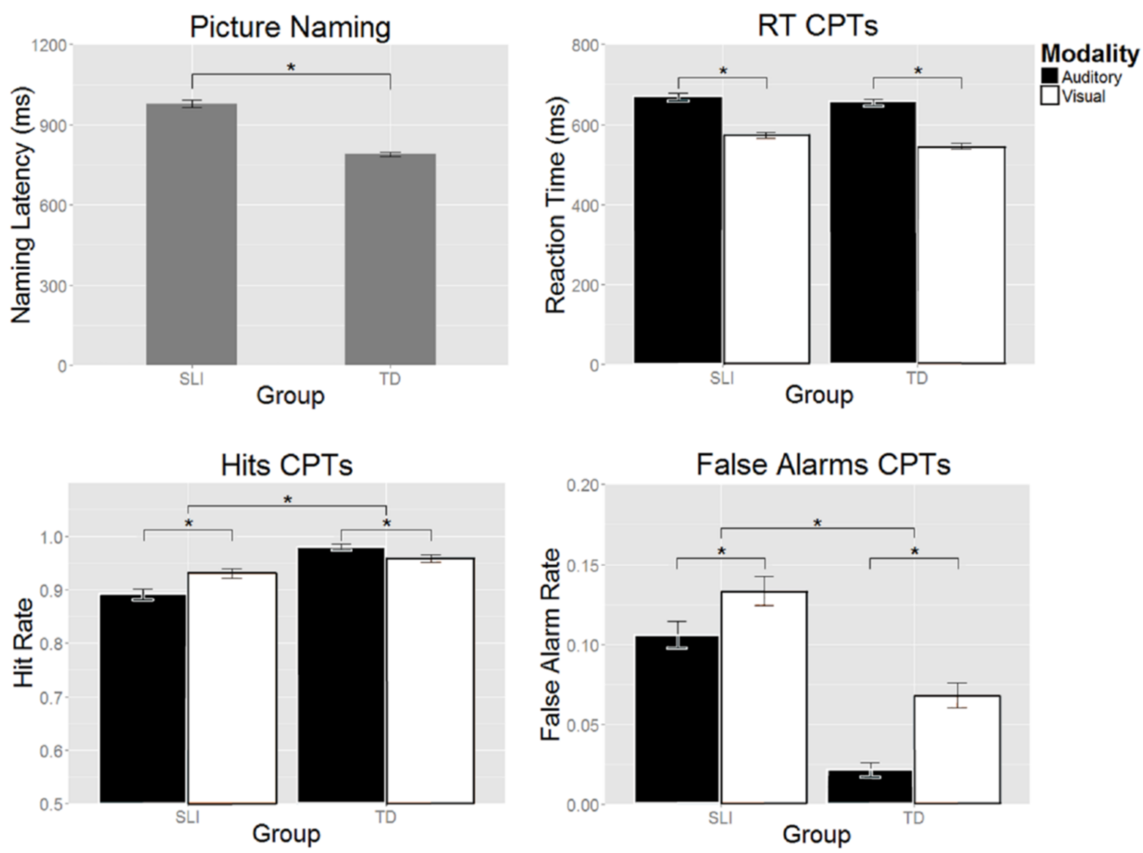

Figure 1. Mean naming latencies for the picture naming task and the mean response latencies, hits and false alarms for the auditory (black) and visual (white) continuous performance tasks for both developmental groups.

Table 3. Correlations between the mean reaction times (RT), hit rate (HR), false alarm rate (FAR), and performance decrement (DECR) of the two continuous performance tasks and the mean latencies (*M*) and the mu (μ) and tau (τ) parameters for picture naming. pearson's *r* (*r*) and *p*-values (*p*) are presented.

Modality	*Measure*	*M*	μ	τ
Auditory	RT	.35*	.32*	.27
	HR	-.48***	-.43**	-.40**
	FAR	.41**	.31*	.37**
	DECR	.03	-.22	.15
Visual	RT	.40**	.43**	.29*
	HR	-.48***	-.34*	-.44**
	FAR	.37**	.14	.41**
	DECR	.34*	.30*	.28*

Correlation significant at *.05 level, **.01 level, ***.001 level.

The RT analysis showed main effects of modality and block. Moreover, group interacted with block. Table 2 summarizes the results for the linear mixed-effects analyses. Children responded faster in the visual task than in the auditory task (561 ms vs. 663 ms). Performance decreased over time, and to a larger degree for the SLI group as compared to the TD group (SLI: first block 573 ms, last block 660 ms; TD: first block 573 ms, last block 607 ms). Figure 1 displays the results graphically.

Individual Differences

For both perceptual modalities, mean RT, hit rate, and false alarm rate of the CPT correlated significantly with picture naming latencies. This was also true for the performance decrement on the VCPT, but not for the ACPT. These correlations were observed not only for the mean picture naming RTs but also for the μ and τ parameters. Table 3 lists the correlations between all measures of sustained attention and picture naming. We tested whether the correlations differed between the SLI and TD groups using Fisher's *z* statistic. When correcting for multiple comparisons, none of the significant correlations in Table 3 differed between groups. Thus, both visual and auditory sustained attention ability correlated with picture naming performance for both SLI and TD children.

Discussion

In the present study, we examined the role of sustained attention in picture naming by SLI and TD children. Groups of 7-9 year olds performed a picture naming task and auditory and visual CPTs. We made the following key observations with regard to our four main questions. First, we observed that SLI children performed worse than TD children on picture naming. Second, SLI children performed worse on the sustained attention tasks than TD children. Third, this held true for both visual and auditory modalities rather than only for the auditory domain. Fourth, sustained attention ability correlated with picture naming performance, across perceptual modalities and developmental groups. In the remainder, we discuss these finding and their implications in more depth.

First, we observed that children with SLI were slower to name pictures than TD children. Both groups made very few errors, even though higher error rates for SLI children, together with increased naming latencies, are usually reported (Lahey & Edwards, 1996, 1999). The low error rate in the current study, even for SLI children, can be due to several factors. First, we selected pictures that were relatively easy to name: All object names were monosyllabic, of high frequency, had a low age of acquisition, and did not contain any initial consonant clusters. We chose these object names intentionally because we wanted to use a relatively simple production task so that children with SLI would be able to finish the task. Moreover, for ex-Gaussian analyses of the naming latencies many data points are required (for quantile maximum likelihood estimation as used here at least 40 trials). The low error rate could also have been due to the initial practice phase, where children were given the correct name by the experimenter in case they did not produce it after approximately ten seconds. Without a practice phase, we would undoubtedly have seen more errors in both groups of children.

Second, we observed that children with SLI had poorer sustained attention ability than TD children. This impairment was evident from several sustained attention performance measures, namely from hit and false alarm rates and the performance decrement in RTs. Children with SLI tended to miss more targets, more often responded incorrectly to non-targets, and their responses became slower over time to a larger extent than found in TD children. The only CPT measure that showed no difference between the two groups was mean RT. The lack of a difference for mean RT has been repeatedly reported. The meta-analysis by Ebert and Kohnert (2011) showed that only one out of thirteen studies that measured RTs revealed a difference between SLI and TD children. Our results indicate that there is in fact a deficit, but it is a more subtle one. Whereas the mean RT does not differentiate SLI and TD children, the change of RT over time does. Thus, our study replicated the finding of impaired sustained attention for SLI documented in the literature.

Third, the difference in sustained attention ability between SLI and TD children held true for both visual and auditory modalities rather than for the auditory modality only. Some previous studies found a deficit for SLI children in the auditory modality only, and not in the visual modality (Dodwell & Bavin, 2008; Noterdaeme, Amorosa, Mildenberger, Sitter, & Minow, 2001; Spaulding, Plante, & Vance, 2008). In the present study, sustained attention performance was tested both in the visual and auditory domain, and apart from modality the two tasks were identical. We found impaired performance not only on the auditory CPT but also on the visual CPT, replicating Finneran, Francis, and Leonard (2009). This suggests that a specific deficit in the auditory modality does not hold. Our results argue against separate sustained attention systems for the auditory and visual modality as proposed by Spaulding et al. (2008).

However, it must be noted that there were differences in performance between CPT tasks. For both groups of children, the false alarm rate was higher in the visual modality than in the auditory modality: It was harder to withhold a response to a visual non-target than to an auditory non-target. This was accompanied by the finding that children were faster to respond in the VCPT than the ACPT. This suggests a speed-accuracy trade-off, but why children shifted their response criterion is unclear. It might be related to the fact that during the visual task their eyes had to be focused on the screen, whereas during the auditory CPT they could look anywhere, causing a slight difference in task demands. Whatever the reason for the possible criterion shift, it argues neither for nor against separate domain-specific sustained attention systems. Finally, the hit rate was lower on the auditory task than on the visual task for SLI children, which was reversed for the TD group. This could possibly indicate a slightly larger impairment for the auditory rather than the visual modality in children with SLI. More research is needed that directly compares the auditory and visual modality with respect to sustained attention.

Fourth, we observed that all measures of sustained attention, except the performance decrement in the auditory CPT, correlated with the mean picture naming latency. This suggests that children with poorer sustained attention (as indicated by longer RTs, lower hit rates, more false alarms, and larger decrements over time) were slower to name pictures than children with better sustained attention. This held for both visual and auditory CPTs. Moreover, correlations were present for both SLI and TD groups, and these correlations did not differ between groups. This further corroborates the view that children with SLI are impaired in a domain-general sustained attention ability, and that this ability is correlated with naming performance, just as it is for TD children.

Sustained attention ability was not only correlated with mean picture naming latencies, but also with parameters characterizing the normal part (μ) and the right tail (τ) of the underlying RT distribution. In previous research on adults, the relationship between sustained attention ability and picture naming performance was evident only for the τ parameter. Adult individuals with worse sustained attention were not consistently slower to name but showed a larger number of very slow responses, as compared to adult individuals with better sustained attention (Jongman, Meyer, & Roelofs, 2015; Jongman, Roelofs, & Meyer, 2015). The current study shows that the relationship between sustained attention and picture naming in children diverges from that of adults, as the correlations were not only found for the τ parameter but also for the μ parameter. Children with poorer sustained attention were slower in naming the pictures on most of the trials (as evident from the correlation with μ) and they had a larger proportion of very slow responses than children with better sustained attention (as evident from the correlation with τ). This indicates that sustained attention might play a more important role in naming in children, when language is still developing, than in adults.

To conclude, we observed that children with SLI perform worse than TD children on picture naming and on both auditory and visual sustained attention tasks. Moreover, children with poorer sustained attention performance took longer to name pictures, which held regardless of perceptual modality (auditory, visual) and developmental group (SLI, TD). These results provide evidence for a relationship between domain-general sustained attention and picture naming performance in both typically developing and language impaired children.

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Appendix

Target names of pictures, with English translation.

aap (monkey), arm (arm), bed (bed), boot (boat), bus (bus), deur (door), duim (thumb), ei (egg), kerk (church), kip (chicken), lamp (lamp), mes (knife), muur (wall), neus (nose), oor (ear), paard (horse), pan (pan), ring (ring), touw (rope), zon (sun)

Chapter 5

Sustained Attention Ability Affects Simple Picture Naming

Sustained attention has previously been shown as a requirement for language production. In a range of experiments, sustained attention ability correlated with language production in such a way that individuals with poor sustained attention showed a large number of abnormally slow responses when naming or describing a picture (Jongman, Meyer, & Roelofs, 2015; Jongman, Roelofs, & Meyer, 2015). However, the correlations were strongest for naming in a relatively difficult setting, such as a dual-task situation. The current study provides corroborating evidence that this relationship holds even for simple picture naming. Sustained attention was measured by a digit discrimination task where participants responded only to the digit zero, and withheld a response to all other digits. Sustained attention ability was previously indexed by participants' reaction times only; in the current study the relationship with picture naming also holds for individuals' hit rate (the proportion of correctly detected targets). Finally, the need to sustain attention was manipulated by changing the speed of stimulus presentation. Research has suggested that fast event rates tax sustained attention resources to a larger degree than slow event rates. However, in this study the fast event rate did not result in increased difficulty, neither for the picture naming task nor for the sustained attention task. Instead, the results point to a speed-accuracy trade-off in the sustained attention task (lower accuracy but faster responses in the fast than in the slow event rate), and to a benefit for faster rates in the picture naming task (shorter naming latencies with no difference in accuracy). Performance on both tasks was largely comparable, supporting our previous findings that sustained attention is called upon during language production.

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Introduction

Accumulating evidence suggests that word production requires attention even though it is a highly practiced skill. For instance, speaking can have a detrimental effect on an unrelated task such as driving (Kubose et al., 2006). Several other studies have shown similar effects and argued that word production draws from a central attentional system (Cook & Meyer, 2008; Ferreira & Pashler, 2002; Roelofs, 2008a). However, it remains unclear which attention system these studies refer to. Attention is a broad term that comprises different functionally and anatomically separate subsystems. Posner and colleagues have proposed there are three such attention systems: executive control, orienting, and alerting (Petersen & Posner, 2012; Posner & Petersen, 1990; Posner & Rothbart, 2007). One or all of these systems could contribute to language production, possibly in different ways.

Executive control refers to the ability to remain goal-directed and has been studied in relation to language, mostly in comprehension (for a review see Ye & Zhou, 2009) but also recently in production (Shao, Roelofs, & Meyer, 2012). Shao et al. decomposed executive control into three subcomponents - updating, inhibiting, and shifting - as suggested by Miyake and colleagues (Miyake et al., 2000). Updating (the ability to maintain or actively manipulate the contents of working memory and monitor incoming information), and inhibiting (the ability to resolve conflict or lower activation of unwanted information) were found to contribute to word production. However, the third component, shifting (the ability to rapidly switch back and forth between tasks or mental sets) did not contribute. This indicates that not all types of executive attention are called upon during word production.

Orienting, a second attentional system, concerns the ability to shift the locus of processing towards a source of information. Alerting, the third system, is the ability to achieve and maintain alertness, either briefly (e.g., in response to a warning signal) or prolonged over extended periods of time. This type of attention is often referred to as vigilance or sustained attention. Sustained attention has been suggested to play a role during word production, based on results of studies using the individual differences approach (Jongman, Meyer, & Roelofs, 2015; Jongman, Roelofs, & Meyer, 2015). In three experiments we showed that individuals with poor sustained attention performance showed a larger amount of abnormally slow responses when naming or describing pictures compared to individuals with relatively good sustained attention ability. This suggests that sustained attention is involved in language production.

