Speech production and working memory:
The influence of cognitive load on sentence planning

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For the last four decades, psycholinguistic research has dealt with the question to what extent elements of simple sentences like “The monk read the book” are planned ahead both on the abstract-lexical and phonological processing level. While a number of studies have shown that all up to the final element can be activated on these two levels, empirical evidence on the flexibility of the respective planning scopes is inconsistent, and a systematic delineation of the influence of different forms of cognitive load has not yet been provided. This thesis presents a series of 9 picture-word interference experiments in which participants produced subject-verb-object sentences while ignoring auditory distractor words. Advance planning was assessed at an abstract-lexical (lemma) level and at a phonological (word form) level under varying working memory load conditions (no load, or visuospatial load, or verbal load). In the absence of a concurrent working memory load and with a concurrent visuospatial working memory load, subject and object nouns were found to be activated at the abstract-lexical and the phonological level prior to speech onset. By contrast, with a concurrent verbal working load, the scope of advance planning at the phonological level was reduced, while the scope of advance planning at the abstract-lexical level remained unaffected. Moreover, sentence planning had a more disruptive effect on verbal working memory performance than on visuospatial working memory performance. Overall, these results suggest that advance planning at the phonological level is more adaptive to external factors than advance planning at the abstract-lexical level. Also, they indicate an overlap of resources allocated to phonological processing in speech production and verbal working memory.
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Selbstständigkeitserklärung
1. Introduction

»How small the cosmos (a kangaroo's pouch would hold it), how paltry and puny in comparison to human consciousness, to a single individual recollection, and its expression in words!«

–Vladimir Nabokov, *Speak, Memory*

Speaking is one of the most fascinating abilities of humans. Seemingly effortless, we are capable of formulating speech that ranges from short exclamations to long monologues, and in surprisingly many cases, this speech is meaningful, contextually adequate, and grammatically and phonologically correct. On top of this, in the majority of the cases we are even engaged in a concurrently performed, more or less demanding task while speaking, and although our performance on either speaking or the other task or both may drop, we can still manage surprisingly well. The focus of the experiments presented in this work was to investigate the limitations of this perceived ‘multi-tasking ability’. Specifically, the goal was to explore to what extent speakers’ ability to activate all elements of a simple sentence like “The monk read the book” both on an abstract-lexical and phonological level (hereafter referred to as the advance planning scope) can be modulated by an additionally imposed cognitive load. Moreover, varying the contents of this load (i.e., having it contain visuospatial or verbal information) should allow inferences to what extent speech planning and specific working memory processes interact.

All established models of speech production agree that the process of speaking can be distinguished into three different parts: conceptualisation, formulation, and articulation. The current work assessed the flexibility of processes taking place during formulation. At this stage, it is assumed that speakers access an abstract concept of the intended utterance (abstract-lexical planning) and subsequently retrieve the corresponding phonological information (phonological planning) to allow for a correct utterance. In the last decades, a number of studies have investigated the extent to which the elements of an utterance whose length exceeds the single-word level (i.e., complex noun phrases like “the big red dog” or simple sentences like “the frog is next to the mug”) can be activated on these two planning stages prior to
speech onset (e.g., Costa & Caramazza, 2002; Jescheniak, Schriefers, & Hantsch, 2003; Meyer, 1996; Oppermann, Jescheniak, & Schriefers, 2010; Schnur, Costa, & Caramazza, 2006; Smith & Wheeldon, 2004; Wagner, Jescheniak, & Schriefers, 2010).

The majority of these studies used variations of the picture-word interference paradigm, in which speakers name a visually presented display and ignore a visual or auditory distractor word (Glaser & Düngelhoff, 1984; Rosinski, 1977; Schriefers, Meyer, & Roelofs, 1990). The relation between target utterance and distractor word can be manipulated on different levels, as can be the time lag between picture and distractor onset (stimulus onset asynchrony, SOA). Varying these two factors allows for an assessment of the time course of abstract-lexical or phonological activation. When participants name a target picture using a single-word utterance (e.g., "cat"), distractors semantically related to the target word (e.g., “dog”) have been found to increase the naming latencies compared to an unrelated word (e.g., “glass”). This inhibitory effect is interpreted as the concurrent co-activation of a competitor on the abstract-lexical level. By contrast, phonologically related distractors (e.g., “cap”) speed up naming latencies compared to an unrelated condition (cf. Damian & Martin, 1999; La Heij, 1988), which indicates that an overlap of word form segments between target and distractor facilitates the naming response. Employing this method for subject-verb-object sentences by presenting distractors that are related or unrelated to different elements in the utterance (i.e., either the subject or the object), the current study intended to trace the amount of activation at the abstract-lexical and phonological level both with and without a concurrent cognitive load.

This work is structured as follows: Chapter 2 focuses on the speech production aspect of this work by introducing a theoretical framework based on Levelt, Roelofs, and Meyer (1999), providing an overview of the state-of-the-art with respect to information flow in the mental lexicon and existing research on advance planning in complex utterances. Chapter 3 first summarises the two most dominant working memory models, addresses the question of working memory capacity limitations and eventually attempts to bridge the two theoretical domains speech production and working memory by reviewing the few existing studies investigating their interaction. Chapter 4 constitutes the empirical part of this work, presenting nine experiments which investigated the influence of a concurrent cognitive load on advance planning in sentence production. Finally, Chapter 5 summarises the obtained findings, embeds them in the current scientific context and provides suggestions for future research.
2. **Speech Production**

2.1. **The Speech Production Process**

When planning an utterance, speakers have to execute three steps: conceptualisation, formulation, and articulation, which will be briefly illustrated here. The following descriptions are largely based on the speech production model proposed by Levelt, Roelofs, and Meyer (1999) and initially focus on single-word production; chapters 2.3 and 2.4 will extend these findings to multi-word utterances and sentence production.

**Conceptualisation** is a deliberate process in which the speaker translates an abstract concept of what she or he intends to say into a so-called preverbal message. More precisely, she or he needs to select the lexical concept appropriate to her or his articulatory intention. Because the speaker has to select out of a multitude of possible lexical concepts describing one and the same thing, the so-called verbalisation problem may arise. For example, the picture of a house could be named as “house”, “building”, “villa”, etc. Furthermore, perspective taking needs to be employed to differentiate between various properties of the message, e.g., whether the house is “big”, “small”, “old”, of a specific colour etc. To overcome these obstacles, the speaker consciously decides which concepts best suit her or his intention, usually by comprising pragmatic and contextual information. Levelt et al. (1999), based on the spreading activation theory of semantic processing by Collins and Loftus (1975), propose that lexical concepts are organised in a network-like structure, in which each lexical concept is represented by a genuine node, with activation being spread between nodes. This implies that not only the intended lexical concept is activated but also its semantic cohort, that is, semantically related concepts.

During formulation, the prepared message is transformed into a linguistic form. First, the appropriate lexical concept needs to be selected, which involves the rejection of its semantic competitors (i.e., co-activated related concepts). The selected lexical concept is then assigned its specific syntactic role and structure by deriving the target lemma(s) from the mental lexicon. Lemmas are defined as abstract entities that specify a word’s syntactic properties and, consequently, the syntactic frame of the utterance. Thus, retrieving a lemma from the mental lexicon determines the functional structure of the utterance. In order to compose a sequential structure, positional processing, which generates the phrasal structure of the utterance, is required. In short, grammatical planning sets the functional and sequential structure of the intended utterance. Furthermore, a phonological plan is made up. In order to cre-
ate the phonological word, or lexeme, the speaker has to derive the morphological, metrical, and segmental properties of the word from the mental lexicon. Moreover, prosodic characteristics of the utterance, e.g., pitch, speed, and rhythm, are selected.

\[ \text{READ}\langle(i\text{(MONK)},i\text{(BOOK)})\rangle \]

\[
\begin{align*}
\text{MONKn, BOOKn, READ}_v \\
/\text{the/ monk/ read/ the/ book/} \\
/\text{ðæl} /\text{Imɔŋk} /\text{rɔd} /\text{ðæl} /\text{bʊk/} \\
S((\text{NP}_{\text{nom}}) V(\text{O}(\text{NP}_{\text{acc}}))) \\
det, \text{NP, V, det, NP}
\end{align*}
\]

Figure 1. Schematic illustration of the speech production process as proposed by Levelt, Roelofs, and Meyer (1999). The left part lists the specific steps and the right part provides respective examples for a given target utterance (i.e., "the monk read the book").

Finally, the phonological plan is translated into motor programmes during articulation. The speaker executes the relevant articulatory gestures to create the sound wave that is the intended utterance. It is also assumed that speakers can control their utterances through a process of self-monitoring during conceptualisation and formulation, which allows them to correct wrong utterances before they are entirely articulated.

2.2. Lexical Access in Speech Production

Current models of speech production assume that lexical access is divided into two steps. As mentioned above, two different processing levels within the mental lexicon are distinguished: the lemma level, which refers to the lexical entries, and the lexeme level, which refers to the respective word form (first introduced by Kempen and Huijbers, 1983). After forming the preverbal message, the respective concept retrieves its corresponding lemma from the mental lexicon. This includes semantic and syntactic features such as number, gender, and contextual information. In a second step the morphological and phonological properties of the word, e.g., the number of morphemes and metrical information, are accessed. In
their model, Levelt et al. (1999) assume that each lemma is represented as an individual node whereas accessing the phonological form of the word is separated into word form access and segmental spellout.

Collecting and analysing spontaneously occurring speech errors has been one of the first methods in speech production research to establish hypotheses regarding multiple lexical access. Garrett (1975, 1980) showed that different kinds of speech errors follow different constraints. Word exchange errors (e.g., “although murder is a form of suicide” instead of “although suicide is a form of murder”) were found within the same syntactic category but spanned across phrases. In contrast, sound exchange errors (e.g., “the little burst of beaden” instead of “the little beast of burden”) occurred independent of the syntactic category but within a limited scope. From these findings, Garrett reasoned that both types of error must occur on two distinct processing levels, i.e., word exchange errors on a syntactic, functional level and sound exchange errors on a phonological, positional level.

The analysis of tip-of-the-tongue states, i.e., the inability to access the phonological form of a selected lemma, provided further evidence for two separate processing levels. It has been shown that in situations where participants, including aphasic patients (Badecker, Miozzo, & Zanuttini, 1995), are not able to name a given target, they can still accurately determine its syntactic properties, e.g., its grammatical gender (Caramazza & Miozzo, 1997; Vigliocco, Antonini, & Garrett, 1997) or number (Vigliocco, Vinson, Martin, & Garrett, 1999). This supports the idea that accessing syntactic features requires a different processing stage than retrieving phonological information.

