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Sustained attention in language production: An individual differences investigation

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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 the 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.

Keywords: Sustained attention; Language production; Object naming; Individual differences.

Language production is a highly practised 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

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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 morphophonological 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 occurs not only 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 (2008) 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. (2012) 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., 2012). 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 morphosyntactic problems (Leonard, 1998). 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 performance in a language production task, either picture description (Experiment 1) or picture naming (Experiment 2). In Experiment 1, participants were presented with coloured objects, which they described using either 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 not only examined 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 colours. On half the trials, participants were asked to describe the coloured object by producing determiner–noun phrases referring to the object but not its colour, such as “de fiets” (the bike), henceforth “short phrases”. On the other half of the trials, participants had to refer not only to the object but also to its colour 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 colours 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, 2008). 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.

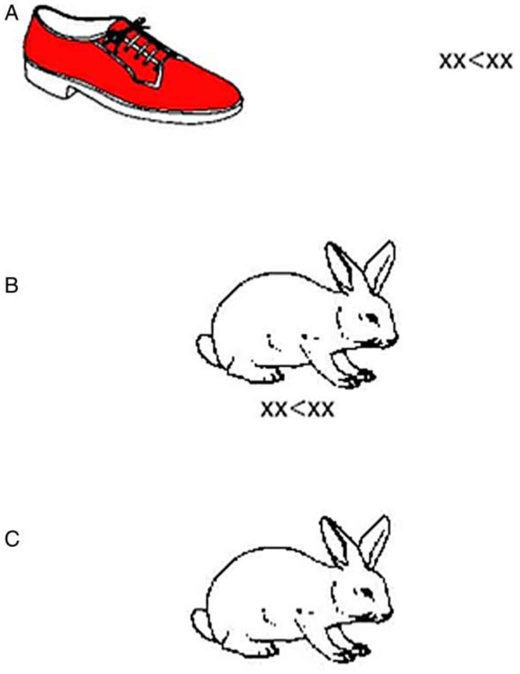

Figure 1. *Illustration of the visual stimulus displays used in Experiment 1 (A) and in Experiment 2, separately for the dual-task condition (B) and the single-task condition (C). To view this figure in colour, please visit the online version of this Journal.*

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 name. 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 a deficit in the visual modality.

For Experiment 1, we created two CPTs that differed only in modality, modelled 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 nontarget was a red square. Stimuli were 3.2 × 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 nontarget 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 nontargets, 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 interstimulus interval ranged from 1500 to 2500 ms. Each sustained attention task took approximately 12 min.

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 nontargets. The visual and auditory CPTs were analysed using R (R Core Team, 2012) and the R packages lme4 (Bates, Maechler, & Bolker, 2013) and languageR (Baayen, 2011). The data were analysed with a linear mixed effects model including modality and block and the interaction as fixed effects. Factors were mean-centred, 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., 2005). They are monosyllabic, of non-neuter gender, and from different semantic categories.

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

The coloured pictures were presented in the centre of the left half of the computer screen, fitted into a virtual frame of 4 × 4 cm. On the right side of the screen an arrow flanked by rows of "x"s on both sides was presented (font Times New Roman, size 20). There were four objects with four possible colours, thus resulting in 16 stimuli. These objects could be accompanied by either a left arrow or a right arrow, which yielded 32 displays. These 32 displays were presented in a randomized order in 10 blocks, so that there were 320 trials in total.

In half of the blocks, participants described the coloured objects by producing determiner–noun phrases, such as "de fiets" (the bike). In the remaining blocks, they named the object colour as well by producing determiner–adjective-noun phrases. The determiner was always "de", and in the long phrases, all colour 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 the 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 analysed with a linear mixed effects model with phrase type and block as fixed effects including their interaction. Fixed effects were centred, 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 effects 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 the 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 13 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 effects 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 effects model analyses of the log-transformed reaction times for the two continuous performance tasks in Experiment 1*

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*

Note: The estimated coefficient (ß), standard error (*SE*) and *t*-value (*t*) are presented.