One problem with these previous studies is that the strongest correlations were found for picture naming in a relatively difficult setting, i.e. in dual-task situations where participants named pictures and concurrently performed a second task, either non-verbal or linguistic. Significantly smaller correlations were found for simple picture naming. One aim of the present study is to see whether this relationship between sustained attention and single word production can become more evident by increasing the need for sustained attention within a simple picture naming paradigm. More importantly, the problem with these previous studies is that they provide only correlational evidence. These individual differences studies point to a role of sustained attention during language production, but as of yet there is no definitive evidence that sustained attention is required to produce words. Manipulating the need for sustained attention during a language production task could provide more direct evidence that sustained attention is required for successful language production.

Sustained attention was first studied by Mackworth during the second world war; he showed that radar operators monitoring for rare events tended to increasingly fail to detect such events towards the end of their watch (Mackworth, 1948). Since then it has been shown that sustained attention can be affected by three factors: task parameters, participant characteristics, and environmental conditions (for reviews see Ballard, 2001; Langner & Eickhoff, 2013; Oken, Salinsky, & Elsas, 2006; Robertson & O'Connell, 2010; Sarter, Givens, & Bruno, 2001). Task parameters that tax sustained attention include infrequent target signals, degraded stimuli, spatial uncertainty and high speed of stimulus presentation (McFarland & Halcomb, 1970; Mouloua & Parasuraman, 1995; Parasuraman, 1979; Parasuraman, Nestor, & Greenwood, 1989). The second factor that can influence sustained attention performance relates to individuals' characteristics. Older participants have more difficulty with maintaining attention than younger adults (Parasuraman et al. 1989). Some clinical populations appear to have deficits in sustained attention, such as persons with schizophrenia and individuals with ADHD ((Epstein, Johnson, Varia, & Conners, 2001; Liu et al., 2002). Finally, environmental factors such as noise can affect sustained attention performance (Broadbent & Gregory, 1965).

In the present study one of the variables known to tax sustained attention was manipulated, namely the speed of stimulus presentation. The speed of stimulus presentation can be manipulated either by changing the inter-stimulus-interval (ISI) or by changing the duration of the stimulus itself. Jerison and Pickett (1964) first reported a threefold decrease in the hit rate when the event rate in a visual vigilance task was increased from 5 events per minute to 30 events per minute. In other words, there are more failures to detect a target when the stimuli are presented in rapid succession. Other studies have also observed lower hit rates for faster event rates (Ballard, 2001; Coull, Frith, Frackowiak, & Grasby, 1996; Lanzetta, Dember, Warm, & Berch, 1987). Some studies have, in addition, found a greater vigilance decrement (worse performance as time on task increases) for higher event rates compared to slow event rates (Parasuraman, 1979; Parasuraman & Giambra, 1991). The fact that fast event rates cause worse performance on sustained attention tasks has been argued to be due to faster depletion of a limited pool of attentional resources (Warm, Parasuraman, & Matthews, 2008).

These mentioned studies have all mainly looked at accuracy, not reaction time (RT). Ballard (2001) did measure RTs and found that participants responded faster in a fast event rate as compared to slow event rates. The decrease both in hit rate and in RTs for fast compared to slow event rates could indicate a speed-accuracy trade-off instead of reflecting sustained attention depletion differences between fast and slow tasks. However, findings that false alarms, failures to withhold response to a non-target, are higher for slow event rates than for fast rates argue against this idea of a speed-accuracy trade-off (Koelega et al., 1992; Lanzetta et al., 1987). Moreover, a large vigilance decrement in the fast event rate in both hit rate (a decrease over time) and RTs (an increase over time) would also argue against such a trade-off.

There have been several studies reporting contrasting results, such that fast event rates actually cause better performance than slow rates. This is true for sustained attention studies with children (Chee, Logan, Schachar, Lindsay, & Wachsmuth, 1989; Rose, Murphy, Schickedantz, & Tucci, 2001) but has also been found in a study using adults, albeit in an experiment not designed to test sustained attention. De Jong, Berendsen, and Cools (1999) had participants perform a spatial version of the Stroop task (i.e. the word LOW/HIGH presented above/below the center, with participants responding to location only), either in a fast or in a slow event rate design. Participants were faster to respond in the fast event rate condition, with no loss in accuracy levels, as compared to participants in the slow event rate condition. Interestingly, there was a large reduction in the Stroop effect (slower responses to incongruent trials, such as LOW presented above the center, than to congruent trials) in the fast condition compared to the slow condition. The authors argued that in the fast event rate attention was sharply focused on the task, resulting in fast responses and fewer opportunities for the word meaning to interfere.

One goal of the present study was to provide a better picture of whether differences in the degree of depletion of sustained attention account for effects of event rate, whether it is a mere speed-accuracy trade-off or whether event rate differences reflect variation in the focusing of attention. Participants performed a digit discrimination task (DDT) measuring sustained attention with fast and slow event rate conditions. The DDT is a visual continuous performance task in which digits are presented on the screen one by one and participants are instructed to respond to an infrequent target only, i.e. the digit zero among foils one to nine (i.e., Matthews & Davies, 2001; Parasuraman et al., 1989; Sepede et al., 2012). In the present experiment, the ISI between digits was manipulated to create the fast and slow event rate conditions. Stimulus duration was held constant for both conditions. The analyses not only focused on hit rate and false alarms but also on RTs. People should be faster to respond in the fast event rate, as shown in previous studies. If there is no loss in accuracy then the findings are in accordance with the sharp focusing of attention in the fast rate as in De Jong and colleagues (1999). If however, hit rates are lower for the fast event rate condition as compared to the slow rate this would not hold. If fast event rates indeed tax sustained attention to a larger degree, a larger decrement should be found in both hit rates and RTs such that participants have fewer hits and respond more slowly over time as compared to the slow rate. Lack of such an increased decrement would point to a mere speed-accuracy trade-off.

The main goal of this study however, was to show that word production requires sustained attention. Participants not only performed a sustained attention task, but also a picture naming task. The naming of pictures occurred either in a fast event rate or in a slow event rate condition. In both conditions, pictures of simple objects were presented for one second and participants were asked to name them. In the fast event rate condition pictures were separated by a blank screen for only 500 ms, whereas the ISI was 2000 ms in the slow event rate condition. If sustained attention is required for word production we would expect patterns in error rates and RTs for the two event rates comparable to the pure sustained attention task. So if the fast event rate in the picture naming task depletes attention to a larger degree, one should find more errors and a larger decrement over time in both errors and RTs as compared to the slow naming task. Conversely, if the fast event rate helps to maintain focus on the task at hand, RTs should be faster in the fast rate and accuracy levels should be the same or higher when compared to the slow condition.

Moreover, if sustained attention ability is involved in the picture naming task, word production performance should correlate with performance on the pure sustained attention task. Thus individuals who are better at the sustained attention task should also be better at the picture naming task. Participants who show a large performance decrement on one task should also show a large decrement on the other. In our previous studies accuracy in the sustained attention tasks and language production tasks was very high, and sustained attention ability was always defined by RTs. Manipulating event rate should result in more errors and allow us to describe sustained attention ability not only in RTs but also in accuracy.

Mean RTs on the picture naming task were divided into two separate components to see whether event rate affected all or only a subset of responses. Ex-Gaussian analysis decomposes the underlying RT distribution into two parameters, the μ parameter that reflects the normal part of the distribution, and τ which reflects the tail end of the distribution. In previous experiments (Jongman, Meyer, & Roelofs, 2015; Jongman, Roelofs, & Meyer, 2015), we found sustained attention ability to correlate only with the τ parameter of the picture description latencies, not μ. The τ parameter indexes the abnormally slow responses. In other words, individuals with poorer sustained attention ability did not consistently name or describe pictures slower than individuals with better sustained attention; instead they had a larger number of very slow responses. We interpreted τ as reflecting lapses of attention as suggested by Unsworth, Redick, Lakey, and Young (2010). It could very well be the case that the effect of event rate is manifested mostly in the τ parameter and as such correlations could be stronger for τ as compared to μ.

In summary, the aim of the present study was to manipulate the need for sustained attention within a language production task by varying event rate, and compare it to the effect of the same manipulation in a sustained attention task. Does the event rate manipulation cause similar effects in both tasks? Are differences between a fast and slow event rate due to differences in attention depletion, adjustments in focusing of attention, or does it simply reflect a speed-accuracy trade-off? Another aim of this study was to see if sustained attention ability, as measured not only by RTs but also by accuracy, correlates with simple picture naming, extending previous individual differences studies on sustained attention and language production.

Method

Participants

Twenty-eight students of the Radboud University Nijmegen or the Hogeschool van Arnhem en Nijmegen took part in the experiment. All participants were native speakers of Dutch and had normal or corrected-to-normal vision. The average age was 23.1 years (range: 19-32 years), twenty-five participants were female. Participants were paid for taking part in the study.

General Procedure

Participants were tested individually in a dimly illuminated room. They were seated in front of a 17 inch (Iiyama LM704UT) screen. Participants first performed the picture naming task, with alternating fast and slow event rate blocks. Participants then performed the digit discrimination task, again with alternating fast and slow event rate blocks.

Picture Naming Task

Materials and design. Thirty common objects were presented to the participants, each thirty times. The object names were monosyllabic and highly frequent (mean lemma frequency: 600 tokens per million; CELEX database, Baayen, Piepenbrock, & Gulikers, 1995). The pictures were selected for high name agreement (mean 89%; Severens, Van Lommel, Ratinckx, & Hartsuiker, 2005). See Appendix for all object names.

The pictures were presented in the center of the computer screen, fit to a virtual frame of 300 by 300 pixels, corresponding to visual angles of 7.0° horizontally and 6.4° vertically when viewed from the participant's position, approximately 60 cm away from the screen. In each block, the 30 pictures were presented in a pseudorandomized order such that two objects of the same semantic category never followed one another, nor did two names starting with the same phoneme.

Procedure. Before the experiment, participants were familiarized with the pictures and the corresponding names. In the first familiarization block, each picture was presented in the middle of the screen with its name written below. The participant pressed Enter to proceed to the next picture. In the second familiarization block, a picture was presented and participants were asked to name the picture. Once the voicekey was triggered the correct name was shown on the screen, and participants were asked to check if their response matched the written text. Once all thirty pictures had been named, the participant proceeded with the actual experiment.

In the fast event rate, a trial started with a blank screen shown for 500 ms, then the picture was shown for 1000 ms. In the slow event rate condition, the blank screen initializing the trial was presented for 2000 ms. The duration of picture presentation was identical to the fast event rate condition, thus 1000 ms. These durations were chosen based on the taxonomy suggested by Parasuraman and Davies (1977), and Lanzetta and colleagues (1987). The first study suggested a cut-off of 24 event rates per minute as the transition from a slow event rate to a fast event rate, whereas the latter study suggested a higher cut-off such as 48 events per minute for a simple task (i.e. when the current trial does not depend on information from the previous trial). Here, 40 events were presented per minute in the fast event rate, chosen to be near the Lanzetta cut-off whilst still allowing for enough time to name each picture before the start of the next picture onset.

In the fast event rate condition a total of 600 pictures were presented, divided over two blocks. The slow event rate condition consisted of 300 pictures in total, also over two blocks. Fast and slow event rate conditions had equal durations, namely 15 minutes. Fast and slow event rate blocks alternated, and block order was counterbalanced across participants.

Analyses*.* Vocal responses were recorded by a voicekey (Sennheiser ME64). Responses below 400 ms were checked manually using the program Praat (Boersma & Weenink, 2012). Description errors and hesitations were coded offline and discarded from the analyses. Furthermore, a reliability check was performed by manually annotating 200 trials randomly selected from 4 randomly chosen participants and comparing them with the RTs as measured by the voicekey. The voicekey measured RTs in a highly comparable manner to manual annotation, the intraclass-coefficient (ICC) was .88 and so was the correlation between the two measurements. Therefore, the naming latencies as measured by the voicekey seem reliable and are used for the following analysis.

The naming latencies were analyzed using R (R Core Team, 2012) and the R packages *lme4* (Bates, Maechler, & Bolker, 2013) and *languageR* (Baayen, 2011). The linear mixed effects model included event rate (fast vs. slow) and block (first block vs. second block) as fixed effects as well as their interaction. RTs were log transformed because of positive skewing. Variables were dropped that did not reliably contribute to model fit, models were compared using a likelihood ratio test. Participant and item were treated as random effects with both intercepts and random slopes included for both factors and their interaction (Barr, Levy, Scheepers, & Tily, 2013).

Digit Discrimination Task

Materials and design. Single digits in white (font Arial, size 40) were presented on a black background using Presentation Software (Version 16.2, www.neurobs.com). The digit 0 was the target digit, and all other digits (1 through 9) were non-targets. Targets were presented with a probability of 25%. Stimuli were presented in a pseudorandom sequence with the restriction that identical targets never directly followed one another and that targets were preceded by each non-target an equal number of times. A total of 72 practice trials and 1728 experimental trials were presented.

Procedure. Digits were presented for 100 ms each, with an inter-stimulus-interval (ISI) of 500 ms in the fast event rate condition and an ISI of 2000 ms in the slow event rate condition. The fast event rate, with 100 events per minute, was far above the suggested cut-off of 48 events per minute as suggested by Lanzetta and colleagues (1987). Participants responded to the target stimuli with a button press using their dominant hand. The fast event rate condition consisted of 1344 trials, divided over two blocks. The slow event rate condition included 384 trials in total. Both event rate conditions lasted for 13.5 minutes. Event rate blocks alternated, and block order was counterbalanced across participants.

Analysis. RTs were measured and errors were divided into misses and false alarms with the former being failures to respond to targets and the latter being responses to non-targets. A logit mixed model was conducted for the hit rates, correct responses to targets (Jaeger, 2008). The model included event rate (fast vs. slow) and block (first vs. second) as fixed effects as well as their interaction. Participant was included as a random factor, with intercepts and slopes for the main effects. The interaction was not included in the random structure due to failure to converge.

The linear mixed effects model for the correct RTs was computed identically to the model for picture naming, by including the full random structure (see above).