Chronometric evidence comes from a variety of studies. Schriefers, Meyer, and Roelofs (1990) asked participants to name pictures of simple objects (e.g., “bureau” [desk]) while ignoring auditorily presented distractor words semantically (“kast” [closet]) or phonologically related (“buurman” [neighbour]) or unrelated (“muts” [cap]) to the object. These distractors were presented at three different stimulus-onset asynchronies (SOAs; -150, 0, and 150 ms, respectively). The variation of the SOAs displayed a different time course of the semantic and phonological distractors compared to the unrelated condition: The size of the semantic interference effect decreased with increasing SOA (39, 12, and 5 ms, respectively) whereas a phonological facilitation effect was found at later SOAs (0, 47, and 62 ms, respectively). This data pattern led the authors to argue that abstract-lexical precede phonological planning processes.
Jescheniak and Levelt (1994) experimentally investigated the hypothesis of a two-stage lexical access using homophones. Homophones are words that share the same word form, but differ in their semantic meaning (e.g., “arm” as a limb versus “arm” as a weapon). It was assumed that although homophones have identical lexemes, they should be connected to different nodes in the lemma layer, as they do not share the same syntactic-semantic features. The authors assessed the connection between frequency and naming latency for different homophones. They found that high-frequent words were named faster than low-frequent words, but low-frequent words with a high-frequent homophone elicited similar latencies as a high-frequent control non-homophone. The fact that naming latencies for low-frequent words decreased in the presence of a high-frequent homophone was taken as evidence for a representational overlap between homophones. As mentioned, homophones cannot share the same lemma due to their different syntactic and semantic properties. Thus, Jescheniak and Levelt (1994) concluded that homophones are represented by an identical lexeme, and the frequency of a word is located—relatively independent of its syntactic and semantic features—within the word form layer, suggesting once more a two-stage process of lexical access.

In summary, empirical evidence employing a number of methodological approaches suggests that (1) lexical access is divided into a syntactic-semantic and a phonological stage and (2) lemmas and lexemes are represented separately. A question that is more controversial concerns the direction of information flow inside the mental lexicon. Chapter 2.3 will briefly describe the different views taken.

2.3. Information Flow in the Mental Lexicon

In speech production, information flow is assumed to take two directions. Vertical information flow refers to the temporal coordination between the two processing levels (i.e., semantic-syntactic and phonological), that is, to what extent the access of an abstract semantic-syntactic concept (the lemma) and its corresponding word form (the lexeme) interact. Horizontal information flow, on the other hand, describes the coordination when accessing several lexical entries in multi-word utterances. Both aspects are described in more detail in the following two sections.

2.3.1. Vertical Information Flow

The distinction of an abstract-lexical and a phonological stage during lexical access is incorporated in most models of speech production. However, the amount of interaction, or lack
Information Flow in the Mental Lexicon

thereof, between these stages is still a matter of theoretical debate. Broadly speaking, there are three different standpoints, that is, discrete-serial, cascading, and interactive models, and an overview of the evidence for each stance will be described in the following.

Discrete-serial models (e.g., Levelt et al., 1999) claim that the phonological form of a word can only be accessed after the selection of its corresponding lemma has been finished, that is, only the selected lemma spreads activation to the phonological level. Thus, these models assume an information flow strictly from the lemma to the lexeme level, without any interaction between the levels. In contrast, cascading models (e.g., Cutting & V.S. Ferreira, 1999; Peterson & Savoy, 1998) suggest that not only the lemma that got selected, but also competitors from its semantic cohort spread activation to the phonological level, such that also words semantically related to the target word activate their phonological form. Interactive models (e.g., Dell, 1986; Dell & O’Seaghdha, 1991; Dell & O’Seaghdha, 1992) extend this theory by suggesting a bidirectional information flow in which semantic competitors of a target word co-activate their phonological form as proposed by cascading models, but this activated phonological form can also feed back to the syntactic-semantic level and influence the selection of the lemma.

First evidence against discrete-serial models came from speech error research. Dell and Reich (1981) observed two phenomena that contradict a unidirectional information flow. First, they found significantly more mixed errors, in which the wrong utterance is both semantically and phonologically similar to the intended utterance (e.g., “a routine promotion” instead of “a routine proposal” [Fromkin, 1973]), than blends that could only be traced back to one representational level (e.g., “don’t burn your toes” instead of “don’t burn your fingers” on the semantic-syntactic level or “at the bottle of page five” instead of “at the bottom of page five” at the phonological level [Fromkin, 1973]). Furthermore, speech errors resulted more often in existing words rather than non-words, a finding that was termed lexical bias. If syntactic-semantic and phonological processing were two distinct, successive stages, as discrete-serial models propose, these types of errors should only occur at chance level. Based on these results Dell and Reich (1981) postulated interactivity between these processing levels (see also Dell, 1986; Dell & O’Seaghdha, 1991; Dell & O’Seaghdha, 1992) in which mechanisms feeding back from the phonological to the syntactic-semantic level speed up lemma retrieval, especially for low-frequent words. That is, if a word form is easier to retrieve than its syntactic-semantic features, information may be spread from the lower level upwards to facilitate the naming response. However, advocates of discrete models explain this over-representation of mixed errors and lexical bias by the increased difficulty of a postlexical monitoring process to
detect these types of error compared to solely semantic or phonological as well as non-word errors (e.g., Levelt, 1989; Schriefers et al., 1990).

In a combined naming and lexical decision task, Levelt et al. (1991) asked participants to name visually presented objects. On each trial, they had to decide whether another word presented auditorily at SOAs of 73 ms, 373 ms, and 673 ms was a real word or a pseudo-word. These auditory distractors could be semantically or phonologically related to the target (e.g., “stoel” [chair] or “buurman” [neighbour] for the target word “bureau” [desk], respectively), phonologically related to a potential semantic competitor of the target word (e.g., “stoep” [threshold] for the target “bureau” [desk], with the potential semantic competitor “stoel” [chair]), or unrelated (e.g., “muts” [cap]). Longer naming latencies were observed if the distractor was semantically or phonologically related to the target word but no effect was found for the condition in which the distractor was phonologically related to a potential semantic competitor. The authors interpreted these findings in favour of discrete models, suggesting that only the selected lemma spread activation to its phonology.

Peterson and Savoy (1998) used a similar procedure to investigate the information flow in the mental lexicon. In addition to the ordinary object naming task, visual distractors were presented that were to be read aloud. These distractors could be semantically or phonologically related to the preceding to-be-named object (e.g., “snake” and “frost” for the target word “frog”, respectively), or they could be phonologically related to a near-synonym of the target, that is, a strong semantic competitor that equally described the preceding object (e.g. “tone” with a near-synonym of “frog” being “toad”). Peterson and Savoy obtained semantic as well as phonological facilitation of distractors related to the target word, compared to an unrelated condition, and, crucially, also facilitation for distractors phonologically related to the near-synonym of the target. The authors interpreted these results in line with non-discrete, cascading models, as not only distractors related to the selected lemma, but also those related to strong semantic competitors received phonological activation.

In a picture-word interference task, Jescheniak and Schriefers (1998) reported phonological interference if the auditorily presented distractor was phonologically related to a near-synonym. Levelt et al. (1999) reconcile these findings by proposing that near-synonyms are exceptional cases of the semantic cohort because they are a proper naming alternative to the intended target and thus become phonologically activated. In fact, Peterson and Savoy (1998) did not obtain an effect with distractors phonologically related to semantic competitors of the target (e.g., “sneak” for the target “frog”, with the semantic competitor being “snake”).
In summary, the experimental findings can be arranged with discrete models if they allow for specific restrictions, e.g., a post-lexical monitoring system or the privileged role of near-synonyms compared to semantic competitors. Given age-dependent results that support the activity of cascading models in young children (Jescheniak, Hahne, Hoffmann, & Wagner, 2006), one could also hypothesise that the spread of activation decreases with age in favour of language efficiency.

2.3.2. Horizontal Information Flow

The coordination of accessing multiple lexical entries when preparing a complex utterance is another crucial factor in speech production. Normal speech incorporates three important aspects which must be accounted for when proposing mechanisms of horizontal information flow, i.e., the extent to which different words of an utterance are activated (cf. F. Ferreira & Swets, 2002): (1) the utterance must contain the speaker’s communicative goals, (2) speakers have to choose from an almost infinite amount of possibilities as to how to express the intended message, and (3) the utterance should be produced with as few pauses and reparations as possible. To achieve these goals, it is assumed that language is planned incrementally. This means that the planning of an utterance does not have to be finished on one processing level to proceed to the next one, but rather happens in a piece-meal fashion to ensure fluency and efficiency of speech.

To achieve this stepwise build-up of multiple lexical entries with as few errors as possible\(^1\), a slot-filler mechanism has been suggested. On the basis of single words, Shattuck-Hufnagel (1979) proposes that a ‘scan-copier’ assigns pre-selected units to the sublexical slots of the intended utterance and monitors this assignment across the length of the utterance, deleting entries which are likely the product of erroneous unit allocation. Dell (1986) suggests a similar mechanism but assumes that the slots-filling units are retrieved within a spreading-activation network in which the segments that receive the most activation are eventually retrieved and inserted into the units. However, neither of these models offers details as to how the frame comprising several lexical entries is established, and therefore provides only limited insight into the nature of the horizontal information flow.

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\(^1\) Estimates of how often speech errors occur are difficult to retrieve and yield only vague results, ranging from “enough that casual observation will yield one or more examples of each [one of five given error categories] in a week” (Garrett, 1980, p. 179) to “in the one per one thousand range” (Levelt, Roelofs, and Meyer, 1999, p. 4).
Many studies suggest radical incrementality as a construct underlying advance planning. That is, articulation is initiated as soon as the first element of an utterance is available, while the rest of the utterance is prepared ‘on-line’, i.e., in parallel to articulation. Strongest evidence for this conception is provided by studies investigating syntactic choice in picture description. For example, Bock (1986) asked participants to describe scenes depicting an agent performing an action on a patient (e.g., lightning striking a church). Prior to each picture, the participants were presented a word which was either semantically or phonologically related or unrelated to the agent or the patient of the target utterance (e.g., either “thunder” or “worship” in the semantic priming condition, “frightening” or “search” in the phonological priming condition, or an unrelated word, respectively). Given that there were no constraints in terms of the syntax the participants had to use in describing the pictures, Bock examined what effect these lexical priming manipulations would have on the chosen syntactic format of the sentences. She observed that if the sentence production task was preceded by a word semantically related to one of the noun phrases of the scene, participants chose an utterance structure which placed this lexically primed item in an early position in the utterance. For instance, if “thunder” was presented as a prime, participants chose an active structure (i.e., “the thunder is striking the church”). In contrast, if “worship” was the prime, participants produced a passive structure (i.e., “the church is being struck by lightning”). This finding of determining a semantically primed element as the subject, i.e., the sentence-initial element, of the utterance was not paralleled in the phonological priming condition. In fact, there was even a (non-significant) trend towards shifting the primed element towards the end of the sentence. Importantly, although about half of the participants reported after the experiment that they were aware of the semantic, but not the phonological relation induced by the prime words, additional analyses splitting the sample into an ‘aware’ and an ‘unaware’ group showed no difference with respect to the priming effects. Overall then, these results have been interpreted as an indicator that deriving the syntactic structure of a to-be-produced sentence requires the activation of the meaning of at least one of its constituents, but not its word form. Assigning a pre-activated lexical entry to an initial position creates a planning buffer which allows for not-yet activated elements to be shifted to a later position, thus ensuring fluency of the utterance.