*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 effects 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 for 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 the high correlations between the two sessions (22 participants; $r = .88$, $p < .001$, for the

Table 2. *Mean latencies, standard errors, and error percentages 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

Note: Latencies in milliseconds. *SE* = standard error. E% = error percentages.

Table 3. *Results of mixed effects model analyses of the log-transformed latencies for the gaze durations, vocal responses, and manual responses in Experiment 1*

	Gaze			*Vocal*			*Manual*		
Fixed effects	*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*
Phrase × Block	0.00	0.01	0.13	–0.00	0.01	–0.81	0.00	0.01	0.26

Note: The estimated coefficient (ß), standard error (*SE*), and *t*-value (*t*) are presented.
*A coefficient is a significant predictor at $p < .05$ using the criterion that $|t| > 2$.

Table 4. *Mean values of ex-Gaussian parameters mu, sigma, and tau 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

Note: μ = mu; σ = sigma; τ = tau.

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 the 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 ($z = 0.67$, $p = .51$).

The results described above, specifically the presence of correlations of the CPTs with the

Table 5. *Correlations between the mean reaction times of the two continuous performance tasks and the mean latencies and the mu and tau parameters for gaze durations and vocal responses in Experiment 1*

			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

Note: M = mean; μ = mu; τ = tau; VCPT = visual continuous performance task; ACPT = auditory continuous performance task. Pearson's *r* and *p*-values are presented.
$^{*}p < .05$. $^{**}p < .01$.

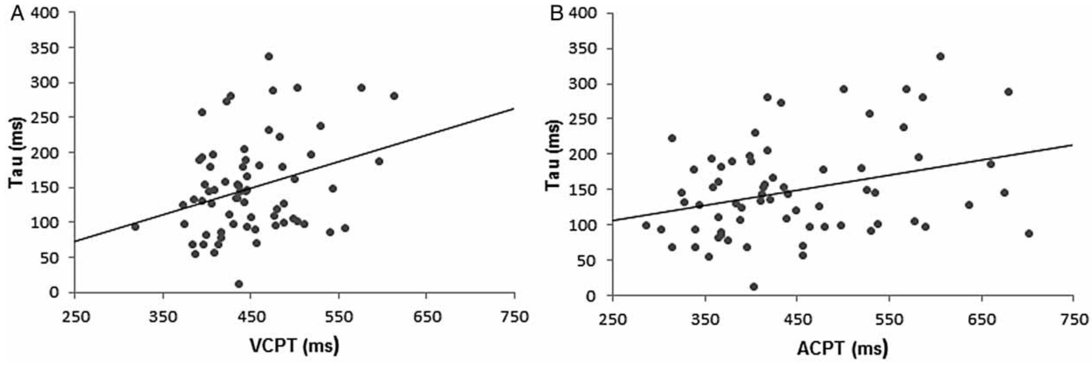

Figure 2. *Scatterplots of the relationship between the tau of the vocal reaction time for the long phrases and the visual continuous performance task (VCPT, Panel A) and auditory continuous performance task (ACPT, Panel B) in Experiment 1.*

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 effects 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