Analyses of Individual Differences

For correct trials in the picture naming task, the ex-Gaussian parameters μ, σ, and τ were estimated using the continuous maximum-likelihood method proposed by Van Zandt (2000). The parameters μ and σ reflect the mean and standard deviation of the normal portion, respectively, and τ reflects the mean and standard deviation of the exponential portion of the distribution. In contrast to the linear mixed effects analyses, latencies were not log-transformed for the ex-Gaussian analyses. The parameters were estimated separately for the fast and slow event rate conditions for each participant using the program QMPE (Heathcote, Brown, & Cousineau, 2004). The parameter σ was not included in the following analyses because it was not of interest in the present study and to limit the number of comparisons. For both event rates, mean RTs and hit rates on the DDT were correlated with the μ and τ parameters of the picture naming task. Moreover, performance decrement was calculated as RTs on the second half minus the first half for both tasks, and then correlated between the two tasks for each event rate.

Since a total of 18 correlations were tested, the Benjamini-Hochberg correction for multiple comparisons was applied. The Benjamini-Hochberg correction controls the false discovery rate instead of the familywise error rate, resulting in greater power than Bonferroni-type procedures (Bender & Lange, 2001; Benjamini & Hochberg, 1995; Benjamini & Yekutieli, 2001; Williams, Jones, & Tukey, 1999). The Benjamini-Hochberg procedure first sorts and ranks the *p*-values with the smallest value getting rank 1, the second rank 2 and the largest rank *N.* Then, each *p*-value is multiplied by *N* and divided by its assigned rank.

Results

Picture Naming Task

Naming errors were made in 1.0% of all trials (fast event rate: 1.1%; slow: 0.8%), hesitations occurred on 0.6% of the trials (fast: 0.7%; slow: 0.3%). Too few errors were made for any further analysis.

The best-fitting linear mixed effects model for correct naming latencies included main effects of event rate ($ß$ = 0.03, *SE* = 0.01, t = 3.59) and block ($ß$ = 0.05, *SE* = 0.01, t = 4.72). Removing either event rate or block significantly decreased model fit (χ^2 (1) = 10.76, p = .001 and χ^2 (1) = 16.43, p < .001, respectively). Including the interaction did not improve model fit (χ^2 (1) = 1.30, p = .25). The model showed that RTs were significantly different for the two event rates such that participants were faster to name the pictures in the fast event rate condition compared to the slow event rate condition (fast: 713 ms, *SD* = 94; slow: 740 ms, *SD* = 102). The main effect of block revealed that participants were slower in the second block of the experiment as compared to the first block (first: 701 ms, *SD* = 93; second: 743, *SD* = 103), independent of the manipulation of event rate.

Digit Discrimination Task

False alarms, responding to non-targets, occurred on 0.6% of the non-target trials (fast event rate: 0.5%; slow event rate: 0.7%), precluding any further analysis. Misses, failures to respond to a target, occurred on 4.4% of the target trials. The logit mixed model on hits, the correct responses to targets, revealed a significant effect of event rate ($ß$ = 2.20, SE = 0.60, z = 3.69, $p < .001$). The block effect did not reach significance ($ß$ = -0.02, SE = 0.20, z = -1.16, p = .25). The interaction between event rate and block was not significant either ($ß$ = -0.30, SE = 0.35, z = -0.86, p = .39). Hit rates were significantly lower for the fast event rate condition as compared to the slow event rate (95% vs 98%).

The linear mixed effects model performed on the correct RTs showed a significant main effect of event rate ($ß$ = 0.08, SE = 0.02, t = 4.77) and of block ($ß$ = 0.05, SE = 0.01, t = 7.02). Dropping either of these two main effects resulted in worse model fit (event rate: χ^2 (1) = 17.15, $p < .001$; block: χ^2 (1) = 29.14, $p < .001$). Including the interaction between event rate and block did not improve model fit (χ^2 (1) = 0.02, p = .89). Participants were faster to respond in the fast event rate condition as compared to the slow event rate (fast: 413 ms, *SD* = 36; slow: 456 ms, *SD* = 71). Performance deteriorated over time, with an average RT of 412 ms (*SD* = 48) for the first half compared to 433 ms (*SD* = 57) for the second half. The lack of an interaction between event rate and block indicates the performance decrement was of similar magnitude in both event rate conditions.

Individual Differences

The μ parameter of the picture naming task, for either event rates, did not correlate with any of the parameters of the DDT. The τ parameters did however; see Table 1 for the *r*-values. Both mean RT and hit rate on the sustained attention task correlate with the τ parameter of picture naming, for both event rates. After correcting for multiple comparisons using the Benjamini-Hochberg procedure, the correlations between hit rate on

Table 1. Correlations between the mean reaction times (RT) and hit rates (HR) of the digit discrimination task (DDT) and the mu (μ) and tau (τ) parameters of the picture naming task, separate for fast and slow event rates.

			Picture Naming			
			Fast		Slow	
Task	Event Rate	Measure	μ	τ	μ	τ
DDT	Fast	RT	.13	.48*	.22	.52*
		HR	-.15	-.47*	-.27	-.61*
	Slow	RT	-.03	.45*	.12	.57*
		HR	.13	-.38	-.00	-.42

*Correlation significant after Benjamini-Hochberg correction for multiple comparisons

the slow condition of the DDT and picture naming no longer reach significance. This may have been due to higher hit rates in this condition in general, and as such there was less variation between participants. Overall, participants who showed worse sustained attention ability, as measured by both RTs and hit rates, had a larger amount of abnormally slow responses when naming pictures than individuals with better sustained attention.

Performance decrement on the DDT (mean RT second half - mean RT first half) for the fast event rate did not correlate with performance decrement for the fast event rate of the picture naming task $r = .30$, $p = .12$. Performance decrement during the slow event rate on the DDT did correlate with the decrement of picture naming in the slow condition: $r = .46$, $p = .01$. Thus participants who became increasingly slow over time did so for both the sustained attention task and picture naming, but this relationship only became evident for the slow event rate.

Discussion

The current study had three aims. Firstly, to test whether manipulating event rate in both a sustained attention task and picture naming task would result in corresponding effects. Secondly, to find out whether differences between a fast and slow event rate are due to differences in attention depletion, adjustments in focusing of attention, or whether it simply reflects a speed-accuracy trade-off. Thirdly, to show sustained attention ability correlates with language production, even in a simple naming paradigm.

The first aim was to find out if the event rate manipulation would result in similar effects for the sustained attention task and picture naming. In both tasks participants were faster to respond when stimuli were presented in rapid succession as compared to a slower presentation rate. Moreover, in both tasks, there was a performance decrement in RTs for both event rates, but there was no difference in the magnitude of the decrement between conditions. Finally, the performance decrements between the slow event rate conditions for the two tasks were correlated, such that individuals who became increasingly worse over time did so for both a sustained attention task and a picture naming task, albeit only when stimuli were presented at a relatively slow pace. A performance decrement is one of the key findings in the sustained attention literature (Davies & Parasuraman, 1982; See, Howe, Warm, & Dember, 1995). The correlation suggests picture naming can show a similar decrement as found in sustained attention tasks.

The only difference between the two tasks was in accuracy levels, such that hit rates were lower for the fast event rate of the DDT than for the slow rate, whereas there were hardly any errors made when naming pictures for either rate. RT and error data taken together could suggest that naming pictures in a fast event rate is actually easier than in a slow event rate. This brings us to the second aim of this study: The picture naming data support the proposal that the differences between fast and slow event rates are due to an adjustment in focusing of attention, in line with De Jong, Berendsen, and Cools (1999). They found faster RTs without a decline in accuracy for the fast rate in a spatial Stroop task as compared to a slow rate. They argued that the fast rate helped to keep focus on the task at hand, whereas the slow condition gave rise to more fluctuations in attentional state, allowing word reading to interfere with responding to the location of the word. It could thus be the case that certain tasks benefit from a fast presentation rate, perhaps tasks where a response has to be given on each trial instead on only a subset of trials as in the traditional sustained attention tasks.

However, the possibility remains that the lack of naming errors in both event rates indicates that both conditions were relatively easy and that the fast event rate was actually not fast enough to strongly tax attention. The ISI was very short for a picture naming task, namely 500 ms. However, the picture stayed on the screen for one second. Picture duration was chosen at one second to give people enough time to identify the object, plan the name, and complete the speech output before the next trial started. The total trial length of 1.5

seconds may have been too long to tax sustained attention to a larger degree than the 3 second trial length in the slow event rate. With 40 events per minute, the fast event rate fell just below the cut-off of 48 events per minute for simple tasks as suggested by Lanzetta, Dember, Warm, and Berch (1987). It could be that the naming task is indeed such a simple task. Participants are familiarized with all the items, and repeat all items 30 times. The highly repetitive nature could have made the task too simple and participants had few problems naming pictures, even in the fast event rate condition.

For the sustained attention task, the fast condition did result in lower hit rates than the slow condition. Yet, to prove that fast event rates are more taxing one needs to show a larger decrement in hit rates and/or RTs in the fast condition as compared to the slow event rate. There was no performance decrement for hit rates in either condition. A decrement in the RTs was present, but no interaction with event rate, suggesting the decrement was similar for both event rates. Some previous studies found a larger number of false alarms for the slow event rate, which would argue against a speed-accuracy trade-off, but the current sustained attention task did not show this effect. It should be noted that for the DDT, the number of events per minute was well above the cut-off of 48 events per minute as suggested by Lanzetta et al. (1987), namely 100 events per minute. Therefore, one cannot argue that the fast event rate condition was actually too slow. All in all, a simple trade-off explanation for the DDT cannot be refuted. These findings warrant caution for interpreting fast event rates as more taxing on sustained attention than slow rates. Experiments need to report both hit rates and RTs and show that a decrement for one measure does not go hand in hand with an improvement for the other. Reporting only one measure will not contest the speed-accuracy trade-off.

Previous research has used similar ISIs to differentiate between fast and slow conditions as used in the present study (i.e., Ballard, 2001; Smallwood et al., 2004). Not finding a larger performance decrement in the fast event rates could be due to other task parameters, such as task duration. Each experiment lasted approximately 30 minutes, with blocks around 7 minutes. It could be that the blocks did not last long enough to thoroughly tax sustained attention. Another possibility is that the alternation of fast and slow blocks caused participants to recharge, and as such the second block was not more difficult than the first block. It could be the case that within blocks, the performance decrement was larger for the fast event rates. Post-hoc analyses, adding a factor to the model dividing blocks into two, did not provide evidence for this idea. For the DDT, the interaction between event rate and this new factor did not reach significance for either hit rates (*ß* = 0.06, *SE* = 0.31, z = 0.20, *p* = 0.85) or RTs (*ß* = -0.00, *SE* = 0.01, *t* = -0.36). There was an interaction effect for picture naming (*ß* = 0.01, *SE* = 0.01, *t* = 2.71), but it actually pointed to a larger decrement within the slow blocks than within the fast blocks.

The third aim was to link this study to previous research on sustained attention and its role in language production by correlating individuals' sustained attention ability with picture naming performance. In the previous studies, the correlation was strongest for production latencies when naming occurred in a relatively difficult situation, i.e. a dual-task experiment (Jongman, Meyer, & Roelofs, 2015; Jongman, Roelofs, & Meyer, 2015). The correlation with simple picture naming was significant, but weaker. Here, by increasing the need to sustain attention within a simple picture naming paradigm instead of using a more demanding naming paradigm, sustained attention ability correlated with single word production. As in earlier research, the sustained attention task was found to correlate with the τ parameter of picture naming latencies, not with the μ parameter. Thus, individuals with worse sustained attention were not consistently slower when naming pictures but showed a larger amount of very slow responses as compared to individuals with better sustained attention.

Sustained attention ability was not only quantified by individuals' RTs but also by their hit rates, the proportion of correctly detected targets. Hit rates were lower than we found previously when using a DDT with an intermediate event rate. This allowed for testing the correlation between hit rates and picture naming latencies, and a significant relationship was found. After correcting for multiple comparisons, this relationship remained significant only for the fast DDT, most likely due to lower hit rates and more variation in this condition as compared to the slow event rate. It shows that hit rates can quantify sustained attention ability if there are strong individual differences, and that not only RTs on the DDT correlate with picture naming latencies but also accuracy levels.

In conclusion, one aim was to show that simple picture naming requires sustained attention by manipulating a task parameter that is often used in sustained attention tasks. Sustained attention ability, as measured by RTs and hit rates, correlated with the abnormally slow responses when naming pictures, even in a simple paradigm. The task parameter, event rate, did not lead to the predicted result of fast event rate being more taxing than the slow event rate. However, performance was similar across the sustained attention task and picture naming, providing further support for sustained attention playing a role in language production.

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I thank Gurupriya Ramanathan for help with setting up the experiment, running the participants, and annotating part of the data, and Antje Meyer, Ardi Roelofs, and Brónagh McCoy for valuable comments on an earlier draft of this paper.

Appendix

Target names of pictures, with English translation.

arm (arm), bed (bed), been (leg), bij (bee), blik (can), bloem (flower), boek (book), boom (tree), brief (letter), deur (door), glas (glass), haar (hair), hand (hand), hond (dog), kerk (church), man (man), muur (wall), net (net), oog (eye), oor (ear), paard (horse), raam (window), stad (city), stoel (chair), trap (stairs), trein (train), voet (foot), vrouw (woman), weg (road), zak (bag)

Chapter 6

An electrophysiological signature of lapses of attention: Can pre-stimulus activity predict production speed?

Sustained attention has been shown to correlate with performance in picture naming and picture description tasks (Jongman, Meyer, & Roelofs, 2015; Jongman, Roelofs, & Meyer, 2015). Specifically, correlations were found for sustained attention and language production for the τ parameter of naming latencies, which reflects the tail end of the RT distribution. Individuals with poor sustained attention had a larger τ, which means they had a larger number of very slow naming responses. It has been suggested that these very slow responses, reflected in the τ parameter, index momentary lapses of attention. Studies have shown that prior to such a slow response, the brain shows a different activation pattern than before a fast response. One such change is found in pre-stimulus alpha power as measured by electroencephalography (EEG): as alpha power increases over task-relevant brain areas, so does response time. It seems that for good performance, a phasic decrease in alpha power is required. Moreover, good performance throughout an experiment is associated with increased tonic alpha power. In this study, we used EEG to test whether naming speed during a word production task could also be predicted by pre-stimulus alpha power. We found no evidence for an alpha power modulation, which could either be due to our design, or it could point to a different mechanism than alpha activity that underlies the speed of naming trials.