Wheeldon and Lahiri (1997) provide further support for incrementality. In Experiment 4 of their study, they first presented a noun phrase which differed in the amount of phonological rhyme. Besides this phonological rhyme condition, an onset-related condition (e.g., with the distractor “charge” for the target word “church”; Experiment 2 of this study) was tested as well, which yielded essentially the same null-effect as the rhyme condition.
nological words (i.e., “het water” [the water] is considered to be one phonological word while “vers water” [fresh water] contains two phonological words) on a computer screen, followed by the question “Wat zoek je?” (What do you seek?) via headphones. Participants then had to produce a sentence incorporating these elements (e.g., “Ik zoek het water”/“Ik zoek vers water”). The authors found that onset latencies varied as a function of the complexity of the first phonological word in the sentence. That is, sentences where “ik zoek” alone constitutes the first phonological word were initiated faster than sentences where the determiner “het” is included in the first phonological word. Therefore, although “ik zoek vers water” contains more phonological words than “ik zoek het water”, participants used only the first phonological word as a prerequisite to initiate articulation, presumably completing the remainder of the sentence online. Given that the correct determiner “het” (instead of the second possible determiner “de” in Dutch) had to be retrieved phonologically, it is fair to assume that the entire semantic-syntactic structure had been built up prior to speech onset. Thus, Wheeldon and Lahiri (1997) interpreted their finding as consistent with the claim by Levelt (1989, 1992) that the phonological word is the “preferred unit of output during speech production” (Levelt, 1989, p. 376), i.e., speakers can begin to articulate a sentence after the first phonological word is prepared.

This assumption of the phonological word as the minimal planning unit has been challenged by subsequent studies which could show that more than this unit had been planned ahead before speech onset. For instance, F. Ferreira and Swets (2002) propose strategic incrementality, i.e., “incrementality is not an architectural property of the language production system; instead, it is a parameter of production that is under speaker control” (p. 76). In their study, participants had to formulate the result of arithmetic sums in varying syntactic formats. That is, if they were given the mathematical problem “25 + 25 = ?”, they could either respond with “50” (sum-only condition), “the answer is 50” (frame-sum condition) or “50 is the answer” (sum-frame condition). The difficulty of the mathematical problems was manipulated as well. When participants could choose freely when to respond (i.e., there was no emphasis on speed in the instructions), naming latencies did not differ between the syntactic formats, which speaks against an incremental planning of the sentences (Experiment 1). To encourage incrementality, a second experiment introduced a response deadline and participants were instructed to continuously use a fixed utterance format (i.e., “the answer is <SUM>”). These procedural changes indeed revealed signs of incrementality: Both naming latencies and utterance durations varied as a function of the difficulty of the calculation. That is, participants were slower to initiate their response when the calculation of the ones column, i.e., the first part of the to-be-stated sum, but not the tens column was difficult, while utterance durations for the
syntactic frame “the answer is” were shorter when both the ones and tens column were easy. The authors argued that introducing a response deadline led speakers to articulate more efficiently by decreasing the size of the respective planning units, performing at least some of the calculations as they spoke.

Evidence from eye-tracking studies further support the concept of incrementality, with the most dominant stance being that in planning an utterance, a higher-level message is constructed which determines the order in which the specific increments are encoded. For example, Griffin and Bock (2000) showed that when participants described picture scenes (e.g., a girl shooting a man), their eye movements displayed no preference towards one or the other character in the first 400 ms after picture onset. This was interpreted as extracting the gist of an event in the preferable perspective (labelled event apprehension, in this case either a girl shooting a man or a man being shot by a girl) before lexically encoding the individual elements and thereby predetermining the functional structure of the utterance. In a recent study, however, Konopka and Meyer (2014) argue for a more flexible conception of incrementality. Two eye-tracking experiments showed that when participants were primed lexically before producing sentences similar to those of Griffin and Bock’s study, they tended to initiate utterance planning by encoding the individual characters, whereas structural primes encouraged a higher-level message generation. Konopka and Meyer suggest “a continuum of incremental planning that permits shifts in planning strategies from sentence to sentence” (p. 33). Ultimately, according to this study, the degree of flexibility in incremental sentence generation is driven by the availability of context-specific information, with speakers pursuing a strategy that exploits easy information early to minimise the cognitive load as the sentence unfolds.

By now, however, there is a considerable amount of evidence that the scope of both abstract-lexical and phonological advance planning, i.e., encoded information after message structuring, need not be restricted to the smallest possible element in the utterance. Studies examining this aspect are presented in detail in the following chapter.

2.4. Chronometric Evidence on Advance Planning in Complex Utterances

The focus of the present experiments was to investigate to what extent speakers plan ahead on the abstract-lexical and phonological level when preparing a simple sentence, and to what extent this planning scope is influenced by a concurrent cognitive load. Before chronometric studies systematically addressed this issue, the analysis of speech errors was one of the first methods which provided insight into the processes underlying advance planning in
spoken sentence production. Garrett’s (1975, 1980) dichotomy of word and sound exchange errors not only pointed towards two distinct processing levels (see chapter 2.2.1), but also provided first evidence in terms of the respective planning scopes. He showed that word exchange errors (e.g., “Is there a cigarette building in this machine?” instead of “Is there a cigarette machine in this building?”) spanned across phrases while sound exchange errors (e.g., “I’ve got a load of cooken chicked” instead of “I’ve got a load of chicken cooked”) occurred within a limited scope. Garrett thus concluded that the scope for the latter is notably narrower, ultimately suggesting that phonological advance planning is executed in smaller units compared to abstract-lexical advance planning.

Chronometric evidence regarding the scope of abstract-lexical and phonological advance planning largely stems from studies using the picture-word interference paradigm or variants thereof, where participants name a picture or produce simple sentences while ignoring a distractor word that can be presented auditorily or visually. In single-object naming tasks, distractor words semantically related to the target typically increase naming latencies compared to an unrelated condition (semantic interference effect), whereas phonologically related distractors facilitate the naming response (phonological facilitation effect; e.g., Damian & Martin, 1999; Jescheniak, Schriefers, & Hantsch, 2001; Schriefers et al., 1990; Starreveld & La Heij, 1995). These findings indicate that on the abstract-lexical level, several lexical entries from the same semantic cohort compete for selection, while phonological relatedness boosts activation of to-be-selected phonemes and thus causes facilitation.

By inference, the case of multi-word utterances or simple sentences, respectively, is slightly more complicated. In terms of the abstract-lexical planning scope, semantic interference has been obtained for all elements within simple sentences (i.e., both the subject and the object of subject-verb-object sentences). This illustrates that abstract-lexical advance planning spans up to the final element of multi-word utterances (e.g., Meyer, 1996; Wagner, Jescheniak, & Schriefers, 2010; see Smith & Wheeldon, 2004, for converging evidence using a different paradigm). The size of the phonological planning scope, however, is less clear in the literature: While some studies have shown phonological effects beyond the initial noun phrase, other studies have failed to provide evidence for a larger phonological advance planning scope. Examples for both points will be described in turn in this chapter.

The part of this thesis that is considered with phonological advance planning is based on the so-called graded activation account of phonological encoding proposed by Jescheniak, Schriefers, and Hantsch (2003). It suggests that elements of an utterance are phonologically activated serially, i.e., from left to right, such that utterance-initial elements receive the high-
est activation and subsequent elements less or no activation, depending on whether they are planned in advance. Thus, distractors phonologically related to the initial element speed up naming latencies, as they provide extra activation and do not disturb the serial pattern, which creates a situation comparable to that of single-object naming. In contrast, distractors phonologically related to an element in a later position of the utterance increase activation of this item and interfere with the prevailing linearity, thus leading to an attenuated facilitation effect or interference. Jescheniak et al. (2003) asked participants to name pictures of simple objects using either a bare noun (e.g., “Kamm” [comb]), a simple noun phrase (determiner and noun, e.g., “der Kamm” [the comb]) or a complex noun phrase including two adjectives (e.g., “der große rote Kamm” [the big red comb]) while ignoring auditory distractors semantically or phonologically related or unrelated to the noun. If the distractors were presented simultaneously to picture onset (i.e., SOA 0 ms), comparably sized semantic interference effects were observed from semantically related distractors (e.g., “Bürste” [brush]), whereas the polarity of the phonological effects changed with increasing utterance complexity. Phonologically related distractors (e.g., “Kanne” [jug]) yielded facilitation effects for the bare noun and simple noun phrase (50 and 20 ms, respectively), while a 28-ms interference effect was obtained when participants had to produce complex noun phrases. Jescheniak et al. (2003) thus showed that a phonologically related distractor changes its influence on the naming response as a function of the position of the primed element within the utterance. That is, the facilitation that is continuously observed for single words decreases or even turns into interference as the primed element moves to a later position in a more complex utterance.

In a study by Meyer (1996), participants had to produce coordinated noun phrases (e.g., “de pijl en de tas” [the arrow and the bag]) or simple sentences (e.g., “de pijl staat naast de tas” [the arrow is next to the bag]) while ignoring auditory distractors semantically or phonologically related to the first or second noun. While there was substantial semantic interference for both nouns at SOAs -150 and 0 ms, a reliable phonological facilitation effect was only found for the first noun in both utterance formats. However, there was a trend towards phonological interference for the second noun phrase (marginally significant at SOA 300 ms for the coordinated noun phrases and only significant in the analysis by subjects at SOA 0 ms for the sentences), providing some tentative evidence that the phonological planning scope might exceed the first element.

Similarly, Smith and Wheeldon (2004) reported robust semantic interference but less clear phonology-related influences on speech production. When describing movements of two objects, participants were slower when the objects were semantically related (e.g., “saw” and
"axe") than when they were unrelated (e.g., "saw" and "cat"), and this held both when the objects appeared in the same phrase (e.g., "the saw and the axe/cat move down") and in different phrases (e.g., "the saw moves towards the axe/cat"). When manipulating the targets on the phonological level, only an end-related same-phrase condition (i.e., "the flag and the bag move up" as opposed to "the flag and the brick move up") yielded a phonological facilitation effect, leading the authors to the conclusion that the scope of phonological advance planning is restricted to the first (coordinated) noun phrase in these sentences.

In recent years, however, a number of studies exploring the phonological planning scope observed phonological effects for non-initial elements of an utterance as well (e.g., Costa & Caramazza, 2002; Jescheniak et al., 2003; Miozzo & Caramazza, 1999; Schnur, 2011; Schnur, Costa, & Caramazza, 2006; Schriefers, Teruel, & Meinshausen, 1998). The study that can be considered a contentual predecessor of the current experiments was conducted by Oppermann, Jescheniak, and Schriefers (2010). They asked participants to produce simple past tense subject-verb-object (SVO) sentences (e.g., "die Maus fraß den Käse" [the mouse ate the cheese]) while presenting auditory non-word distractors phonologically related or unrelated to the subject or the object. Subject-related distractors yielded the expected phonological facilitation effect (SOAs 0 and 150 ms), whereas object-related distractors yielded a phonological interference effect (SOA 300 ms). This provided strong evidence that the object, i.e., the sentence-final element, was planned ahead phonologically prior to speech onset. In a subsequent experiment, the authors varied the required utterance format by presenting auditory lead-in fragments which manipulated the required syntactic structure and thus the positions of the primed elements ("vorhin" [a while ago] which requires a VSO sentence and "man sah wie" [one saw how] which requires an SOV sentence). Thus, the primed element could appear in utterance-initial, middle, or final position. Again, facilitation was obtained for the initial element (i.e., the subject in SOV sentences), but interference for the middle element in both formats (i.e., the subject in VSO sentences and the object in SOV sentences, respectively), and no effect for the final element (i.e., the object in VSO sentences). By changing the utterance format from an ordinary SVO sequence to a less frequent syntactic structure, phonological advance planning did not span across the whole sentence any more.