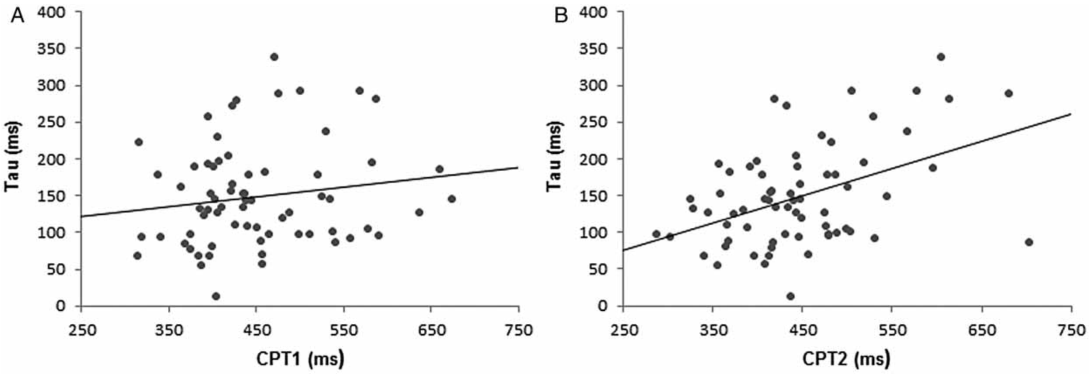

Figure 3. *Scatterplots of the relationship between the tau of the vocal reaction time for the long phrases and the first administered continuous performance task (CPT1, Panel A) and second administered continuous performance task (CPT2, Panel B) in Experiment 1.*

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 the long phrases, $r = .06$ and $r = .15$, respectively. By contrast, Block 2 correlated with $r = .32$, $p < .01$, for the short phrases and $r = .45$, $p < .001$, for the long phrases. Scatterplots 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 coloured 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 et al., 2006; Meyer et al., 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 et al., 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 reflect either 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 an 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 from that 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). Thirty-eight 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 et al., 2005). The object names were highly frequent (mean lemma frequency: 107 tokens per million; CELEX database, Baayen et al., 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 the Appendix for all object names).

The pictures were presented in the centre of the computer screen, fitted to a virtual frame of 8 × 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 analysed similarly to how they were in the preceding experiment. The linear mixed effects 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 nontargets. 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 nontarget 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 nontargets.

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

Analysis. The data were analysed in a similar fashion to that in 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 effects 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 tasks 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 40 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 effects 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 than in 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 effects 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 to that for the naming latencies (ß = −0.04, $SE = 0.01$, $t = -6.31$).

Table 6. *Results of mixed effects model analyses of the log-transformed latencies for the vocal responses in Experiment 2*

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*

Note: The estimated coefficient (ß), standard error (*SE*), and *t*-value (*t*) are presented.

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

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 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 deteriorated over time, with an average RT of 387 ms for the first block compared to 413 ms for the final block.

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

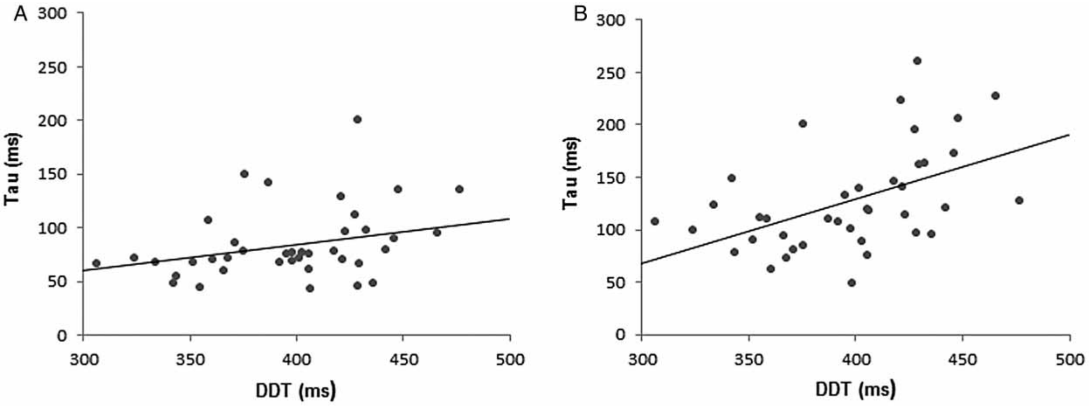

Figure 4. *Scatterplots of the relationship between sustained attention as measured by the digit discrimination task (DDT) and the tau of the naming latencies in the single-task condition (Panel A) and the dual-task condition (Panel B) in Experiment 2.*

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 those 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 interstimulus 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 favours 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, than 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 second half − mean RT first half) 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 et al. (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 than in 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, and 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 et al. (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 et al., 2001; Spaulding et al., 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 that 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 was 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.

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APPENDIX

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).