Jongman, S. R., Roelofs, A., & Meyer, A. S. (in preparation). An electrophysiological signature of lapses of attention: Can pre-stimulus activity predict production speed?

Introduction

Being able to maintain attention over prolonged periods of time, called sustained attention, is an essential cognitive capacity, failing to do so can lead to serious consequences. Research interest in the ability to maintain attention increased during the second world war when radar operators searching for submarines occasionally missed signals indicating enemy presence. Mackworth (1948) showed that signal detection accuracy already declined by 20% after thirty minutes, and would continue to decline gradually throughout the operators' watch period. In our daily life, a lapse of attention will usually have less disastrous consequences, but the question remains why such an essential ability is so vulnerable. Many studies since Mackworth's seminal study have shown that sustaining attention is demanding, and performance quickly deteriorates (for reviews see Langner & Eickhoff, 2013; Sarter, Givens, & Bruno, 2001; Warm, Parasuraman, & Matthews, 2008).

According to an influential theory proposed by Posner and colleagues (Petersen & Posner, 2012; Posner & Petersen, 1990; Posner & Rothbart, 2007), sustained attention is associated with the alerting component of attention (the other components being executive control and orienting). The alerting component is further divided into phasic and tonic aspects. The phasic aspect refers to the ability to increase the level of alertness following a warning signal, whereas the tonic aspect refers to the ability to maintain alertness over prolonged periods of time (i.e., sustained attention). In the present article, we address both phasic and tonic aspects of alertness.

In recent years, research has progressed from investigating when lapses of attention happen to why lapses occur. Using functional magnetic resonance imaging (fMRI), Weissman and colleagues have looked at brain mechanisms underlying lapses of attention by comparing slow responses to fast responses, assuming that a relatively slow response results from a momentary lapse of attention (Chee et al., 2008; Prado, Carp, & Weissman, 2011; Weissman, Roberts, Visscher, & Woldorff, 2006; Weissman, Warner, & Woldorff, 2009). They showed that long reaction times (RTs) on a selective attention task (e.g. a global/local task where participants identified either the large, global letter or the small, local letters composing the large letter) were associated with a distinct pattern of brain activity. Prior to the onset of the trial, slow responses were associated with reduced activity in brain regions underlying attentional control, i.e. the inferior frontal gyrus, middle frontal gyrus, and the anterior cingulate cortex (Corbetta & Shulman, 2002; Kerns et al., 2004;

Miller & Cohen, 2001). In addition, activity in sensory brain areas, the visual cortex in case of the global/local task, was reduced for slower trials compared to fast trials. Moreover, the slowest RTs were related to increased activity in areas of the default mode network thought to be related to task-irrelevant thoughts (Raichle et al., 2001). A lapse of attention therefore seems to involve a less effective employment of control regions and activation of sensory cortex, and a failure to suppress task-irrelevant areas.

Lapses of attention have also been investigated with electrophysiological measures such as electro- and magnetoencephalography (EEG/MEG). Similar to Weissman and colleagues, pre-stimulus electrophysiological signals can be compared for slow versus fast trials. In particular, research has focused on rhythmic neuronal activity, also known as oscillations. There are different frequencies at which neurons synchronize activity. Oscillatory power reflects the number of neurons that discharge synchronously. Several studies have found that as RTs decrease, pre-stimulus oscillatory power in the alpha frequency band (8 to 12 Hz, i.e. 8 to 12 oscillations per second) decreases (Kelly, Gomez-Ramirez, & Foxe, 2009; Thut, Nietzel, Brandt, & Pascual-Leone, 2006). In other words, a phasic decrease in alpha power corresponds to an increase in performance speed. This alpha power decrease is region-specific: Mazaheri and colleagues found the power decrease over visual cortex when participants performed a visual orientation task whereas the power decrease was evident for the superior temporal gyrus during an auditory discrimination task (2014). Besides the relationship between alpha power and RTs, pre-stimulus alpha power has been shown to predict perception performance (Hanslmayr et al., 2007), perception errors (Mazaheri, Nieuwenhuis, van Dijk, & Jensen, 2009), and self-reported attentional state (Macdonald, Mathan, & Yeung, 2011).

Romei, Gross, and Thut (2010) provided evidence that this relationship between pre-stimulus alpha power and subsequent stimulus processing is not merely correlative. Using transcranial magnetic stimulation (TMS) they stimulated visual areas via short trains of rhythmic TMS. When the visual areas were stimulated at a frequency of 10 Hz, a frequency in the alpha band, visual detection was impaired as compared to stimulations at 5 Hz (theta band) and 20 Hz (beta band). Therefore, there seems to be a causal link between alpha power and detection which has been shown using TMS. It has been suggested that these oscillations in the alpha range play a role in attentional control role by regulating information flow through inhibition of task-irrelevant brain areas (Jensen & Mazaheri, 2010;

Klimesch, Sauseng, & Hanslmayr, 2007). This is supported by studies showing not only a decrease in alpha power in relevant areas but also an accompanying increase in alpha power in irrelevant regions, for instance in a visual spatial attention task (Haegens, Händel, & Jensen, 2011; Haegens, Luther, & Jensen, 2012; Kelly, Lalor, Reilly, & Foxe, 2006).

There is some evidence that language production is susceptible to lapses of attention. Language production is a task we are highly familiar with: we talk every day, starting from an early age. It seems a simple task, but our previous studies have shown that sustaining attention on a production task can be harder than one would imagine (Jongman, Meyer, & Roelofs, 2015; Jongman, Roelofs, & Meyer, 2015). Sustained attention ability correlated with performance in picture naming and picture description tasks, such that individuals with poorer sustained attention had a larger number of very slow naming trials than individuals with better sustained attention. We interpreted these very slow responses just as Weissman and colleagues did (2006), namely as trials reflecting lapses of attention. Correlations between sustained attention and language production were strongest in dual-task situations, when the production task occurred simultaneously with a second unrelated task, which was linguistic (Jongman, Meyer, & Roelofs, 2015) or nonlinguistic (Jongman, Roelofs, & Meyer, 2015). Sustained attention seems especially important during language production when two tasks compete for attention. However, even when picture naming was the only task a correlation between sustained attention and production was found (Jongman, submitted). Thus, even when one can focus all of one’s attention on producing words, the task is demanding and lapses of attention occur.

In the present study, we wished to see whether these very slow responses during a simple language production task can be predicted by pre-stimulus alpha power. Besides alpha power, word characteristics (frequency, length) and item characteristics (name agreement, repetition) were also included as predictors of naming latencies. These factors all have well-known effects on naming speed. Low frequency words are named more slowly than high frequency words, the longer a word the later articulation is initiated, low name agreement results in slower naming, and finally, slower responses are made for the first presentation of a picture than after a few repetitions. Our question was whether phasic pre-stimulus alpha power explains any additional variation in naming speed. If so, this would allow us to be more confident in interpreting these slow production trials as momentary lapses of attention, and consequently provide corroborating evidence that production is influenced by the level of alertness. We hypothesize that as RTs increase so should phasic alpha power. This alpha power modulation should occur over visual areas, as the first stage of naming pictures is to identify what is depicted on the screen in order to start planning the correct object name. Alpha power modulations should therefore be found over the occipito-parietal electrodes.

Not only are phasic, trial-to-trial, fluctuations in oscillatory power relevant for the current study, so are tonic power changes. Tonic electrophysiological processes occur at a much slower rate. Dockree and colleagues calculated the average power spectrum over an entire recording period while participants performed a sustained attention task (Dockree, Kelly, Foxe, Reilly, & Robertson, 2007). They showed that individuals with relatively high tonic alpha power had a larger amplitude late of a positive ERP component, which in turn predicted good sustained attention performance. High tonic alpha power was suggested to be indicative of an alert and receptive condition that facilitates anticipation and execution of task goals. Note that this is the reverse of alpha power effects on a trial-to-trial basis, where high alpha power indicates decreased attention. This double dissociation has been found in many studies. Table 1 summarizes the findings for phasic and tonic alpha power changes, reproduced from Klimesch (1999).

Besides alpha power, tonic theta power (4 to 7 Hz) could be indicative of a state of alertness. Smit, Eling, and Coenen (2004) measured EEG before and after participants had to perform either a mentally effortful task in one condition or had no task to perform in the control condition. Performance declined on the sustained attention after the mental effort task. Theta power increased after mental effort, which led the authors to propose that increased theta reflects a vigilance lowering. In other words, low tonic theta power is thought to indicate good sustained attention, which goes in the reverse direction of tonic alpha power (Table 1).

Table 1. Double dissociation between tonic and phasic (event-related) changes in alpha and theta power with respect to cognitive performance. Replicated from Klimesch (1999), pg. 174.

	Increasing performance	
	Theta power	Alpha power
Tonic change	Decreases	Increases
Phasic change	Increases	Decreases

We hypothesize that individuals with high tonic alpha power and/or low tonic theta power will perform better on a language production task, if the production task requires sustained attention. Good performance on the production task is defined as having a small number of very slow responses. One can quantify the number of relatively slow responses by fitting an RT distribution to an ex-Gaussian distribution. Ex-Gaussian analysis decomposes the mean RT into two parameters, the μ parameter reflecting the normal part of the distribution, and the τ parameter reflecting the tail end of the distribution. If the τ parameter is large, it means the distribution has a large tail, i.e. that a large number of 'abnormally' slow responses were made. As mentioned previously, it has been argued that a slow trial is due to a momentary lapse of attention (Weissman et al., 2006). The τ parameter can therefore also be seen as index of the frequency of lapses of attention, as proposed by Unsworth, Redick, Lakey, and Young (2010). Thus, individuals with a small τ have fewer lapses of attention and should, according to our hypothesis, have higher tonic alpha and lower theta power.

To summarize, the objective of this study is two-fold. First, can we show that slow picture naming trials are due to momentary lapses of attention? Pre-stimulus alpha power should be predictive of the subsequent naming latency, with increasing phasic alpha corresponding to slower responses. Second, is overall performance on a picture naming task related to individuals' maintained alertness? If so, high tonic alpha power and low tonic theta power should correspond to a small τ parameter.

Method

Participants

Thirty-seven students from Radboud University Nijmegen or the Hogeschool van Arnhem en Nijmegen participated in the experiment. All participants were native speakers of Dutch, had normal or corrected-to-normal vision and no language impairment. The average age was 21.6 years (range: 19-29 years) with twenty-six participants being female. Participants were paid for taking part in the study. Ethical approval was granted by the Ethics Board of the Faculty of Social Sciences of the Radboud University, Nijmegen. Participants provided written informed consent before the start of the experiment.

Materials

Participants were presented with sixty black-and-white drawings, with each picture shown ten times. The objects were selected from a database of normed pictures (Severens, et al., 2005). The object names ranged in frequency (mean lemma frequency: 47 tokens per million, range: 1-247; CELEX, Baayen, Piepenbrock, Gulikers, 1995) and in length with words consisting of one to three syllables (mean length: 1.6 syllables). Pictures were selected for high name agreement (mean: 96.4%, range: 79-100). See Appendix A for all object names.

Procedure

Before the start of the experiment, while the experimenter was preparing the EEG cap, participants were given a booklet with the sixty pictures and the corresponding names and were asked to go through the booklet two times. After EEG set-up, participants were tested in a dimly lit room while seated in front of a 19 inch (Samsung Syncmaster 961BF) screen, at a distance of approximately 100 cm. Stimuli were presented on the screen using Presentation software (Neurobehavioral Systems). Participants' vocal responses were recorded (Sennheiser ME64), and speech onsets were determined manually using the program Praat (Boersma & Weenink, 2012). A short practice block of ten trials was presented to the participants so they could familiarize themselves with the timing of the trials. Moreover, these trials allowed for adjustment of the voicekey to ensure it was reliably triggered by the onset of speech.

A trial started with a fixation cross in the center of the screen, presented for a duration ranging between 1500 and 2000 ms. Then a picture was presented in the middle of the computer screen, fit to a virtual square of 300 by 300 pixels. The object would disappear 500 ms after the voicekey was triggered or after 3000 ms. Finally, a screen with five hashtags was presented for 1000 ms where participants were allowed to blink. All stimuli were presented in white on a black background.

Ten runs of the sixty pictures were presented to the participants. Presentation was pseudorandomized such that the starting phoneme of the name never occurred twice in a row. Moreover, objects from the same semantic category never followed one another. A total of 600 trials were presented, after 200 and 400 trials a break was inserted, participants chose the length of the break. The experimental session lasted approximately 50 minutes.

Recording and Processing

The electroencephalogram (EEG) was continuously recorded using an EEG cap containing 59 active electrodes, see Figure 1 for the electrode montage. In addition to the electrodes in the cap, one electrode was attached below the left eye to monitor for blinks and two electrodes were directly placed on the left and right mastoids. All electrodes were online referenced to the electrode placed on the left mastoid, the average of the left and right mastoid electrodes was used for offline re-referencing. The impedance was kept below 10 KΩ for all electrodes. The EEG was digitized at a rate of 500 Hz, and recorded with a low cut-off filter of 0.01 Hz and a high cut-off filter of 200 Hz. A low-pass filter at 30 Hz was applied offline.

The EEG processing was performed using the Brain Vision Analyser software (Brain Products, version 2.0.2). First, epochs of 3000 ms were created starting from the onset of the trial, i.e. the onset of the fixation cross. The EEG signal was demeaned and corrected for ocular artifacts, using the Gratton and Coles correction. Trials with a voltage step over 50 µV and trials with an absolute difference of 200 µV were rejected.

Phasic aspect of alertness. To quantify trial-by-trial pre-stimulus alpha power, the power spectra using the one second interval preceding picture onset were calculated. Each one second epoch was submitted to a fast Fourier transform, using a 50% Hanning taper. For each individual trial, alpha power (8-12 Hz) was determined.