However, the results for the initial and middle element are still in line with the predictions of the graded activation account. A distractor phonologically related to the first noun phrase increases its activation and thus speeds up naming latencies, while a distractor phonologically related to a non-initial element withdraws activation from the sentence beginning and thus causes interference. The absence of any effect whatsoever for the final element (i.e.,
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the object in VSO sentences), which is in contrast with the findings of utterances requiring SVO, was explained by the fact that this particular word order is rather rare in German. Producing VSO sentences might therefore demand more cognitive capacity and reduce the planning scope compared to other more common word orders. This observed flexibility in the phonological planning scope as a response to greater task demands is taken as a starting point for the assumptions underlying this thesis. While the few studies that have investigated advance planning on the abstract-lexical level provide fairly consistent results with respect to the size of the planning scope and a reduction thereof has only been observed under very specific conditions (cf. Wagner et al., 2010; see also chapter 3.4), planning on the phonological level appears to be more susceptible to interference.

To sum up, there is an increasing amount of studies that have demonstrated not only abstract-lexical, but also phonological activation of non-initial elements. This indicates a wider planning scope than that inferred from speech error analyses (Garrett, 1975, 1980) and some chronometric studies (e.g., Meyer, 1996; Smith & Wheeldon, 2004; Wheeldon & Lahiri, 1997).

However, in every day life, speaking presumably is never an isolated task, as it was in the studies presented so far. Treating it as such in a laboratory setting has provided valuable insight into the mechanisms of speech planning, but only offers a limited view on the processes at play when we speak in more natural situations. After all, it is reasonable to assume that whenever speakers plan an utterance, they are distracted to different amounts by additional information that they have to keep in working memory throughout the planning. Thus, before turning to the experiments I conducted in chapter 4, chapter 3 will first provide an overview of the concept of working memory and to what extent it has been linked to language processing in the literature so far.
3. Working Memory and Language

Generally speaking, working memory has been defined as “the term used to describe the information one is thinking about at any particular moment” (Cowan, 2013, p. 786). More specifically, it consists “of flexibly deployable, limited cognitive resources, namely activation, that support both the execution of various symbolic computations and the maintenance of intermediate products generated by these computations” (Shah & Miyake, 1996, p. 4) This ability to store and manipulate information in parallel is a crucial attribute of the human cognitive system in that it allows for the relatively unhampered functioning of many complex cognitive activities. Naturally, the comprehension and production of language are two of these activities, and the interaction of working memory and language is the focus of this study.

The goals of this chapter are to (1) outline the two most influential working memory models (i.e., the multi-component model by Baddeley and colleagues and the embedded-processes model by Cowan and colleagues; chapter 3.1), (2) link the capacity limitations of working memory to basal cognitive functions like information processing and attention (chapter 3.2), (3) provide an overview of how working memory and language processing have been linked in the literature (chapter 3.3), and finally (4) review the few studies that have explicitly tackled the question to what extent speech production and working memory interact (chapter 3.4).

3.1. Models of Working Memory

Ever since the concept of working memory as an entity distinct from both simple short-term memory and long-term memory has emerged in the field of experimental psychology, there have been uncounted attempts to tackle its functions and characteristics through behavioural studies conducted with healthy as well as brain-damaged participants, neuroimaging and computational modelling. The overview given here is by no means exhaustive, but only provides a general overview of the two most prominent models (for a more detailed overview, see Miyake & Shah, 1999).
3.1.1. Baddeley’s Multi-Component Model of Working Memory

The multi-component model of working memory put forward by Baddeley and colleagues (e.g., Baddeley, 1986; Baddeley & Hitch, 1974; Baddeley & Logie, 1999) has been one of the most influential working memory models, comprising a vast amount of research conducted both with healthy and brain-damaged participants in the past four decades. The very basic assumption of the model is that it consists of a supervisory system termed the central executive, which coordinates the operations carried out in two specialised storage systems (often referred to as ‘slave systems’), the phonological loop and the visuospatial sketchpad. More recently, the episodic buffer as a third specialized component has been added.

![Diagram of the multi-component model of working memory](image)

*Figure 2.* An illustration of the multi-component model adapted from Baddeley (2003).

*The central executive.* Baddeley (1986, p. 5) described the central executive as “almost certainly the most important component in terms of its general impact on cognition.” However, a detailed description of its functions and mechanisms have been rather sparse compared to the research and subsequent findings associated with the slave systems. In fact, Baddeley only dedicated a short chapter of his 1986 monograph to this component, in which he stated that much of his conception of the central executive has been influenced by the SAS model put forward by Norman and Shallice (1980, cited by Baddeley, 1986) only a couple of years earlier. This model was initially set out to provide an explanatory framework for attentional control in cognition, but proved to be rather applicable to the working memory concept by Baddeley as well. It essentially consists of two layers, a horizontal one which reels off over-
learnt actions in a rather automatic fashion, and a horizontal one coined the supervisory attentional system (hence SAS) which operates to avoid conflict in situations that require adaptive, cognitively flexible behaviour. Analogously, Baddeley reasoned that the central executive comes into play whenever non-routine actions need to be coordinated. Located in the prefrontal cortex, it thus monitors the focussing and switching of attention, but also controls and coordinates the two slave systems and mentally manipulates the materials kept therein.

Crucially, the central executive has been linked to control processes only, but not to temporary storage, which is executed by the slave systems. Empirical evidence regarding this hypothesis stems from comparing (1) dual-task performance of healthy and Alzheimer’s disease (AD) patients (e.g., Baddeley, Bressi, Della Sala, Logie, & Spinnler, 1991), as well as (2) general performance of patients suffering from the so-called dysexecutive syndrome, a disease associated with frontal lobe damage. This clinical condition causes a lack of flexibility as well as perseverations of already established schemata, and patients demonstrate difficulty in initiating tasks, although their performance is less impaired when they are given action-relevant cues. In terms of language production, the syndrome can express itself in the form of dynamic aphasia, that is, the inability to initiate speech, leading to virtual muteness (Baddeley, 1986).

Overall, the central executive (as well as the SAS as an indirect predecessor) acts as a monitoring system that comes into play whenever non-routine actions need to be planned, modified, or controlled.

The phonological loop. The phonological loop is the component responsible for temporary storage of verbal materials. It is fractionated into a passive phonological store (termed the inner ear) where material is represented in the form of phonological codes that are subject to decay, and active rehearsal processes (the inner voice) which constantly refresh the decaying material via subvocalisation. This differentiation has been repeatedly supported by two robust key phenomena, namely the phonological similarity effect and the word length effect.

The phonological similarity effect (e.g., Conrad, 1964; Conrad & Hull, 1964; Baddeley, 1966b) posits that to-be-remembered items that are phonologically similar (e.g., the letters B, V, T, and G) are harder to retain in a given serial order than phonologically dissimilar items, and this has been shown both for letters, words, and non-words. This finding has been interpreted in terms of an articulatory rehearsal process of verbal materials, regardless of whether they are presented visually or auditorily. Crucially, phonologically similar items led to a mas-
sively larger performance decrement in serial recall compared to semantically similar items (9.6% vs. 65%; see Baddeley, 1966a; Baddeley, 1966b).

The word length effect (Baddeley, Thomson, & Buchanan, 1975) demonstrates that shorter words are better recalled compared to longer words, and this finding even holds when two sets of disyllabic words are used. When contrasting words with short vowel durations (e.g., bishop) and long vowel durations (e.g., harpoon), recall was consistently better for the first group, ruling out that the sheer amount of syllables occupying a limited-capacity number of memory slots had caused the word-length effect. Baddeley et al. (1975) interpreted this in terms of decay of verbal material; memory traces of shorter words can be refreshed more often and are thus less susceptible to forgetting. In addition, Ellis and Hennelley (1980) showed that Welsh native speakers consistently performed worse on digit span tests compared to Americans because uttering numbers in Welsh takes remarkably longer than in English. Memory performance, then, cannot be interpreted as worse per se, but one has to take into account the specific characteristics in which the participants are tested. Articulatory rehearsal of longer words takes longer, which in turn reduces the amount of items that can be memorised using such a rehearsal process. Activity of the phonological loop has been localised in the left supra-marginal gyrus, both in healthy and brain-damaged persons (cf. Baddeley & Logie, 1999).

The visuospatial sketchpad. Like the phonological loop, the visuospatial sketchpad has been fractionated into two separate entities (e.g., Klauer & Zhao, 2004; Logie & Pearson, 1997; Logie, 2011). The visual cache (also termed inner eye) stores visual information (i.e., colour, shape) and is tightly linked to the visual perceptual system. Although its capacity is limited and stored materials decay within about two seconds, stimuli containing multiple feature identities (e.g., a red square) can be retained just as well as individual items (e.g., a square), allowing for the storage of objects composed of up to four different features (Vogel, Woodman, & Luck, 2001). The inner scribe stores spatial information (i.e., movement, position) and is involved in the planning and execution of movement. Both components enable the rehearsal of stored material to circumvent decay.

This fractionation has been well demonstrated by a developmental study by Logie and Pearson (1997). They tested school children sampled from three different age groups (on average 5-9, 8-10, and 11-12 years old) on their performance on both recognition and recall in a visual (memorising random patterns of coloured squares) and a spatial task (Corsi blocks: memorising a presented sequence of blocks, cf. Milner, 1971). A clear dissociation in performance between visual and spatial tasks was reported as a function of age. That is, memory for
patterns was significantly better than for block sequences in the two older age groups whereas there was no difference between the two tasks for the younger group. The authors interpreted this finding as being indicative of a differential development of visual and spatial abilities, with the latter evolving significantly slower. This provides evidence that the two memory processes are controlled by different cognitive systems.

The episodic buffer. This component has been added to the model many years after its first instantiation to account for findings that were not compatible with the original fractionation of working memory into a central executive and the two slave systems. For example, some amnesic patients show normal immediate recall of prose passages, suggesting a control centre that, unlike the central executive, is capable of some extra storage and interweaves the already postulated components. Consequently, Baddeley (2000) defined the episodic buffer as a component that integrates multimodal information both from the slave systems and episodic long-term memory and is supervised by the central executive. Most importantly, this multidimensionality allows for the binding of information from different sources into integrated chunks (Baddeley, Allen, & Hitch, 2011), thus providing a useful mediator between the attention-focusing central executive and the two domain-specific storage entities.

3.1.2. Cowan’s Embedded-Processes Model

In contrast to the modular nature of Baddeley’s multi-component model just described, the embedded-processes model put forward by Cowan (1988, 1995) can be considered a more unitary model that does not distinguish between distinct, modality-specific buffers. Instead, it assumes that input information, despite differing in representational codes, is processed in a similar way, with similar items causing greater interference. Cowan thus conceives working memory more in terms of its functions than in terms of its modalities and emphasises the arbitrariness of specifying a fixed set of code categories (e.g., phonological and visuospatial features as specified in Baddeley’s model). Instead, he encourages to regard input modalities as integrating features from different domains (e.g., verbal, visual, tactile), much like the episodic buffer in the multi-component model.
Figure 3. The embedded-processes model, adapted from Cowan (1988, 1999).