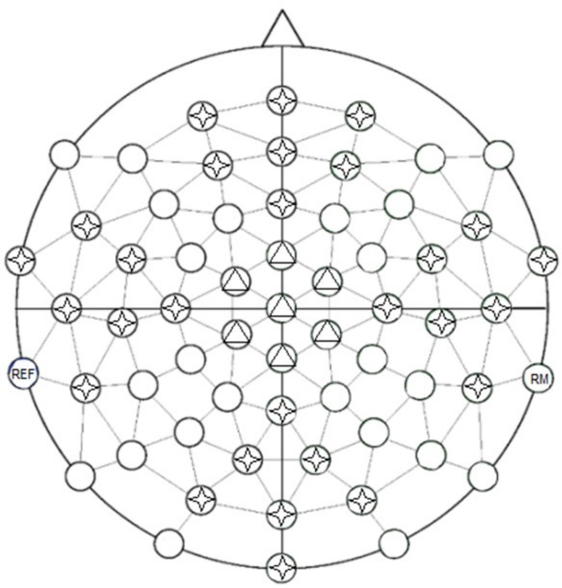


Figure 1. Electrode montage. All electrodes were used for the linear mixed effects models, for the RM-ANOVA five locations were selected as indicated by the symbols.

Tonic aspect of alertness. For the tonic power analyses, the corrected three second epochs were used starting from the onset of the fixation cross. The fast Fourier transform was applied to each of these epochs and then averaged. After averaging, power was determined in two separate frequency bands, namely the theta band (4-7 Hz) and the alpha band (8-12 Hz), for each participant and each electrode.

Statistical Analysis

Phasic aspect of alertness. For the pre-stimulus alpha power analysis, naming latencies were analyzed with linear mixed effects models. Trials with naming latencies below 400 ms and greater than 2500 ms were removed. Moreover, naming errors and hesitations were also excluded from the analysis. The naming latencies were analyzed using R (R Core Team, 2012) and the R packages *lme4* (Bates, Maechler, & Bolker, 2013) and *languageR* (Baayen, 2011). Naming latencies were log transformed to reduce positive skewing. First, it was determined which linguistic variables and task variables contributed significantly to explaining naming latencies. The variables word frequency, name agreement, word length (number of phonemes), and repetition number were included in the initial model. All variables were standardized because of different scaling. Participant was included as a random effect, and intercepts and slopes for all fixed effects were included. Variables were dropped if they did not reliably contribute to model fit as tested with a likelihood ratio test.

The best-fitting model was then used to test whether pre-stimulus alpha power made any additional contribution. This was done separately for each electrode. Alpha power was included as a fixed effect, and the random slope was included to capture additional variability. Whether pre-stimulus alpha power reliably contributed to model fit was tested by comparing it to the model without power as a fixed effect. Since a total of 59 models were tested, the Benjamini-Hochberg correction for multiple comparisons was applied, following previous EEG studies (i.e., Hinterberger, Schmidt, Kamei, & Walach, 2014; Johnson, McCarthy, Muller, Brudner, & Johnson, 2015; Soltész & Szűcs, 2014). The Benjamini-Hochberg correction controls the false discovery rate instead of the familywise error rate, resulting in greater power than Bonferroni-type procedures (Bender & Lange, 2001; Benjamini & Hochberg, 1995; Benjamini & Yekutieli, 2001; Williams, Jones, & Tukey, 1999).

Linear mixed effects models are fast becoming the standard in psycholinguistic research, and some researchers have also applied these models to electrophysiological data (e.g., Frank, Otten, Galli, & Vigliocco, 2013; Wilson et al., 2012). Yet it is not widely used statistical method to analyze EEG data, so we also performed an RM-ANOVA, a commonly used way to analyze EEG data by psycholinguists. In order to run an ANOVA, we binned the naming latencies, similar to Bonnefond and Jensen (2012). For each participant, five RT bins were created with the 20% fastest trials in the first bin, the next 20% fastest trials in the following bin, and so on. Only trials that survived artifact rejection and where a correct response was given were included. The RM-ANOVA included five RT bins and five locations each with seven electrodes (frontal, central, posterior, left temporal, and right temporal). These locations were chosen in order to test the hypothesis the effect should be found over visual areas (posterior location), left temporal was included to test for a possible effect over language areas, see Figure 1.

Tonic aspect of alertness. For the tonic theta and alpha power analysis (the average power taken from three second epochs from start of trial), power from three electrodes corresponding to the Fz, Cz, and Pz electrodes used by Smit et al. (2004) was correlated with participants' μ and τ parameter as determined from their picture naming RT distribution. For correct trials in the picture naming task, the ex-Gaussian parameters μ, σ, and τ were estimated using the continuous maximum-likelihood method proposed by Van Zandt (2000) using the program QMPE (Heathcote, Brown, & Cousineau, 2004). The parameters μ and σ reflect the mean and standard deviation of the normal portion, respectively, and τ reflects the mean and standard deviation of the exponential portion of the distribution. Correlations were only performed for the μ and τ parameter and not for σ, as it is not of interest in the current study and to limit the number of correlations.

Results

Only participants with at least 80% of trials left after artifact rejection were included in the analyses, which resulted in thirty participants. For these thirty subjects, on average 93% of the trials remained after pre-processing. Finally, erroneous trials and hesitations were removed from the analyses, so were trials with latencies below 400 ms or above 2500 ms. This was, on average, an additional 3.1% of the data.

Phasic aspect of alertness. First, it was determined which linguistic and task variables reliably contributed to model fit. The best-fitting linear mixed effects model included frequency, with low frequency words being named faster than high frequency words (*ß* = 0.016, *SE* = 0.002, *t* = 6.86), name agreement, with higher agreement being related to faster responses (*ß* = -0.012, *SE* = 0.002, *t* = -5.00), and repetition number, with response latencies decreasing across repetitions (*ß* = -0.017, *SE* = 0.007, *t* = -2.54). Including word length did not improve model fit (χ^2 (1) = 0.01, *p* = .94). Note that the frequency effect is in the opposite direction to what we had predicted as previous studies have found shorter RTs for high frequency words than for low frequency words. It is not clear why the opposite pattern is found in this experiment, possibly it is driven by a few outliers or by another underlying linguistic variable that we are unaware of. However, the main aim of this study is to see if alpha power can explain additional variation in naming latencies, which can still be addressed with the current linear mixed effects model.

Then, for each electrode, pre-stimulus alpha was included in the model. See Table 2 for the average naming latencies and average pre-stimulus alpha power. Appendix B shows the outcome of all 59 models, and the likelihood ratio tests. Figure 2 indicates which electrodes showed an effect of pre-stimulus alpha power. For the electrodes that showed an effect, a decrease in alpha power corresponded to an increase in naming latencies. After correcting for multiple comparisons using FDR none of the electrodes showed a significant effect.

The control RM-ANOVA showed a significant effect of location (*F*(4,116) = 17.43, *p* = < .001): post-hoc pairwise comparisons revealed alpha power was maximal over posterior electrodes (see Figure 2). The main effect of RT bin was not significant (*F*(4,116) = 1.57, *p* = .21). More importantly, neither was the interaction between bin and location (*F*(16,464) < 1).

Table 2. Mean and standard deviation (SD) for naming latencies and pre-stimulus alpha power averaged over all electrodes.

Naming Latencies		Pre-Stimulus Alpha Power	
Mean (ms)	SD (ms)	Mean (μV^2)	SD (μV^2)
772	224	4.5	5.0

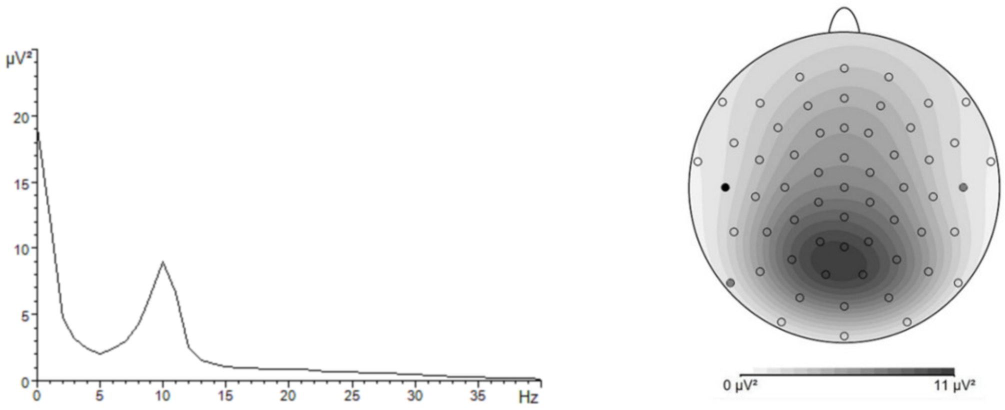


Figure 2. Left panel shows grand average of the spectra calculated -1000 ms to 0 ms over the posterior electrode with maximal alpha power. Right panel shows alpha (8-12 Hz) power from -1000 ms to onset of picture stimulus. Uncorrected *p*-values are indicated by color within electrode: black <.05, grey <.10, no fill >.10.

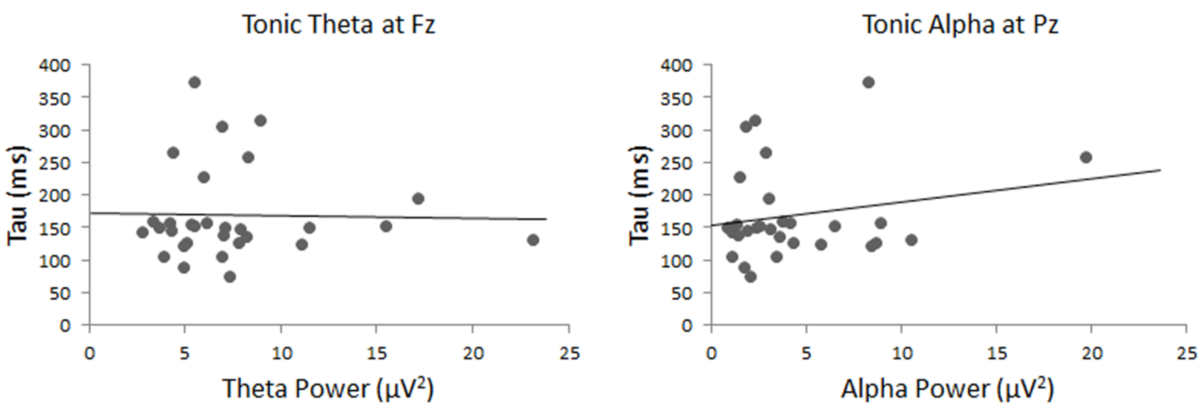


Figure 3. Scatterplots between tonic power and the tau parameter of picture naming latencies. Left panel shows tonic theta power at Fz electrode where theta power was maximal, right panel shows alpha power at Pz electrode where alpha power was maximal.

Table 3. Correlations between the mu (µ) and tau (τ) parameters of the picture naming task and tonic power measured on a frontal electrode (closest to Fz), a central electrode (Cz), and a posterior electrode (closest to Pz), measured separately for the theta and alpha band.

		Theta			Alpha		
Parameter		Frontal	Central	Posterior	Frontal	Central	Posterior
µ	*r*	.14	.07	-.07	.05	.14	.11
	p	.47	.73	.73	.78	.47	.58
τ	*r*	-.02	.01	.07	.03	.13	.20
	p	.91	.95	.72	.87	.51	.29

Tonic aspect of alertness. The individual differences analyses did not point to any relationship between tonic theta or alpha power and the mu and tau of performance on the picture naming task, see Table 3 for the correlations and Figure 3 for scatterplots.[1]

Discussion

Finding and producing a word does not happen at a constant speed. Some words are more difficult to produce, for instance words that contain of more phonemes than shorter words. Articulation of such words takes longer to be initiated. However, even the same word can be produced with different latencies on two different occurrences. Some have argued that relatively slow responses, on any task, are due to a momentary lapse of attention (Weissman, Roberts, Visscher, & Woldorff, 2006). We have suggested that this is also true for language production (Jongman, Meyer, & Roelofs, 2015; Jongman, Roelofs, & Meyer, 2015). In previous studies, we found that individuals who had increased difficulty with maintaining attention on a sustained attention task also had a larger number of relatively slow naming responses in a word or phrase production task. The main aim of the current experiment was to find direct evidence in favor of the hypothesis that slow naming trials are due to a momentary lapse of attention.

To measure possible lapses of attention we used EEG, as it has been suggested that lapses of attention can be measured by pre-stimulus alpha power. Alpha power is seen as a mechanism through which the brain regulates attention. Many studies have shown that a decrease in phasic alpha power over task-relevant areas results in better performance (Hanslmayr et al., 2007; Mazaheri, Nieuwenhuis, van Dijk, & Jensen, 2009). This has also been shown for response times such: A decrease in pre-stimulus alpha power results in a decrease in RTs (Kelly, Gomez-Ramirez, & Foxe, 2009; Mazaheri et al., 2014; Thut, Nietzel, Brandt, & Pascual-Leone, 2006). Thus, if slow naming response are due to lapses of attention, we should find increased pre-stimulus alpha power for those trials as compared to faster naming trials.

We did not find a phasic alpha power modulation as we had predicted. As the first step of picture naming is to look at the picture and identify the depicted objected, we had

[1] No other electrodes, or pooling of electrodes, showed a relationship between picture naming performance and tonic power.

hypothesized that a lapse of attention would be predicted by increased alpha power over visual areas. The electrodes over occipito-parietal regions did not show such a modulation. The only evidence we found for alpha power as a predictor of naming speed was for electrodes over temporal regions (although after controlling for multiple comparisons no electrodes showed a significant effect). For slow naming trials, alpha power was increased as compared to fast trials. This increase could indicate inhibition over task-irrelevant areas, which would support the proposal that alpha plays an attentional role through inhibition of irrelevant regions (Jensen & Mazaheri, 2010; Klimesch, Sauseng, & Hanslmayr, 2007). However, the proposal is based on studies that show this increase of alpha over task-irrelevant areas, but also show a decrease over relevant regions. This latter aspect of the alpha modulation is not present in our data, which makes it difficult to draw any firm conclusions.

Yet, if one were to speculate, the lack of an alpha power modulation over visual areas could indicate that slow naming trials are not due to momentary lapses of attention prior to the onset of the trial. Even when taking word and task characteristics into account, such as word length and number of times the picture was seen previously, unexplained variance in RTs remained. Possibly attention wanes after the picture is presented but before articulation. Unfortunately, the current design does not allow this hypothesis to be tested. Alpha power is also known to decrease before motor preparation and execution (Alegre et al., 2004; De Lange, Jensen, Bauer, & Toni, 2008). This has been shown to hold in spoken word production as well (Piai, Roelofs, & Maris, 2014). In the current study, as soon as the participants were presented with the picture they could start preparing their overt naming response. A decrease in alpha would therefore more likely reflect this motor preparation, not an increase in attention. This issue does not apply to the pre-stimulus alpha power analyses, as participants could not have started to prepare a response since they could not predict which picture would be presented.