Within his framework, Cowan defines working memory as “cognitive processes that retain information in an unusually accessible state, suitable for carrying out any task with a mental component” (Cowan, 1999, p. 62). The emphasis on accessibility highlights the most crucial assumption of the model: Working memory is not viewed as a discrete memory system but as constituting an activated portion of long-term memory as well as the part therein that is currently in the focus of attention. Working memory, then, is the material that is either activated automatically or consciously, and Cowan considers the two concepts of attention and awareness to be symbiotic: Attention is defined as an enhancement, or prioritisation of relevant material, and awareness as an umbrella term for voluntary, controlled processes that require cognitive resources. Material that is in the current focus of attention activates and maintains memory representations while irrelevant stimuli are inhibited. This control of working memory is implemented by a central executive that operates according to an *a priori* determined set of rules and, in line with Baddeley, only contains processing, but not storage abilities. Cowan considers it to be capacity-limited, comprising approximately four chunks (i.e., items of bundled information, cf. Miller, 1956), while he rejects a general capacity limit of
Capacity Limitations in Working Memory

3.2. Capacity Limitations in Working Memory

In a very comprehensive review, Cowan (2001) listed numerous experimental evidence converging on one finding, namely that the capacity limit of working memory is restricted to about four items or chunks. He proposes that capacity limitations occur in the case of an information overload or when long-term memory recoding or rehearsal is suppressed. Critically, his embedded-processes model assumes that only the focus of attention is subject to capacity limitations whereas the storage elements are not. In other words, this model assumes that the only limiting factor in processes requiring working memory is the extent to which relevant information can be kept in a heightened attentional activation state, similar to the spotlight of attention postulated for the visual domain (Posner, Snyder, & Davidson, 1980).

Many studies have shown a relationship between working memory capacity and specific attentional performance measures, with participants with a high working memory span executing attentional tasks more efficiently than participants with a low working memory span. For example, Conway, Cowan, and Bunting (2001) found that 65% of their low-span partic-

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3 However, Cowan (2001) acknowledges that materials which are in an enhanced activation state but have not yet crossed the threshold to enter the focus of attention “are limited by time and susceptibility to interference” (p. 91).

4 The conception of the famous “magical number 7 ± 2” introduced by Miller (1956), which defined the storage capacity limit as between 5 and 9 chunks, is largely outdated and has been questioned by researchers already in the 1970s (e.g., Broadbent, 1975; Henderson, 1972).
pants showed the cocktail party effect, i.e., they perceived the presentation of their own name while they were instructed to focus on another auditory stream, as opposed to only 20% of their high-span participants. Crucially, when not controlling for individual differences in working memory capacity, as was the case in the original study by Moray (1959), it was found that 33% of the participants could identify their name, which lends fair support to the hypothesis that the efficiency of attentional control is mediated by working memory capacity.

Furthermore, the ability to suppress competing attention-capturing information in the anti-saccade task has been related to higher working memory capacity. In this task, participants are asked to shift their gaze to the opposite direction of a presented cue as soon as possible. For example, if they perceive a dot to the left of a fixation point, their task is to look to the right; looking to the left would be considered an erroneous saccade. The anti-saccade task was originally developed to measure the amount to which patients with frontal lobe damage are able to inhibit task-irrelevant information, thus providing an estimate for cognitive control in the presence of neuropsychological damage (Guittton, Buchtel, & Douglas, 1985). Roberts, Hager, and Heron (1994) showed that this reduction in inhibition as reflected by more erroneous saccades can be mimicked in neurologically healthy participants under a high working memory load. Moreover, Kane, Bleckley, Conway, and Engle (2001) showed that working memory capacity was correlated to the rate of erroneous saccades in this task. That is, low-span participants were slower and made more mistakes in an anti-saccade task compared to high-span participants, whereas there was no difference between these groups in pro-saccade task performance (although switch costs as measured by errors made when changing between tasks were higher for low-span participants). This suggests that automatic orienting is not mediated by working memory capacity while the controlled orienting of attention—and presumably inhibiting distractors as an accompanying effect—is susceptible to limits of working memory.

Similarly, alongside smaller Stroop interference effects (i.e., the ability to suppress task-irrelevant information when naming the colour of a printed word, e.g., the word “blue” printed in red, cf. Stroop, 1935) for high-span participants, Shipstead and Broadway (2012) found a differential influence of ‘warning’ participants of a post-experimental recognition memory test. In this study, neutral words were embedded between experimental trials in a classic Stroop task. Half of the participants were informed that they had to recognise these words after the experiment while the other half was not given any information and had to perform the memory test without being warned. The results showed that high-span participants who were not informed about the memory test performed worse on the recognition test.
than high-span participants who had been warned. Low-span participants, in contrast, were
not affected by the warning. The authors concluded that an increased working memory capa-
city enables participants to suppress irrelevant information (as reflected by less Stroop inter-
ference) and to flexibly deploy attentional resources. In contrast, a lower working memory
capacity leads to easier distractibility and a decreased ability to both inhibit irrelevant infor-
mation and differentiate efficiently between relevant and irrelevant material.

In sum, it has been shown that working memory is a capacity-limited system and that
the individual variation thereof affects performance in cognitive tasks. Specifically, a higher
working memory capacity appears to be related to more efficient attentional focussing and
distractor inhibition. Speech production constantly requires these abilities, thus it is feasible
that working memory plays a significant role therein. The following chapter summarises the
prevailing evidence on the relationship between working memory and language.

3.3. Working Memory and Language Processing

The interaction of working memory and language has been investigated largely in the
field of language comprehension, but remarkably less so in the domain of language produc-
tion. By now, the consensus is that high working memory capacity is correlated with high
comprehension abilities of oral and written speech (Daneman & Carpenter, 1980; Daneman &
Merikle, 1996). During comprehension, the central executive is thought to activate represe-
ntations of both single words and complex schemata in long-term memory. Comprehension
performance is thus defined as the combined ability to both store a high amount of repre-
sentations and activate and integrate them for further processing. The claim that it takes this
combined effort for efficient comprehension is supported by findings both from healthy indi-
viduals and patients with a short-term memory deficit (e.g., Caplan & Waters, 1999; Daneman

The task that is frequently used to assess working memory capacity (as opposed to
short-term memory capacity which solely measures passive storage abilities) is the reading-
span task introduced by Daneman and Carpenter (1980). In this task, participants have to
read aloud or perform true/false judgments on a set of unrelated sentences and afterwards
recall the last word of the respective sentences, with the amount of words correctly recalled
being taken as an estimate of the verbal working memory span. The authors found that this
span varied from two to five recalled words in college students, and that this measure was a
very good predictor of comprehension performance as measured by the Verbal Scholastic Ap-
Working Memory and Language

titude Test (VSAT). It was thus reasoned that working memory, i.e., the storage and manipulation of given material, and language comprehension processes were tightly linked. Specifically, reading and comprehending a sentence not only requires the passive storage of the individual words, but also their integration into a meaningful syntactic, grammatical, and referential structure.

Daneman and Merikle (1996) conducted a meta-analysis which contrasted 77 studies with almost 6,200 participants that had investigated the correlation between verbal working memory, measured by either the reading-span task or an equivalent mathematical operation span task (Turner, 1989), and language comprehension. They found that verbal working memory span was highly correlated with global comprehension and vocabulary knowledge as well as more specific comprehension abilities such as monitoring inconsistencies or abstracting the main theme of a text ($r = .41$ and .52, respectively). In contrast, storage-only measures (digit span, letter span) predicted comprehension abilities less well ($r = .28$ and .40, respectively), strengthening the assumption that language comprehension depends on a system that employs both storage and processing. Importantly, the latter effect size ($r = .40$ for the relationship between verbal storage-only and specific comprehension measures) dropped to $r = .18$ when the authors controlled for the varying age of the participants, which lends more fine-grained support to the idea that simple span measures are not predictive of language comprehension abilities.

Given the similarities between language comprehension and production (e.g., Pickering & Garrod, 2007; Pickering & Garrod, 2013), it is reasonable to assume that the same or similar cognitive systems related to working memory are employed when preparing an utterance. In fact, Acheson and MacDonald (2009) provide an overview showing that a number of verbal working memory phenomena can be incorporated within a production-based account (see also Ellis, 1980). That is, errors that occur during serial recall in verbal working memory tasks are often paralleled in normal speech errors, which led the authors to suggest that “the same mechanisms responsible for serial ordering in language production underlie these processes in verbal working memory” (p. 50).

Assuming that an additional load drains cognitive resources which are normally used for the sentence production task in a no-load condition, one would generally expect an impact of a secondary task on the planning processes. A recent study by Boiteau, Malone, Peters, and Almor (2014) addressed this question. Participants were asked to converse with a partner (thus incorporating both comprehension and production aspects) while at the same time continuously tracking a moving dot. The difficulty of this visual motor tracking task was varied.
throughout the experiment by changing the speed at which the dot was moving. Overall, the authors found that tracking performance as measured by the distance to the moving dot decreased with increasing tracking difficulty. Specifically, Boiteau et al. split each trial into different time phases associated with the conversational task (that is, control, talk, listen, prepare, overlap, pause) and located the largest performance decrement during production, and more specifically in the planning and monitoring phases. Furthermore, performance on the tracking task decreased as a function of task difficulty, i.e., the speed at which the to-be-tracked point moved. This suggests that in a dual-task condition, both tasks appear to draw resources from a central capacity system which allocates the available resources in a bipartite fashion. However, this study has only investigated the influence of a concurrent visual load. According to Wickens (2008), interference should be even larger when a verbal load is imposed because both tasks would overlap to a greater degree.

3.4. Advance Planning under Cognitive Load

The literature on the relationship between working memory and language production tasks is sparse, and to my knowledge only a handful of studies have directly addressed this question. Those that have examined advance planning in sentence production at the semantic-syntactic level so far have provided inconsistent result with regard to the flexibility of the planning scope under different cognitive load conditions.

Power (1985) presented participants semantically related or unrelated noun pairs (e.g., “uncle—aunt” or “baby—dust”) and asked them to freely formulate sentences containing both words (e.g., “Every Sunday, I visit my aunt and uncle” or “The baby is eating the dust”). When participants concurrently had to memorise three or six digits for subsequent free recall, the syntactic complexity of the sentences decreased compared to a no-load condition. That is, the presence of a verbal load led speakers to plan fewer words which can be interpreted as a reduction of the grammatical planning scope. Interestingly, overall naming latencies also decreased in the verbal load condition, but this is readily explained by the fact that the sentences were shorter overall compared to the no-load condition.

In contrast, Wagner et al. (2010) observed that grammatical advance planning is reduced if it is preceded by a conceptual decision task determining the utterance format of the target sentence, but not when participants have to maintain a concurrent verbal load. Participants had to describe multi-object displays (e.g., a frog and a mug presented next to each other and displayed in different colours, resulting in a sentence of the format “the frog is next
to the mug") while ignoring auditory distractors semantically related or unrelated to the first or second noun phrase. In a first experiment, the authors showed that both the first and the second noun phrase were activated on the abstract-lexical level, as indexed by semantic interference effects obtained from related distractors. Additionally, two load conditions, a verbal and a conceptual one, were tested. In the verbal load condition, participants had to memorise five digits or adjectives prior to each trial and perform a recognition task after having produced the sentence. The conceptual load condition introduced a size decision task prior to the sentence production task; depending on the natural size of a presented object, participants had to produce the sentences either with or without prenominal colour adjectives. The verbal load did not reduce the planning scope; distractors semantically related to the first or second noun phrase still yielded semantic interference effects compared to an unrelated condition. In contrast, when flexibly adjusting the utterance format in the conceptual load condition, a semantic interference effect was obtained for the first noun phrase only, i.e., the planning scope was reduced and did not span over the entire utterance any more. However, it is not entirely clear whether this span reduction can be attributed to the cognitive load imposed by the conceptual decision task. Instead, it might be attributed more to the task demands, i.e., having to switch between utterance formats on a trial-by-trial basis.