A second aim was to see whether tonic theta or tonic alpha power would predict individual differences in picture naming performance. Both have been linked previously to individual differences during a sustained attention task. High tonic alpha power has been suggested to reflect an alert and receptive state (Dockree, Kelly, Foxe, Reilly, & Robertson, 2007), whereas high tonic theta power is associated with vigilance lowering (Smit, Eling, & Coenen, 2004). We predicted that participants with a larger τ parameter, so a larger number of very slow responses, would show lower tonic alpha power and higher tonic theta power compared to individuals with better performance when naming pictures. However, we found no relationship between these oscillatory powers and τ. A sustained attention task is very monotonous. Even though our picture naming task was also very repetitive, it could be the case that participants were still more engaged than they would be during a sustained attention task, so that the relationship between tonic oscillatory power and picture naming performance did not become evident.

A possible reason that we did not find either the phasic or tonic power modulation could be that our task was too simple. For instance, Mazaheri and colleagues found pre-stimulus alpha power to predict visual/auditory discrimination times only in a distractor condition (2014). We showed previously that the relationship between sustained attention and language production is strongest when naming takes place in a more difficult setting such as a dual-task experiment (Jongman, Roelofs, & Meyer, 2015). Perhaps there weren't enough slow trials in the present study. However, this does not seem to be the case when one looks at the τ parameter, an index of the number of slow responses. When comparing the current experiment to our previous dual-task experiment where participants named pictures by using just nouns, we actually find a larger τ parameter for the current study (174 ms, SD: 78 ms vs. 118 ms, SD: 51). A different picture set was used, so a direct comparison cannot be made, but it does indicate that participants found it difficult to name pictures at a consistent speed. Yet, the possibility remains that pre-stimulus alpha power would be a better predictor of naming latencies if the task demands are higher.

To conclude, we asked whether slow naming trials are due to momentary lapses of attention. Was pre-stimulus phasic alpha power predictive of subsequent naming latency such that better performance is preceded by decreased alpha? Second, we investigated whether tonic alpha and theta power predicted overall performance on a picture naming task. We did not find an answer to either question. More research is needed to reveal the underlying brain mechanism behind slow language production trials.

Acknowledgments

I thank Ashley Lewis for helpful suggestions regarding data processing.

Appendix A

Target names of pictures, with English translation.

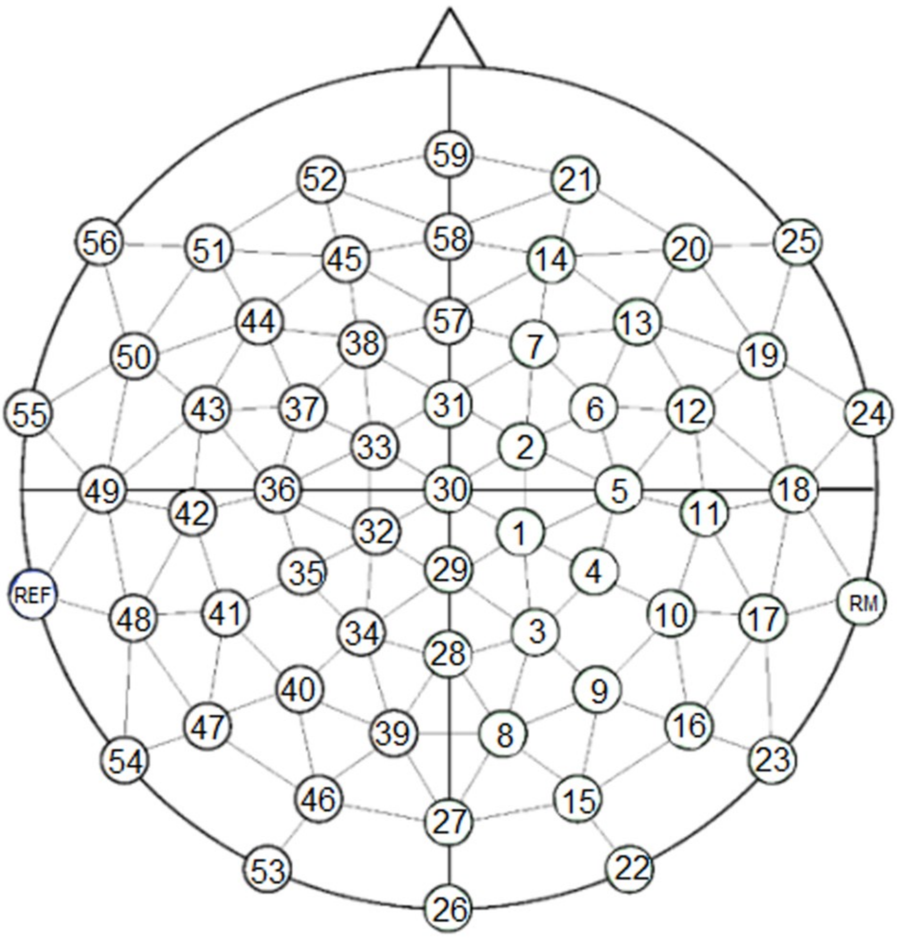
ananas (pineapple), anker (anchor), baby (baby), ballon (balloon), banaan (banana), blad (leaf), bloem (flower), boot (boat), bureau (desk), clown (clown), dokter (doctor), doos (box), gieter (wateringcan), gitaar (guitar), hert (deer), kanon (cannon), kast (cupboard), kasteel (castle), kerk (church), kikker (frog), koe (cow), kok (cook), kom (bowl), koning (king), kruis (cross), lepel (spoon), mes (knife), neus (nose), nijlpaard (hippo), paard (horse), peer (pear), pet (hat), potlood (pencil), puzzel (puzzle), regen (rain), schaar (scissors), schommel (swing), sigaret (cigarette), sjaal (scarf), slee (sled), sleutel (key), soldaat (soldier), spiegel (mirror), spin (spider), spook (ghost), springtouw (jumprope), stofzuiger (vacuum), tafel (table), telefoon (telephone), tomaat (tomato), trap (stairs), trein (train), vinger (finger), vleugel (wing), vlieger (kite), vliegtuig (airplane), vork (fork), worst (sausage), wortel (carrot), zwaan (swan)

Appendix B

Estimate, standard error (SE), *t*-value presented for fixed effect pre-stimulus alpha power when included in linear mixed effects model. Chi-square and uncorrected *p*-value for likelihood ratio test comparing full model to a model without alpha power as predictor. Values are presented for each electrode separately, the spherical coordinates (theta, phi) are given (see Figure for electrode montage with channel numbers).

Channel	Theta	Phi	Estimate	SE	*t*-value	Chi square	*p*-value
1	23	-30	-0.0031	0.0030	-1.02	1.06	0.30
2	23	30	-0.0012	0.0025	-0.47	0.24	0.62
3	46	-66	-0.0028	0.0027	-1.05	1.07	0.30
4	46	-33	-0.0030	0.0028	-1.06	1.12	0.29
5	46	0	-0.0048	0.0036	-1.34	1.78	0.18
6	46	33	-0.0042	0.0031	-1.37	1.85	0.17
7	46	66	-0.0031	0.0024	-1.26	1.45	0.23
8	69	-78	-0.0021	0.0027	-0.74	0.54	0.46
9	69	-54	0.0010	0.0039	0.27	0.08	0.78
10	69	-30	0.0002	0.0046	0.04	0.00	0.95
11	69	-6	-0.0044	0.0034	-1.29	1.67	0.20
12	69	18	-0.0047	0.0033	-1.42	2.02	0.16
13	69	42	-0.0024	0.0021	-1.12	1.04	0.31
14	69	66	-0.0027	0.0023	-1.17	1.31	0.25
15	92	-68	-0.0002	0.0064	-0.03	0.00	0.99
16	92	-45	0.0014	0.0053	0.26	0.08	0.78
17	92	-22	-0.0018	0.0043	-0.43	0.17	0.68
18	92	0	-0.0070	0.0039	-1.80	3.23	0.07 .
19	92	22	-0.0033	0.0040	-0.82	0.66	0.42
20	92	45	-0.0005	0.0027	-0.18	0.05	0.83
21	92	68	0.0008	0.0027	0.30	0.03	0.85
22	115	-65	-0.0001	0.0038	-0.04	0.00	0.98
23	115	-40	-0.0039	0.0053	-0.73	0.47	0.50
24	115	10	-0.0018	0.0024	-0.75	0.55	0.46
25	115	35	-0.0017	0.0025	-0.68	0.48	0.49
26	115	-90	0.0009	0.0034	0.26	0.10	0.75
27	92	-90	-0.0002	0.0031	-0.06	0.00	0.99
28	46	-90	-0.0034	0.0033	-1.04	1.07	0.31

Channel	Theta	Phi	Estimate	SE	*t*-value	Chi square	*p*-value
29	23	-90	-0.0021	0.0029	-0.71	0.52	0.47
30	0	0	-0.0010	0.0026	-0.39	0.16	0.69
31	23	90	-0.0007	0.0023	-0.29	0.07	0.79
32	-23	30	-0.0020	0.0028	-0.71	0.52	0.47
33	-23	-30	-0.0012	0.0022	-0.54	0.28	0.60
34	-46	66	-0.0024	0.0033	-0.73	0.56	0.45
35	-46	33	-0.0027	0.0029	-0.95	0.92	0.34
36	-46	0	-0.0026	0.0022	-1.14	1.25	0.26
37	-46	-33	-0.0013	0.0021	-0.61	0.17	0.68
38	-46	-66	-0.0022	0.0024	-0.94	0.76	0.38
39	-69	78	-0.0026	0.0033	-0.78	0.57	0.45
40	-69	54	-0.0018	0.0029	-0.61	0.35	0.55
41	-69	30	-0.0025	0.0026	-0.99	0.90	0.34
42	-69	6	-0.0033	0.0024	-1.38	1.74	0.19
43	-69	-18	-0.0032	0.0021	-1.49	1.94	0.16
44	-69	-42	-0.0011	0.0019	-0.58	0.70	0.40
45	-69	-66	0.0006	0.0019	0.30	1.09	0.30
46	-92	68	-0.0004	0.0028	-0.15	0.15	0.70
47	-92	45	-0.0021	0.0027	-0.77	0.48	0.49
48	-92	22	-0.0036	0.0023	-1.51	2.11	0.15
49	-92	0	-0.0079	0.0029	-2.66	5.88	0.02*
50	-92	-22	-0.0001	0.0019	-0.08	0.00	0.99
51	-92	-45	-0.0008	0.0019	-0.41	0.16	0.69
52	-92	-68	-0.0015	0.0018	-0.81	1.04	0.30
53	-115	65	-0.0023	0.0021	-1.09	1.51	0.22
54	-115	40	-0.0051	0.0025	-2.03	2.92	0.09 .
55	-115	-10	-0.0005	0.0019	-0.29	0.06	0.80
56	-115	-35	-0.0026	0.0049	-0.52	0.23	0.63
57	46	90	-0.0003	0.0022	-0.14	0.14	0.70
58	69	90	0.0007	0.0019	0.35	0.10	0.75
59	92	90	-0.0008	0.0024	-0.34	0.05	0.82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Chapter 7

General Discussion and Conclusions

The main question of this dissertation was whether sustained attention is required for successful language production. The short answer is: yes. However, as is often the case in research, the story is a little more complicated than that. In each of the five experimental chapters, I have tried to find one piece of the puzzle at a time to end up with a complete picture. Here I describe what we now know about sustained attention and language production, and whether the puzzle is still lacking some pieces. First I briefly describe what I mean by sustained attention and the processes of word production. Then I summarize the main findings of each chapter, and finally I discuss what they entail for models of language production, sustained attention, and specific language impairment (SLI).

The first relevant concept for this dissertation is sustained attention, i.e. the ability to maintain alertness for a longer time period. It is part of the alerting network, one of three functionally and anatomically separate networks that together form what we colloquially refer to as attention (Petersen & Posner, 2012; Posner & Petersen, 1990). Sustained attention is an essential cognitive capacity, yet one that has proven to be rather demanding. Sustained attention is typically tested with simple, repetitive tasks where participants are required to monitor for an infrequent target amongst foils. The second concept that is essential for this dissertation is word production. Throughout this thesis I have followed the word production model by Levelt, Roelofs, and Meyer (1999). They have proposed that in order to produce a word one must go through the following stages: conceptual preparation, lemma retrieval, and finally word-form encoding, which includes morphological, phonological, and phonetic encoding. The final step is the execution of the speech movements.

In Chapter 2 an individual differences approach was taken to see whether there is a relationship between sustained attention and language production in adults. Sustained attention ability correlated with picture description latencies: Individuals with poorer sustained attention showed worse performance when describing pictures than individuals with relatively good sustained attention. Besides examining the mean naming latencies, I decomposed these means into two parameters using ex-Gaussian analyses characterizing the underlying RT distribution. This resulted in the μ parameter reflecting the normal part of the distribution, and the τ parameter indexing the tail end of the distribution. The relationship between sustained attention and language production was not evident for all trials, but only for the slowest subset (i.e. the τ parameter). In other words, it wasn't the case that the individuals with poor sustained attention were always slower to name pictures, but they had a larger number of very slow responses. I interpreted these very slow trials, or the τ parameter, as reflecting a momentary lapse of attention (Unsworth, Redick, Lakey, & Young, 2010; Weissman, Roberts, Visscher, & Woldorff, 2006). So, people with poor sustained attention ability experience more lapses of attention in the naming task than people with good sustained attention.

Interestingly, the correlation between sustained attention and picture description was only evident for the naming latencies, but not for gaze durations to the pictures. Eye-tracking was used to measure how long individuals fixated on the to-be-named picture. Previous picture naming research has shown that individuals tend to keep looking at a picture up to and including phonological encoding (i.e., Griffin, 2001; Meyer, Sleiderink, & Levelt, 1998). The lack of a correlation with gaze durations suggests that sustained attention does not play a significant role for these early stages of word production in this particular experiment. The correlation with naming latencies points to an effect of sustained attention on the final stages of word production: phonetic encoding and articulation. Participants were asked to carry out a second, unrelated task after naming the picture: an arrow discrimination task. This was included so that individuals would make a gaze shift away from the picture. However, this introduced a dual-task setting increasing the task demands. It could be that I only found the correlation between sustained attention and the final stages of word production because these last stages co-occurred with processing of the arrow on the other side of the screen.