At this point, it is important to note that the discrepancy with respect to the effect of a verbal load (three or six digits in Power’s study and five digits or five adjectives in Wagner et al.’s study, respectively) might have arisen due to the pre-experimental instructions. While Power, following the rationale of the experiments by Baddeley and Hitch (1974), requested participants to focus on correct memory recall, possibly at the expense of language performance, Wagner et al. did not place any specific priority on one task over the other. This difference might have promoted distinct strategies of the participants, rendering the conclusions of the two studies with respect to a verbal load only partially comparable.

Another study by Slevc (2011) showed that a concurrent verbal load selectively alters syntactic planning processes compared to a no-load or a visuospatial load condition. Participants had to describe pictures containing a subject, a direct object and an indirect object (e.g.,

Note that a comparable reduction of the phonological planning scope was obtained in a study by Oppermann, Jescheniak, and Schriefers (2010, Experiment 4). When participants had to finish an auditorily presented lead-in sentence, which resulted in different syntactic structures depending on its respective nature (either SOV or VSO), the object-related phonological interference effect persisted when the object appeared in utterance-middle position (i.e., SOV) but disappeared when the object appeared in utterance-final position (i.e., VSO).
a pirate giving a book to a monk), and it was their free choice whether to use a prepositional dative phrase (e.g., “the pirate gave the book to the monk”) or a double-object phrase (e.g., “the pirate gave the monk the book”). The subject of the sentence was always given in the form of a post-trial question posed by the experimenter (e.g., “What’s going on with the pirate?”). In Experiment 1, accessibility, i.e., the tendency to produce easier-to-retrieve elements earlier in the sentence, was manipulated by additionally presenting either the goal (i.e., book) or the theme (i.e., monk) on a computer screen. Furthermore, to assess the involvement of working memory in the planning processes, on half of the trials participants had to memorise two words during the sentence production task and recall them afterwards. Slevc found that in the no-load condition, participants displayed a clear accessibility effect, that is, they chose a syntactic structure that placed the already visually presented item in an early position. However, this effect disappeared in the verbal load condition, leading Slevc to argue that syntactic planning processes and a verbal working memory load share the same resource. In Experiment 2, the accessibility of one object was increased by including it in the pre-trial question (e.g., “What’s going on with the pirate and the monk?” or “What’s going on with the pirate and the book?”) leading to the same result pattern (i.e., given material was produced earlier in the sentence without a concurrent load but not when under a verbal load). In Experiment 3, Slevc directly contrasted a verbal and an equally difficult visuospatial load (memorising two dots in a 5 × 5 grid). Again, the given object was produced more often in an early position under the visuospatial load while this ordering effect was significantly reduced in the verbal load condition. Overall, these results indicate that verbal working memory and syntactic planning processes are subject to similarity-based interference while a concurrent visuospatial load appears to be handled relatively independently from speech planning. It is important to note, however, that both the processing level and the lexical processes manipulated differed from those investigated by Wagner et al. (2010): While the latter explored the multiple retrieval of abstract-lexical elements in grammatical advance planning, the focus of Slevc (2011) was the choice of syntactic structures.

In a recent study by Martin, Yan, & Schnur (2014), participants described multi-object displays while concurrently performing a phonological, semantic or visuospatial working memory task. The complexity of the initial noun phrase was varied depending on the visual stimulus, i.e., sentences could begin with a simple noun phrase (e.g., “the dog moves above the kite and the house”) or a complex noun phrase (e.g., “the dog and the kite move above the house”). Naming latencies were longer for sentences starting with a complex noun phrase, suggesting that both elements of this noun phrase had been planned ahead on a lexical level.
before articulation. However, this complexity effect was not affected by any of the concurrent working memory tasks, speaking for a robust planning scope on the semantic-syntactic level.

Taken together, the extant studies suggest an influence of an additional cognitive load on speech planning, although the mechanisms of this influence are not fully consistent (i.e., some studies point toward a susceptibility to a concurrent verbal working memory load while others do not find such an effect). Moreover, the studies cannot be directly mapped to the phonological planning processes, as semantic-syntactic planning as the first of the two processing levels might reflect a broader planning scope whereas phonological planning under load may be reduced to smaller units. Furthermore, the two studies that have contrasted the influence of two comparably difficult working memory tasks in the visuospatial and verbal modality, respectively, found conflicting results, with Slevc (2011) reporting an influence of verbal load on planning while Martin et al. (2014) did not. Power (1985) exclusively investigated different verbal loads, and Wagner et al. (2010) contrasted a purely verbal with a conceptual decision task, which is unlikely to tax any working memory at all. By directly testing the influence of a visuospatial and verbal load on both the abstract-lexical and the phonological planning scope in sentence production, the present experiments intend to shed some new light on the mechanisms connecting language production and working memory.
4. Own Experiments

Overview of the Experiments

The nine experiments presented in this thesis addressed the question to what extent different concurrently performed cognitive tasks affect the way speakers plan their utterances. More specifically, they investigated (1) whether a speaker’s scope of advance sentence planning at both the abstract-lexical and the phonological level is affected by a concurrently performed working memory task, and (2) whether this potential decrement is affected in a differential way, depending on the nature of the secondary task (verbal vs. visuospatial). By designing the experimental procedures as parallel as possible, direct comparisons between manipulating both the processing levels of advance planning and the modality of the working memory task can be drawn. The obtained results, then, shall provide new insights about the degree of flexibility in speech planning as well as the kinds of resources recruited at these respective processing levels.

In all experiments (except for Experiment 4, which required inflected verb production), participants produced subject-verb-object (SVO) sentences (e.g., “the monk read the book”) in response to picture stimuli while ignoring auditorily presented distractor words. These distractors were either semantically related, or phonologically related, or unrelated to the subject or to the object of the utterance. Comparing naming latencies in the related and the unrelated distractor condition then allowed to assess whether subject and object noun were activated at the abstract-lexical or phonological level prior to speech onset.

Experiments 1–4 investigated advance planning at the abstract-lexical level: Experiment 1 served as the reference experiment, as it determined the advance planning scope at the abstract-lexical level without a concurrent working memory load. Thus, it tested the suitability of the present materials and utterance format to detect semantic interference effects for elements beyond the initial noun phrase. Experiments 2 and 3 explored whether this established scope would be affected in the presence of a concurrent visuospatial working memory load (Experiment 2) or a concurrent verbal working memory load (Experiment 3). Finally, Experiment 4 served as a control experiment to rule out the possibility that the obtained distractor effects had come about merely because the sentence triggered by the visual input automatically activated all elements of the sentence in the form of a memory chunk.
A largely parallel set of experiments (Experiments 5–9) investigated advance planning at the phonological level under corresponding working memory load conditions. That is, Experiment 5 established the phonological advance planning scope without a concurrent working memory load, while Experiments 6 and 7 (analogous to Experiments 2 and 3) introduced a visuospatial and verbal working memory load, respectively, to test for a potential flexibility of this planning scope. Experiment 8 was identical to Experiment 7, with the only difference that instead of SOAs 150 and 300 ms it tested SOAs 300 and 450 ms. Finally, Experiment 9 employed a within-participants design to directly contrast a no-load with a verbal load condition.

Using a dual-task paradigm allows one to investigate two dependent variables, that is, an effect on the speech production task as well as an effect on the working memory task. Overall, a performance decline in the load conditions compared to the no-load conditions is expected both for the speech production task and the working memory task. That is, both naming latencies and error rates should increase in the presence of a cognitive load. Specifically, in line with previous research on dual-task costs, this decline should be larger in the more similar dual-task situation (i.e., verbal working memory with sentence production) than in the less similar dual-task situation (i.e., visuospatial working memory with sentence production, cf. Baddeley, 1986; Baddeley & Hitch, 1974; Baddeley & Logie, 1999; Cowan, 1995, Cowan, 2005; Wickens, 2008). As explained throughout chapter 3, a greater overlap in the materials causes more interference compared to a lesser degree of overlap; thus, performance in a verbal working memory task (which requires the maintenance of verbal information) should be more effortful when performed concurrently with the sentence production task than maintaining visuospatial information in working memory. Likewise, performance in the sentence production task should be slower and/or more error-prone in the presence of the verbal than the visuospatial working memory task.

In terms of the question to what extent advance planning is affected by a concurrent working memory task, the rationale is as follows: If a particular (semantic or phonological) distractor effect obtained in the no-load condition disappears in the presence of a concurrent visuospatial or verbal load, this is taken as an index for a reduction of the planning scope at the respective processing level (abstract-lexical vs. word form). That is, provided that in the no-load condition (Experiments 1 and 5), semantic and phonological distractor effects are observed for the object, i.e., the utterance-final element, any failure to obtain a comparable effect when participants have to concurrently perform a working memory task can be interpreted as direct evidence that advance planning at the respective processing level as well as the respective working memory task are subserved by a common cognitive system. Analo-
gously, if the object-related distractor effect persists, this would provide evidence that the advance planning processes at stake and the respective working memory task operate independent of each other.
Experiment 1: Abstract-Lexical Advance Planning Without Cognitive Load

Experiment 1 sought to establish the size of the abstract-lexical planning scope in a simple sentence production task in the absence of a concurrent cognitive load task. After having learnt the material set, participants saw the agent of a scene and had to produce the appropriate sentence while ignoring auditory distractors semantically related or unrelated to the subject or object of the utterance. In addition, participants were tested on their working memory performance on both visuospatial and verbal levels to control for equally distributed participants groups across experiments. In light of earlier findings regarding abstract-lexical advance planning in sentence production (e.g., Meyer, 1996; Wagner et al., 2010), semantic interference from both subject- and object-related distractors was expected, indicating that both the initial and final element of the utterance were planned on the abstract-lexical level prior to speech onset.

Methods

Participants

32 native speakers of German (28 female; mean age = 23.6, SD = 3.0, range = 18-30), most of them students from the University of Leipzig, took part in the experiment. In this and all experiments reported below, participants were paid € 8 or received course credit. None of them had any known hearing deficit, and they had normal or corrected-to-normal vision. Participants with less than eight out of possible 20 data points in any of the eight experimental conditions were replaced (one participant), and this exclusion criterion was applied to the remaining experiments as well. No participant took part in more than one of the experiments reported in this work.

Because the experiments were concerned with the effects of a concurrent working memory load on sentence planning, each participant’s visuospatial and verbal working memory capacity was assessed at the beginning of the experimental session with the Wechsler Memory Scale subtests ‘block span backwards’ and ‘digit span backwards’ (WMS-R; Härting et al., 2000) to check for the comparability of participant groups across experiments. The results are found in Table 1. To anticipate, participant samples across experiments did not differ substantially in their performance, for backward block span task, $F(8,279) = 1.32$, $p = .23$, for backward digit span task, $F(8,279) = 1.14$, $p = .33$. 
Table 1

Mean, standard deviations and range of working memory capacity scores (visuospatial = WMS block span; verbal = WMS digit span) for all experiments.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>WMS block span</th>
<th>WMS digit span</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Abstract-lexical advance planning (Experiments 1 – 4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>9.2</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>9.5</td>
<td>1.4</td>
</tr>
<tr>
<td>3</td>
<td>8.7</td>
<td>1.9</td>
</tr>
<tr>
<td>4</td>
<td>9.2</td>
<td>1.5</td>
</tr>
</tbody>
</table>

| Phonological advance planning (Experiments 5 – 9) |     |      |       |     |      |       |
| 5          | 9.0 | 1.8 | 5-12   | 7.3 | 1.9 | 4-12   |
| 6          | 8.8 | 1.7 | 5-12   | 8.2 | 2.2 | 5-12   |
| 7          | 8.4 | 1.6 | 6-12   | 8.3 | 1.8 | 5-12   |
| 8          | 9.3 | 1.9 | 6-12   | 7.4 | 1.6 | 4-11   |
| 9          | 9.3 | 2.0 | 4-12   | 8.2 | 1.8 | 5-12   |

**Materials**

For the sentence production task, twenty line drawings of simple scenes adapted from Oppermann et al. (2010) were used. Each line drawing depicted a subject performing a simple action on or with an object, e.g., a monk reading a book, and was about 15 × 15 cm in size. During the initial learning phase, the complete subject-verb-object scene was presented, and during the test phase, only the subject was presented to avoid the automatic activation of the context object solely upon visual presentation (cf. Oppermann, Jescheniak, & Schriefers, 2008). For each subject and object, a semantically related distractor was selected (e.g., distractor “Priester” [priest] for the subject “Mönch” [monk] or distractor “Zeitung” [newspaper] for the object “Buch” [book]). Unrelated control conditions were created by reassigning the distractors to different subjects (for the subject-related distractors) or objects (for the object-related distractors); see Appendix A for a complete list of the materials. To rule out the contamination of semantic effects by gender congruency mechanisms (e.g., Schriefers, 1993),
gender congruency was controlled for during the assignment of the distractors, such that both the related and the unrelated condition of a given sentence were either gender-congruent or incongruent to the target.

The auditory distractors were spoken by a female native speaker of German and varied in duration from 463 ms to 979 ms with an average of 681 ms ($SD = 123$ ms). All auditory materials were digitized at a sampling rate of 48 kHz for presentation during the experiment. An additional set of five scenes with corresponding distractors was selected for the construction of practice and warm-up trials.

For the working memory tasks, a dot-in-matrix task for the visuospatial modality and a digit string task for the verbal modality were used. To allow for comparable task difficulty, a pre-test with 12 participants contrasted different amounts of dots and digits, respectively. Comparable task difficulty in terms of error rates was found for four dots and five digits (5.25 % for visuospatial task, 5.33 % for verbal task, $t(11) < 1$). Consequently, the visuospatial working memory task consisted of a $5 \times 5$ matrix, about $15 \times 15$ cm in size, and four identical dots presented at random positions within the matrix, with the constraint that dots did not appear within the same row or column. There were 80 different patterns and 40 corresponding “incorrect” probes in which only one dot deviated from its original position by one field, resulting in 40 correct trials and 40 incorrect trials. Analogously, the verbal working memory task consisted of 80 random five-digit strings, half of which received an incorrect probe in which a single digit was either replaced with another one or the series of the string was swapped between two digits. The position of those digit changes (first to fifth) was roughly balanced across the trials. For both working memory tasks, five additional items were created that served as practice trials.

**Design**

The experimental design included the crossed variables primed element (subject vs. object), relatedness (semantically related vs. unrelated), and SOA (0 ms vs. 150 ms). The two SOAs were used because experiments on phonological advance planning using similar materials have shown reliable phonological effects at SOAs 150 and 300 ms for the subject and object, respectively (see Oppermann et al., 2010, Experiment 1). Given that abstract-lexical precedes phonological advance planning it was assumed that moving the SOAs one step backward might increase the probability of tapping into the abstract-lexical planning processes.

All variables were tested within participants and within items. Each item was presented each of the resulting eight conditions once, yielding a total of 160 experimental trials per par-
participant. SOA was blocked, and the sequences of SOA blocks were counterbalanced across participants. The sequence of distractor conditions within an SOA block was counterbalanced using a sequentially balanced Latin square procedure. The order of the items was pseudo-randomized for the test phase according to the following criteria: (a) repetitions of a picture of a given subject were separated by at least eight intervening trials, (b) repetitions of the same distractor was separated by at least three intervening trials with different distractors, (c) no more than three trials from the same distractor condition were presented in direct succession, and (d) no more than three trials from the same subject gender were presented in direct succession.

**Apparatus**

The visual stimuli were presented on a 19-inch EIZO S1910 computer screen as black line drawings on a light grey background (RGB 244 244 244). Viewing distance was about 60 cm. The presentation of the visual and auditory stimuli and the on-line collection of the data were controlled by the NESU hardware and software (Max-Planck-Institute for Psycholinguistics, Nijmegen, NL). Auditory distractors were presented with Sennheiser HD 280 headphones at a comfortable volume. Speech onset latencies were measured to the closest millisecond with a Sennheiser ME 64 microphone via a voice-key connected to the computer. Speech errors and dysfluencies were coded online by the experimenter. Responses to the working memory tasks were measured via a two-button box.

**Procedure**

Each participant was tested individually. The participant was seated in a dimly lit room, separated from the experimenter by a partition wall. Prior to the actual experiment, each participant’s individual verbal and visuospatial working memory scores were measured using the subtests ‘digit span backwards’ and ‘block span backwards’ of the Wechsler Memory Scale (WMS-R; Härting et al., 2000). Then, participants were instructed in writing that their task would be to describe pictures of simple scenes as fast and as accurately as possible. They were familiarized with the pictures of all subject-verb-object (SVO) scenes in a booklet. Below each scene, the corresponding SVO sentence describing this scene in present tense was printed (e.g., “Der Mönch liest das Buch.” [the monk reads the book]). In a first practice block, each of the subjects was presented in isolation and participants were instructed to describe what this subject had done in the previously learnt scene by producing a simple SVO sentence in past tense (e.g., “der Mönch las das Buch” [the monk read the book]). If participants responded er-
ronerously, they were corrected by the experimenter right away. Then the target disappeared and the next trial was initiated. This practice block was then repeated with a different randomization of the trials and without immediate verbal feedback and followed by two longer practice blocks in which each item was repeated three times each. Next, distractors were introduced in a practice block consisting of 15 trials showing the practice items three times each. Then the working memory task was introduced with a practice block consisting of 15 practice trials. Participants were instructed to memorise a visually presented stimulus (four points in a matrix or five digits, depending on the load modality) and then press the left button if a subsequently presented visual stimulus was identical to the previous one or the right button if it differed from the previous one. This was followed by a longer block consisting of 80 trials. Then another short practice block reintroducing the sentence production task with auditory distractors, as well as two experimental blocks followed. Each SOA block started with five warm-up trials containing practice items. Finally, the second working memory task was administered via a practice and an experimental block. The sequence of load modality (visuospatial first vs. verbal first) was counterbalanced across participants. All other experiments reported here followed the same sequence of events. Figure 4 provides a schematic outline of the experimental sessions. An experimental session lasted approximately one hour and 15 minutes.

An experimental trial of the sentence production task was structured as follows. First, the target picture was presented for 1000 ms at the centre of the computer screen. Auditory distractors were presented either at picture onset (SOA 0 ms) or shortly thereafter (SOA 150 ms), depending on SOA block. Participants produced the target sentence as quickly as possible. Speech onset latencies were measured from the onset of the picture, and participants had to reply within the first 3000 ms following picture presentation. After 700 ms the next trial was initiated.

An experimental trial of the working memory task was structured as follows. At first, a fixation cross appeared for 800 ms at the centre of the screen. Then, the to-be-remembered stimulus was presented for 750 ms, a time period in which visuospatial stimuli cannot be encoded verbally (Shah & Miyake, 1996). After presenting a blank screen for 1500 ms, the stimulus which required the button press, indicated by a question mark below the stimulus, was shown for 2000 ms, which corresponded to the response window. 700 ms after this time window had elapsed, the next trial was initiated.
Results and Discussion

For this and all subsequent experiments, performance data from the working memory tasks (% errors) and performance data from the sentence production task (mean naming latencies and % errors) are reported.

Working Memory Task

Error rates for the visuospatial working memory task and the verbal working memory task, both of which were performed as single tasks only, amounted to 9.2% (SE = 0.9) and 10.3% (SE = 0.9), respectively. These values did not differ, t(31) = 1.17, p = .252, again confirming comparable single-task difficulty as identified in the pre-test.
Sentence Production Task

Observations from the speech production task were discarded from the naming latency analyses whenever (a) a picture had been responded to other than expected; (b) a speech-unrelated sound preceded the target utterance, triggering the voice-key; (c) a dysfluency occurred or an utterance was corrected; (d) a speech onset latency exceeded 3000 ms; (e) an obvious pausing within the utterance occurred, or (f) the voice-key was not triggered due to technical errors. In all of these cases, with the exception of case (f), these observations were included in the error analyses. Observations deviating from a participant’s and an item’s mean by more than two standard deviations were considered as outliers and also discarded from the naming latency analyses without coding an error. According to these criteria, 837 observations (16.0 %) were marked as erroneous and 56 observations (1.1 %) as outliers. Separate analyses were performed for distractors that were related or unrelated to the subject and for distractors that were related or unrelated to the object. Averaged naming latencies were submitted to analyses of variance (ANOVAs). Statistical analyses involved the two fixed variables relatedness (semantically related vs. semantically unrelated) and SOA (0 ms vs. 150 ms). Table 2 displays mean naming latencies and error rates broken down by primed element (subject vs. object), SOA, and relatedness.

Effects from subject-related distractors. For naming latencies, there was a main effect of relatedness, indicating longer naming latencies from subject-related distractors compared to unrelated distractors, $F_1(1,31) = 15.86$, $p < .001$, $\eta^2_G = .011$, $F_2(1,19) = 6.39$, $p < .05$, $\eta^2_G = .055$. Although numerically the effects were larger at SOA 0 ms, the interaction of relatedness and SOA was only marginally significant in the analysis by participants and not significant in the analysis by items, $F_1(1,31) = 3.37$, $p = .076$, $\eta^2_G = .001$, $F_2(1,19) = 1.25$, $p = .278$, $\eta^2_G = .006$.

In the analysis of error rates, there was a main effect of relatedness, indicating higher error rates in the related compared to the unrelated condition, $F_1(1,31) = 4.17$, $p = .050$, $\eta^2_G = .014$, $F_2(1,19) = 4.91$, $p < .05$, $\eta^2_G = .033$. None of the other effects reached significance, all $ps > .190$.

Effects from object-related distractors. For naming latencies, there was a main effect of relatedness, indicating longer naming latencies in the related condition, $F_1(1,31) = 28.20$, $p < .001$, $\eta^2_G = .020$, $F_2(1,19) = 6.19$, $p < .05$, $\eta^2_G = .090$. The main effect of SOA was not reliable in the analysis by participants and only marginally significant in the analysis by items, $F_1 < 1$, $F_2(1,19) = 3.67$, $p = .070$, $\eta^2_G = .015$. 
In the analysis of error rates, there was a main effect of relatedness, indicating higher error rates from object-related compared to object-unrelated distractors, $F_1(1,31) = 9.85, p < .01, \eta^2_G = .038, F_2(1,19) = 5.61, p < .05, \eta^2_G = .082$. As for the naming latencies, there was a trend for a main effect of SOA which was not significant in the analysis by participants and only approached significance in the analysis by items, $F_1(1,31) = 1.75, p = .196, \eta^2_G = .012, F_2(1,19) = 3.26, p = .087, \eta^2_G = .027$. There were no reliable interactions, $Fs < 1$.