The second experiment in Chapter 2 compared picture description in a dual-task experiment as in the first experiment to picture description as the only task. Only naming latencies were measured, not gaze durations as this is not possible when only one stimulus is on the screen. The correlation between the τ parameter of the naming latencies and sustained attention was present for both tasks, but significantly stronger for the dual task as compared to the single task. This suggests that sustained attention is needed even in a simple production task, but is especially important in situations where two tasks require attention.

In Chapter 3, I tried to further define under which conditions sustained attention is strongly called upon. When phrase production took place in a dual-task setting, the relationship between sustained attention and production became most apparent. One could argue that in natural language production the role of sustained attention is quite minimal, and that the result of Chapter 2 was due to an artificially created setting. In this experiment, I compared picture description in a dual-task setting to picture description of two objects using a conjoined noun phrase. This latter task can also be regarded as combining two tasks, but in this case both tasks are linguistic. A conjoined noun phrase is a construction that occurs in natural language production, and so the phrase production task is more ecologically valid than the dual-task experiment used in chapter two. The results indicate that sustained attention is required for both of these situations to the same extent, and so I am confident in saying that sustained attention is needed not just in the lab but also in natural multi-phrase production. Interestingly, the correlation between sustained attention and picture description was once again only found for the naming latencies, but not for the gaze durations. This provides more evidence that when the last stages of word production co-occur with the processing of new visual information, either to make a nonverbal judgment or when planning to name a second picture, sustained attention is necessary to maintain alertness in producing the name for the first picture.

The idea for this dissertation, to study sustained attention and its contribution to language production, was inspired by studies on specific language impairment. In the last decade, it has become increasingly clear that children with SLI do not only have problems with language but also with attention. By now, it is well established that in these children sustained attention is impaired. However, even though it has been suggested that impaired sustained attention could underlie the linguistic deficits in children with SLI, there is only limited evidence for this. In Chapter 4 children with SLI were tested for sustained attention and language production and were compared to typically developing children. The results showed both poorer sustained attention and language production for children with SLI. However, the relationship between the two cognitive capacities was similar in both groups of children. Children with poorer sustained attention were slower to name pictures, in both developmental groups.

In Chapter 5, I investigated whether sustained attention also played a role in simple picture naming in healthy adults. Chapters 2 and 3 have shown that sustained attention is needed in dual-task situations. Chapter 4 showed that in children the relationship between sustained attention and language production is already evident for simple picture naming. I set out to investigate whether there are situations where even simple picture naming can be made difficult enough for adults to reveal the relationship between sustained attention and naming latencies. By changing the speed of picture presentation this was made possible and a strong correlation between sustained attention and simple picture naming was found. Moreover, this study tried to move beyond correlational evidence to find more direct evidence for the involvement of sustained attention in production. Two conditions were created with different event rates, a condition where sustained attention should be taxed and a situation that should be relatively easy. These two conditions were also used in a classic sustained attention task. The event rate manipulation had the same effect for both types of tasks, providing evidence that manipulating the need for sustained attention not only influences attention itself but also language production. This in turn points to a causal role of sustained attention in language production.

This causal role of attention was further investigated in Chapter 6, using electroencephalography. In all adult experiments, the correlation between sustained attention and language production was only found for the τ parameter of naming latencies, not the μ parameter. The τ parameters indexes the tail end of the RT distribution, so the 'abnormally' slow responses. As mentioned earlier in this chapter, these slow trials have been suggested to be due to a lapse of attention (i.e., Weissman et al., 2006). Such lapses of attention have been shown to have a specific neural signature: using EEG it has been shown that slow trials are preceded by a phasic increase in alpha power (indexing the level of phasic alertness) or tonic decrease in alpha power (indexing the level of tonic alertness). It has been suggested that alpha oscillations play an important role in regulating information flow (Jensen & Mazaheri, 2010; Klimesch, Sauseng, & Hanslmayr, 2007). In this experiment, I tested whether slow naming responses were also preceded by an increase or decrease in alpha power. I found no evidence for such a regulatory role of alpha in picture naming. This could point to a different mechanism than pre-stimulus alpha oscillations behind slow naming trials. Possibly slow naming responses are due to waning of attention only after word production planning has been initiated.

Word production requires attention all the way through

A surprising implication of this thesis is that attention seems to be necessary for all processes of word production. The idea that attention is necessary for language production is not novel, but it was always assumed that the need for attention held only for the initial stages of word production. As one proceeds from concept preparation to lexical selection to word-form encoding the need for attention was assumed to become less and less (Garrod & Pickering, 2007). The earliest models of word production only assumed message generation to require attention, all the other stages were thought to be automatic (Levelt, 1993). Since then, several experiments have tested this hypothesis and have shown that even later stages require attention. These studies used dual-task experiments to test the attention demands of word production: if two tasks interfere they are assumed to draw from the same central attentional pool. Using this logic, it was shown that the lexical selection stage requires attention (Ferreira & Pashler, 2002). This was also shown for phonological encoding (Cook & Meyer, 2008; Roelofs, 2008a), although there is also some evidence in favor for automaticity of this stage (Ferreira & Pashler, 2002).

No one has found evidence for the last stages of word production needing attention. Based on eye-tracking evidence, these stages are considered to be fully automatic. People tend to shift gaze away from a picture after phonological encoding (i.e., Griffin, 2001; Meyer et al., 1998), and gaze shifts have been taken to represent visual attention shifts (Deubel & Schneider, 1996). So visual attention can already be shifted away from word production before speech output has been produced, suggesting less attention is required after phonological encoding. However, the studies presented in Chapters 2 and 3 of this dissertation suggest otherwise. Sustained attention ability correlated only with naming latencies, not gaze durations. This points to the possibility that especially the stages that occur after the gaze shifts are in need of sustained attention. This is corroborated by the finding that the correlation between sustained attention and naming latencies is strongest for dual-task experiments. When individuals shifted their gaze away from the object, they already started to process the second stimulus, dividing attentional capacity between the two tasks. If picture description is the only task it is relatively easy to maintain attention on all stages of production, so individual differences in sustained attention are less pronounced. The dual-task experiment is more challenging, and more so for some individuals than others resulting in individual differences in sustained attention to surface.

The experiments do not allow distinguishing between processes making up the last phase of word production, which includes phonetic encoding, (possibly) self-monitoring of inner speech, and initiation of articulation. It could be that all of these processes need sustained attention, or only one or two. In fact, one can think of these last stages of word production as a dual-task situation since the word production model by Levelt, Roelofs, and Meyer (1999) assumes self-monitoring of phonological representations to co-occur in parallel with phonetic encoding. This co-occurrence in itself can be somewhat taxing, and so when another task is added (i.e. arrow discrimination) the system is under even more pressure. However, this is rather speculative, so more research is needed to test whether combined phonetic encoding and self-monitoring is taxing.

Differential effects of subcomponents of attention on language

The focus of this dissertation was sustained attention but in Chapter 3 I also tested two other attentional components. The operation span task was included to test individuals' working memory span and the flanker task was used to test inhibition ability. These two components are part of the executive control network and have previously been shown to be involved in language production (Shao, Roelofs, & Meyer, 2012). In this experiment, neither inhibition nor updating ability correlated with sustained attention. This suggests that executive control and sustained attention are separate abilities, as suggested by Posner and colleagues (Petersen & Posner, 2012; Posner & Petersen, 1990). Moreover, this also suggests that the correlation between sustained attention and naming latencies found repeatedly in my studies, is not due to an indirect influence from executive control abilities.

It is likely that these different types of attention all play somewhat different roles in language production. First of all, the type of attention that is called upon depends on the particular situation of the speaker. Shao et al. (2012) found that updating and inhibiting were involved in picture naming in different ways. Updating ability only correlated with the τ parameter of naming latencies, not the μ parameter. This is similar to the results reported in Chapters 2 and 3, and could point to a close connection between updating and sustained attention. Failing to maintain attention, a lapse of attention, can result in having to start over and update the task goal in working memory. This in turn causes a slow naming trial. Even though I did not find a significant correlation between sustained attention ability and updating ability, a tighter link between these two capacities has previously been found

(Unsworth et al., 2010). Similarly, the τ parameter has been related to both sustained attention and to working memory (Schmiedek, Oberauer, Wilhelm, Süß, & Wittmann, 2007; Unsworth et al., 2010). Although separable components, sustained attention and updating could be involved in the same kind of language production situations.

In Shao et al.'s study, inhibition differs from updating as it also correlated with the μ parameter of naming latencies when participants described action pictures. This suggests that inhibition is more regularly called upon than updating. Shifting did not contribute to naming latencies in Shao et al.'s study, which would suggest that shifting plays a limited role in picture naming. However, in a study that involved switching between phrase types in picture description, Sikora, Roelofs, Hermans, and Knoors (2015) obtained correlations between updating, inhibiting, and shifting abilities and production performance. One can imagine there are other situations where engaging the shifting ability might be necessary, such as when a bilingual speaker has to switch from one language to the other (i.e., Prior & MacWhinney, 2010). What one can conclude from Shao et al.'s and Sikora et al.'s studies, and from this dissertation, is that some attention components are involved more often in language production than others. Moreover, these studies show that the degree of involvement can depend on the task situation. Exactly which stages of word production are especially targeted by a specific type of attention is not yet completely known and should be further investigated.

Whereas dual-task experiments can test if certain stages require attention (Cook & Meyer, 2008; Ferreira & Pashler, 2002; Roelofs, 2008a), they do not provide information on which type of attention is needed. Conversely, the individual differences approach is a useful way to test which kind of attention correlates with language production, but it is more difficult to pinpoint a certain production stage. A combination of the two methods, as used in Chapters 2 and 3 will likely provide more answers. Another way forward is by combining neuroscience with psycholinguistics to see when and what kind of attention is needed during language production. Whereas this is a difficult combination, as overt speech causes many movement artifacts contaminating the recorded neurophysiological signal, I believe it will prove to be a fruitful endeavor. In Chapter 6 I made an attempt to combine EEG and word production to investigate lapses of attention. The period of interest was the time before the picture was shown, a period sure to be free of mouth movements. I did not find any evidence for a lapse of attention preceding a slow naming trial. This could perhaps indicate that a lapse of attention that happens while a speaker has already started planning a word is more detrimental than when attention is momentary lost before planning is initiated.

Sustained attention is domain general

Whereas it was not the main aim of this dissertation to investigate sustained attention itself, some of my findings are interesting for the sustained attention research field as well. One question that I investigated was whether sustained attention is domain general or whether there are modality specific attentional systems. The latter was suggested by Spaulding, Plante, and Vance (2008) who found evidence for a sustained attention deficit specific to the auditory domain for children with SLI (see also Noterdaeme, Amorosa, Mildenberger, Sitter, & Minow, 2001). In Chapters 2 and 4, both an auditory and visual sustained attention task were used to test this possibility. Sustained attention in both modalities has rarely been tested in the same sample. The few studies that have done so used two tasks that differed on more parameters than just modality. The two studies in this dissertation used two almost identical sustained attention tasks, where participants either responded to tones or to shapes. In adults and in children, I found very similar performance in both tasks and a high correlation between the two tasks. Moreover, both tasks correlated with picture naming performance. These results argue for one sustained attention system. It must be noted that performance in the two modalities was not identical, which indicates some domain specific processing, most likely due to differences in early processing of the visual and auditory input.

Chapter 5 raised another interesting issue for sustained attention research. It is largely accepted that maintaining attention can be made increasingly difficult by increasing the event rate (Coull, Frith, Frackowiak, & Grasby, 1996; Parasuraman, 1979; Parasuraman & Giambra, 1991; Warm, Parasuraman, & Matthews, 2008). In other words, when stimuli are presented in rapid succession performance is worse than when the pace is slower. I used both a fast and slow event rate in a sustained attention task, and I found lower hit rates (correctly detected targets) in the fast rate. This indeed points to worse performance. However, participants were also faster to respond in the fast event rate condition. Moreover, the performance decrement across tasks was similar in both event rates. These results point to a speed-accuracy trade-off. The studies reporting fast event rates as being more taxing only reported response errors, not RTs, and therefore could not identify possible speed-accuracy trade-offs. Future studies need to report both measures to show a manipulation does indeed tax sustained attention more than another.

Sustained attention in SLI

Sustained attention is impaired in children with SLI. This has been shown in several studies (Ebert & Kohnert, 2011), and is also shown in Chapter 4. Notably, Chapter 4 showed this impairment to be present for both the auditory and visual modality. This is in contrast to the idea that only attention in the auditory domain is impaired in children with SLI (Noterdaeme et al., 2001; Spaulding et al., 2008). However, the impairment in sustained attention does not seem to underlie the language problems in children with SLI. In both children with SLI and in for typically developing children, sustained attention correlated with naming latencies. Children with worse sustained attention were slower to name pictures. Although this correlation suggests that training sustained attention could possibly have a beneficial effect on production, this would hold for all children.

The correlation between sustained attention and picture naming was not only found for the τ parameter, but also for the μ parameter. This is in contrast to what I found for adults, where the relationship was only evident for τ, the proportion of very slow responses. For children, the relationship is found for all trials. So children with poorer sustained attention are slower to name pictures in general, and they show a larger amount of very slow responses. This could point to a more important role of sustained attention when language is still developing than when it has reached adult competence. It would be interesting to see whether language development can be bolstered through attention training.

Conclusion

We all talk, every day, starting at a very early age. Most of the time speaking comes quite naturally to us, but sometimes we make errors or produce disfluencies (which will likely happen to me during my defense of this thesis). The difficulties we sometimes encounter when speaking suggest that production does not always run fully automatically. Throughout this dissertation I have shown that sustained attention is required for fluent language production. I have shown that individuals with poorer sustained attention are worse at naming and describing pictures. Especially when production takes place under more straining demands, sustained attention comes into play. For adults, the relationship between sustained attention and language production is only evident for a subset of trials, namely the very slow responses. For children, however, sustained attention is involved throughout their performance, pointing to an important role of sustained attention during language development.

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Samenvatting

Rond het eerste levensjaar produceren we onze eerste woordjes, tegen de tijd dat we volwassen zijn komen er zo'n 20.000 woorden per dag uit onze mond. Met een gemiddelde snelheid van 130 woorden per minuut zijn we per dag bijna 2,5 uur aan het woord. Je zou verwachten dat met zo veel oefening praten ons makkelijk afgaat, maar dit blijkt niet helemaal te kloppen.

Tot voor kort nam men aan dat praten geen bijzondere aandacht vergt, maar Kubose en collega's (2006) hebben laten zien dat als mensen praten tijdens het autorijden, ze meer verkeersfouten maken dan wanneer ze het autorijden zwijgend uitvoeren. Als er geen aandacht nodig zou zijn voor taalproductie, zou autorijden ook niet moeilijker moeten zijn. Er zijn meerdere studies verschenen die aantonen dat aandacht een belangrijke rol speelt bij taalproductie maar er zijn nog een aantal onbeantwoorde vragen. Een eerste vraag is welke processen van taalproductie een beroep doen op aandacht. Een tweede vraag is om wat voor soort aandacht het dan gaat. Eerst zal ik deze vragen nader toelichten, om daarna te bespreken hoe ik heb geprobeerd ze te beantwoorden.

Laten we de simpelste vorm van taalproductie onder de loep nemen, namelijk het produceren van een enkel woord. Het blijkt dat er een aantal processen moet worden doorlopen (i.e., Dell, 1986; Caramazza, 1997; Levelt, Roelofs, & Meyer, 1999). In deze dissertatie volg ik het model van Levelt en collega's. Als eerste stap moet het concept worden gekozen dat het beste past bij de over te brengen boodschap. Daarna wordt het woord geactiveerd dat dat bij het concept hoort met de daarbij behorende eigenschappen. Hebben we bijvoorbeeld te maken met een zelfstandig naamwoord, zo ja, is het een de of het woord? Daarna wordt de woordvorm samengesteld; uit welke klanken bestaat het? Deze klanken moeten vervolgens worden geactiveerd en de mond- en tongspieren moeten worden aangestuurd, om uiteindelijk het woord daadwerkelijk te produceren. Aanvankelijk werd er gedacht dat alleen de eerste stap, het formuleren van een boodschap, aandacht nodig heeft (i.e., Levelt, 1989). Sindsdien zijn er studies geweest die hebben laten zien dat aandacht mogelijk ook betrokken is bij daaropvolgende processen (Cook & Meyer, 2008; Ferreira & Pashler, 2002; Roelofs, 2008a), maar er is nog geen concensus waar precies de overgang van aandacht naar automatisme plaatsvindt.

Tot nu toe heb ik het over aandacht gehad als één uniform concept. Echter, aandacht is een combinatie van een aantal componenten. Zo hebben Posner en collega's beargumenteerd dat er sprake is van drie onafhankelijke aandachtssystemen (Petersen & Posner, 2012; Posner & Petersen, 1990, Posner & Rothbart, 2007). Het eerste systeem wordt 'executieve controle' genoemd, oftewel het vermogen om het doel voor ogen te houden, ook als je wordt afgeleid. Het tweede systeem is 'oriëntatie', de capaciteit om je aandacht te verschuiven naar een nieuwe bron van informatie. Het laatste systeem verwijst naar het vermogen om alert te reageren: 'alertheid'. Van het eerste systeem is aangetoond dat dit betrokken is bij taalproductie (Shao, Roelofs, & Meyer, 2012), de andere twee systemen zijn nog niet getest in relatie tot taal. In mijn dissertatie gaat het om het laatste systeem, alertheid.

Ook alertheid bestaat uit verschillende componenten, namelijk enerzijds het alert reageren op een waarschuwingssignaal en anderzijds het vasthouden van alertheid voor een langere tijd. Mijn onderzoek concentreert zich op dit laatste aspect van alertheid. Een aanwijzing dat dit aspect taalproductie beïnvloedt, komt uit onderzoeken naar kinderen met een taalontwikkelingsstoornis (TOS). Er werd altijd gedacht dat TOS een aandoening was waar alleen de taalontwikkeling het slachtoffer is, maar uit recente onderzoeken blijkt dat bij kinderen met TOS ook het vasthouden van de aandacht een probleem is (Ebert & Kohnert, 2011). Wellicht veroorzaken de moeilijkheden met alertheid de problemen met taal, maar dit is nog nauwelijks onderzocht. Deze dissertatie beoogt de relatie tussen het vasthouden van aandacht en taalproductie te belichten.

Om te onderzoeken in hoeverre het vasthouden van aandacht nodig is voor woordproductie heb ik in meerdere hoofdstukken gebruik gemaakt van de “individuele verschillen” methode. Dit houdt in dat proefpersonen zowel een aandachtstaak als een woordproductietaak uitvoeren; de prestaties op beide taken worden gecorreleerd om vast te stellen of er een relatie is. Tijdens de aandachtstaak zien mensen bijvoorbeeld de cijfers 0 t/m 9 gedurende 10 minuten waarbij ze alleen moeten reageren op de 0. Voor de woordproductietaak wordt proefpersonen gevraagd om plaatjes te benoemen ('de fiets') of te beschrijven ('de rode schoen'). Uit de resultaten van de hoofstukken twee en drie blijkt dat er inderdaad een relatie is tussen beide taken: individuen die slechter zijn in het vasthouden van aandacht tijdens een aandachtstaak, hebben vaker een zeer late reactie bij het benoemen van plaatjes. Deze individuen zijn niet consequent langzamer, maar ze hebben een groter aantal zeer trage responsen. Dit wekt de indruk dat deze mensen hun aandacht op deze momenten hun aandacht niet hebben weten vast te houden, waardoor ze significant later beginnen te spreken dan anders. Het kost vervolgens enige tijd om de aandacht weer terug te krijgen bij het benoemen van de plaatjes en bij het succesvol doorlopen van alle processen van woordproductie.

Deze relatie tussen alertheid en spreken is het meest evident waar de productietaak relatief ingewikkeld is. In hoofdstuk twee werd plaatjes benoemen als enige taak vergeleken met plaatjes benoemen in een tweedelige taak. In de tweedelige taak benoemden proefpersonen eerst het plaatje met direct daaropvolgend een ongerelateerde taak om de richting van een pijl aan te geven. Correlaties tussen de snelheid waarmee ze plaatjes benoemden en hun prestaties op de aandachtstaak waren sterker in de tweedelige taak dan in de eendelige taak. Als een plaatje benoemen de enige taak is, speelt het vermogen om aandacht vast te houden een kleine rol. Met andere woorden: ook individuen die meer moeite hebben met alertheid kunnen zonder problemen plaatjes benoemen. Wordt de taalproductie echter moeilijker gemaakt, dan komen individuele verschillen in alertheid naar voren. Het vasthouden van aandacht wordt belangrijker naarmate de complexiteit in taalproductie toeneemt. De complexiteit in hoofdstuk twee is tamelijk kunstmatig: de tweedelige taak is uiteraard niet iets wat zich op deze manier in het dagelijks leven voordoet. In hoofdstuk drie zien we dat taalproductie ook moeilijker kan worden gemaakt in een meer natuurlijke situatie, namelijk door het vormen van een korte frase in de vorm van het benoemen van twee plaatjes achter elkaar zoals 'de wortel en de emmer'. Ook dit is in essentie een tweedelige taak, en ook hier heb ik een sterke correlatie tussen alertheid en taalproductie gevonden.

Een van de doelen van dit proefschrift was om te onderzoeken welke processen van taalproductie onderhevig zijn aan aandachtsprocessen. Zoals eerder beschreven is het heersende idee dat de eerste stages van spreken aandacht nodig hebben, terwijl de laatste processen zonder aandacht doorlopen worden (Garrod & Pickering, 2007). Dit kan, onder andere, worden onderzocht door oogbewegingen te registreren. Eerder onderzoek heeft laten zien dat mensen naar een plaatje kijken totdat ze de woordvorm hebben samengesteld en vervolgens hun blik al op een volgende taak kunnen richten, terwijl ze de klanken van de voorafgaande taak nog moeten formuleren en uitspreken (Griffin, 2001; Meyer, Sleiderink, & Levelt, 1998). Deze kennis, in combinatie met onderzoek dat aantoont dat een blikverschuiving samengaat met een verschuiving in aandacht (Deubel & Schneider, 1996), suggereert dat aandacht nodig is tot en met woordvormsamenstelling en dat de processen die daarop volgen automatisch verlopen. In hoofdstuk twee en drie laat ik echter zien dat soms ook deze laatste stadia aandacht vragen. De correlaties tussen alertheid en taalproductie waren wel evident voor de spraaksnelheid maar niet voor de oogbewegingen. Het lijkt er op dat in deze experimenten het vasthouden van aandacht vooral belangrijk is bij de processen die plaatsvinden tussen het moment van de blikverschuiving en de daadwerkelijke spraak.

Zoals gezegd vormden eerdere studies naar kinderen met TOS de aanleiding om de rol van alertheid in taalproductie te onderzoeken. In hoofdstuk vier werden kinderen met TOS vergeleken met kinderen die een normale taalontwikkeling vertonen op zowel een aandachtstaak als op een taalproductietaak. Hoewel deze taken apart al eerder zijn onderzocht in beide groepen kinderen, zijn ze nooit eerder samen getest en dus kon een eventuele correlatie nooit direct worden vastgesteld. De resultaten laten zien dat kinderen met TOS op beide taken slechter scoren, maar dat de relatie tussen de twee taken soortgelijk is in beide groepen kinderen. Het trainen van alertheid in kinderen met TOS zou bevorderlijk kunnen zijn voor hun taalproductie, maar eigenlijk geldt dit voor alle kinderen. Het lijkt echter niet zo te zijn dat aandachtsproblemen het verschil tussen de taalontwikkeling van kinderen met en zonder TOS kan verklaren. Als de resultaten van hoofdstuk vier worden vergeleken met die van hoofdstuk twee en drie valt er een interessant verschil op tussen kinderen en volwassen. Waar volwassenen met een slechter vermogen tot het vasthouden van aandacht niet consistent langzamer zijn met het initiëren van spraak, geven ze wel vaker een zeer traag antwoord dan proefpersonen met een goed aandachtsvermogen. Daartegenover beginnen kinderen die meer moeite hebben met alertheid wel consequent later met spreken. Wellicht speelt het vasthouden van aandacht een belangrijke rol tijdens taalontwikkeling, maar neemt die rol af naarmate we ouder worden.

Uit eerdere studies naar alertheid is gebleken dat een aandachtstaak moeilijker wordt naarmate stimuli elkaar sneller opvolgen in de veronderstelling dat dan meer aandacht nodig is en zo de 'aandachtsbron' sneller uitgeput raakt. (Warm, Parasuraman, & Matthews, 2008). In hoofdstuk vijf heb ik geprobeerd om de vereiste alertheid in een taalproductie-taak te vergoten. Uit hoofdstuk twee bleek dat het vasthouden van aandacht een minimale rol speelde als proefpersonen één plaatje per keer benoemden. Het experiment in hoofdstuk vijf is zo opgezet dat zelfs een dergelijke simpele taak meer aandacht behoeft. Proefpersonen kregen zowel een aandachtstaak als een plaatjes-benoemtaak onder twee verschillende condities: één waar stimuli snel na elkaar werden gepresenteerd en één waar stimuli langzaam voorbij kwamen. De productietaak vertoonde soortgelijke resultaten als de aandachtstaak. Een manipulatie die de vraag om alertheid vergroot kan dus invloed uitoefenen op een simpele taalproductie taak.

Een andere manier om naar aandacht te kijken is gebruik maken van een elektro-encefalogram (EEG) waarbij hersengolven worden gemeten via kleine elektroden die op de schedel geplakt zijn. Neuronen geven signalen door in een bepaald ritme; men neemt aan dat de frequentie waarin deze signalen worden doorgegeven een specifieke functie heeft. Zo is er gesuggereerd dat de alfafrequentie (8 tot 12 Hz) een rol speelt bij aandacht. In hoofdstuk zes heb ik gebruik gemaakt van deze techniek terwijl proefpersonen plaatjes benoemden. Wat interessant is voor het huidige onderzoek is dat eerdere studies hebben laten zien dat de alfa frequentie voorafgaande aan een stimulus kan voorspellen hoe snel daarop wordt gereageerd (Kelly, Gomez-Ramirez, & Foxe, 2009). In dit experiment wilde ik kijken of dit ook geldt voor een taaltaak. Dit was echter niet het geval: ik heb geen verschil gevonden in alfafrequentie voor laat-geïnitieerde spraak vergeleken met snelle reacties. Het lijkt erop dat een modulatie in de alfafrequentie niet de verklaring is voor de snelheid waarmee mensen beginnen te spreken. Verder onderzoek moet aantonen wat er in de hersenen gebeurt vlak voor of tijdens taalproductie.

Samengevat heeft dit proefschrift laten zien dat het vasthouden van aandacht zeker een rol speelt bij taalproductie. Dit is vooral het geval waar de taaltaak wat moeilijker is, iets wat over het algemeen het geval is ons dagelijks taalgebruik. Voor volwassenen is de relatie tussen alertheid en taalproductie tamelijk subtiel, omdat individuen die moeilijk aandacht vasthouden niet stelselmatig langzamer zijn tijdens taaltaken dan individuen die goed scoren op de aandachtstaak. Ze hebben echter wel een groter aantal zeer trage reacties. Voor kinderen daarentegen lijkt het vasthouden van een aandacht een prominente rol te spelen, omdat de kinderen die alertheidsproblemen hebben consistent langzamer spraak initiëren. Het vasthouden van aandacht lijkt dus een belangrijke rol te spelen tijdens taalontwikkeling, maar het belang van die rol neemt ~~dan~~ wel af, maar speelt nog steeds een rol bij de spraak van volwassenen.

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"If you're going to try and walk on water make sure you wear your comfortable shoes."

Alex Turner (Arctic Monkeys)

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Curriculum Vitae

Suzanne Rosa Jongman was born in 1989 in Rotterdam, The Netherlands. She obtained her Bachelor's degree in Linguistics from Leiden University in 2010 (cum laude), after which she completed the Research Master Cognitive Neuroscience at Radboud University in 2012 (cum laude). She then started work as a PhD student at the Psychology of Language Department at the Max Planck Institute for Psycholinguistics in Nijmegen, funded by an International Max Planck Research School for Language Sciences Fellowship granted by the Max Planck Society. Together with Richard Kunert, she was awarded the Interdisciplinary Innovation Grant by the MPI for Psycholinguistics in 2014.

Publications

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