Overall, the first experiment replicated the pattern obtained in previous picture-word interference studies on abstract-lexical advance planning: Distractors semantically related to the primed element interfered with the naming latencies, and this held for both the subject (i.e., the utterance-initial element) and the object (i.e., the utterance-final element). From this it follows that in the absence of a concurrent working memory load, the entire utterance was planned ahead on the abstract-lexical level prior to speech onset. Considering these semantic interference effects to be the baseline effects for the given material, it was next investigated whether this planning scope might be modulated by a concurrent visuospatial or verbal working memory load.
Table 2

Mean naming latencies (in ms) and error rates (in %) broken down by SOA, primed element, and relatedness for Experiment 1.

<table>
<thead>
<tr>
<th>SOA</th>
<th>0 ms M</th>
<th>0 ms E%</th>
<th>150 ms M</th>
<th>150 ms E%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject-related</td>
<td>1062 (42)</td>
<td>18.6 (2.1)</td>
<td>1015 (43)</td>
<td>15.5 (2.2)</td>
</tr>
<tr>
<td>Subject-unrelated</td>
<td>993 (39)</td>
<td>14.4 (1.8)</td>
<td>983 (48)</td>
<td>14.5 (1.5)</td>
</tr>
<tr>
<td>Difference</td>
<td>68***/* (16)</td>
<td>4.2†/* (2.2)</td>
<td>32*/ns (16)</td>
<td>0.9 (1.6)</td>
</tr>
<tr>
<td>Object-related</td>
<td>1035 (44)</td>
<td>18.1 (2.1)</td>
<td>1009 (42)</td>
<td>20.3 (2.6)</td>
</tr>
<tr>
<td>Object-unrelated</td>
<td>964 (35)</td>
<td>13.3 (1.4)</td>
<td>951 (37)</td>
<td>16.1 (1.9)</td>
</tr>
<tr>
<td>Difference</td>
<td>71***/† (17)</td>
<td>4.8*/* (2.0)</td>
<td>57*/ns (18)</td>
<td>4.2†/ns (2.4)</td>
</tr>
</tbody>
</table>

Note. Standard error of the mean (SE) is given in brackets. Positive difference scores reflect semantic interference. Superscripts indicate significance: † p < .10 (marginally significant), * p < .05, ** p < .01, *** p < .001.
Experiment 2: Abstract-Lexical Advance Planning Under Visuospatial Load

Experiment 1 showed that the sentence production task yielded the semantic effects associated with a planning scope beyond the first noun phrase. Next, it was investigated whether this planning scope would persist if an additional visuospatial working memory task was imposed. According to the multi-component model (Baddeley, 1986; Baddeley & Hitch, 1974; Baddeley & Logie, 1999), visuospatial and verbal materials are processed in different storage systems, so a concurrent visuospatial working memory task should not alter the pattern of semantic activation beyond the initial noun phrase obtained in Experiment 1. Comparable results have been shown by Slevc (2011) who found no change in accessibility effects in the presence of a dot-in-matrix task (see also Martin et al., 2014).

Regardless of a potential modulation of the planning scope, it can be hypothesised that both speech production and the respective working memory contents are subject to one superordinate system which allocates attentional resources between the tasks (Cowan, 1995, 1999, 2005). Assuming a central capacity limit thereof, this should result in a performance detriment on the speech production task, the working memory task, or both.

Methods

Participants

32 native speakers of German (26 female; mean age = 25.5, SD = 2.9, range = 18-30) participated in exchange for course credit or a monetary reimbursement of 8 €.

Materials, Design, & Apparatus

The materials, design, and apparatus were identical to Experiment 1, with the exception that participants only performed one single-task working memory block presenting the visuospatial working memory task.

Procedure

The procedure was identical to Experiment 1 with the following exceptions. After practising the sentences, all participants first performed the visuospatial working memory task as a single task and then, during the experimental sentence production blocks, as a concurrent task. Participants were instructed to memorise the positions of the dots, then produce the learnt sentence upon target presentation and finally compare the memory probe with the
previously seen one by pressing either the left (i.e., the pattern is identical) or right (i.e., the pattern is different) button of a button box.

One such experimental trial was structured as follows (see Figure 5 for an example trial): A fixation cross appeared for 800 ms at the centre of the screen, then the memorandum was presented for 750 ms. After the presentation of a blank screen for 150 ms, the subject of the respective scene appeared for 1000 ms, and auditory distractors were presented at the same time of or 150 ms after picture onset, depending on SOA block. Again, participants had 3000 ms to respond, starting from picture onset. Finally, the memory probe, indicated by a question mark below the stimulus, appeared for 2000 ms. After 700 ms, the next trial started.

**Results and Discussion**

**Working Memory Task**

Error rates for the visuospatial working memory task substantially increased in the dual-task situation (i.e., when the task was performed concurrently with the sentence production task) compared to the single-task situation, \( t(31) = 16.38, p < .001 \). In the single task, participants made 9.4 % errors (\( SE = 0.8 \)), as opposed to 20.5 % (\( SE = 1.3 \)) in the dual task.
Sentence Production Task

The raw data were treated as in Experiment 1. 970 observations (18.9 %) were marked as erroneous and 52 (1.0 %) as outliers. Separate analyses were performed for distractors that were related or unrelated to the subject or object, respectively. Again, averaged naming latencies were submitted to analyses of variance (ANOVAs) involving the fixed variables relatedness (semantically related vs. unrelated) and SOA (0 ms vs. 150 ms). Table 3 displays mean naming latencies and error rates broken down by SOA, primed element, and relatedness.

Effects from subject-related distractors. For naming latencies, there was a main effect of relatedness, reflecting slower naming latencies in the related compared to the unrelated condition, $F_1(1,31) = 20.46, p < .001, \eta^2_G = .013, F_2(1,19) = 10.69, p < .01, \eta^2_G = .077$. None of the other effects reached significance, all $ps > .132$.

Effects from object-related distractors. Again, there was a main effect of relatedness, showing that distractors related to the object increased naming latencies compared to the unrelated condition, $F_1(1,31) = 14.19, p < .01, \eta^2_G = .008, F_2(1,19) = 4.51, p < .05, \eta^2_G = .073$. None of the other effects reached significance, all $ps > .265$.

Overall, the persistence of an object-related semantic interference effect showed that despite a concurrent visuospatial working memory load the entire utterance up to the final element was activated on the abstract-lexical level prior to speech onset. This provides evidence that abstract-lexical advance planning proceeds independent of visuospatial working memory processes. Experiment 3 tested whether this also holds for a concurrent verbal working memory task.
### Own Experiments

Table 3

*Mean naming latencies (in ms) and error rates (in %) broken down by SOA, primed element, and relatedness for Experiment 2.*

<table>
<thead>
<tr>
<th></th>
<th>SOA 0 ms</th>
<th></th>
<th>SOA 150 ms</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>E%</td>
<td>M</td>
<td>E%</td>
</tr>
<tr>
<td><strong>Subject-related</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1039</td>
<td>18.1</td>
<td>1019</td>
<td>20.6</td>
</tr>
<tr>
<td></td>
<td>(43)</td>
<td>(1.7)</td>
<td>(47)</td>
<td>(2.5)</td>
</tr>
<tr>
<td><strong>Subject-unrelated</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>975</td>
<td>17.2</td>
<td>972</td>
<td>18.0</td>
</tr>
<tr>
<td></td>
<td>(40)</td>
<td>(1.5)</td>
<td>(46)</td>
<td>(1.8)</td>
</tr>
<tr>
<td><strong>Difference</strong></td>
<td>64***/*</td>
<td>0.9</td>
<td>46**/*</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>(14)</td>
<td>(2.0)</td>
<td>(15)</td>
<td>(2.0)</td>
</tr>
<tr>
<td><strong>Object-related</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1024</td>
<td>20.8</td>
<td>1006</td>
<td>18.6</td>
</tr>
<tr>
<td></td>
<td>(46)</td>
<td>(2.0)</td>
<td>(50)</td>
<td>(2.2)</td>
</tr>
<tr>
<td><strong>Object-unrelated</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>967</td>
<td>19.1</td>
<td>973</td>
<td>19.2</td>
</tr>
<tr>
<td></td>
<td>(40)</td>
<td>(1.6)</td>
<td>(49)</td>
<td>(2.3)</td>
</tr>
<tr>
<td><strong>Difference</strong></td>
<td>58**/*</td>
<td>1.7</td>
<td>33*/ns</td>
<td>-0.6</td>
</tr>
<tr>
<td></td>
<td>(19)</td>
<td>(2.0)</td>
<td>(13)</td>
<td>(2.7)</td>
</tr>
</tbody>
</table>

*Note.* Standard error of the mean (SE) is given in brackets. Positive difference scores reflect semantic interference. Superscripts indicate significance: † $p < .10$ (marginally significant), * $p < .05$, ** $p < .01$, *** $p < .001$. 
Experiment 3: Abstract-Lexical Advance Planning Under Verbal Load

The aim of Experiment 3 was to test whether a verbal working memory task would affect the abstract-lexical planning scope differentially compared to a no-load and visuospatial load condition, respectively. Thus, while keeping all other aspects of Experiment 2 constant, the visuospatial working memory load was exchanged with a verbal working memory load. If abstract-lexical advance planning and maintaining a load from the same modality both access the same cognitive systems, this should affect the size of the planning scope compared to the previous load conditions. Alternatively, if abstract-lexical advance planning and verbal working memory processes operate independently, the object-related semantic interference effect should persist, indicating that concurrently performing a verbal working memory task did not reduce the planning scope on the abstract-lexical level.

Methods

Participants

32 native speakers of German, most of them students from the University of Leipzig, participated in exchange for course credit or a monetary reimbursement of 8 €.

Materials, Design, Apparatus, & Procedure

The materials, design, and apparatus were identical to Experiment 2, except that the verbal working memory task (i.e., memorising a 5-digit string) was used. The procedure was identical to that of Experiment 2, except that instead of the visuospatial working memory task, participants had to execute the verbal working memory task both as a single task and concurrently to the sentence production (see Figure 6 for an example trial for the dual-task condition).
Own Experiments

Figure 6. Illustration of an example trial for the verbal load condition. Participants were instructed to memorise the serial order of the five digits, then to produce the sentence while ignoring the auditory distractor, and finally to verify via button press if the digit string in the recognition probe was identical to the memorised digit string.

Results and Discussion

Working Memory Task

Error rates for the verbal working memory task substantially increased in the dual-task situation (i.e., when the task was performed concurrently with the sentence production task) compared to the single-task situation, $t(31) = 17.66, p < .001$. In the single task, participants made 11.3 % ($SE = 1.2$) errors, as opposed to 31.8 % ($SE = 1.5$) in the dual task.

Sentence Production Task

The raw data were treated as in the previous experiments. 851 observations (16.6 %) were marked as erroneous and 104 observations (1.0 %) as outliers. Separate analyses were performed for distractors that were related or unrelated to the subject or object, respectively. Again, averaged naming latencies were submitted to analyses of variance (ANOVAs) involving the fixed variables relatedness (semantically related vs. unrelated) and SOA (0 ms vs. 150 ms). Table 4 displays mean naming latencies and error rates broken down by SOA, primed element, and relatedness.

Effects from subject-related distractors. As in Experiment 2, there was a main effect of relatedness for naming latencies, indicating that distractors related to the subject resulted in higher naming latencies, $F_1(1,31) = 16.10, p < .001$, $\eta^2_G = .013$, $F_2(1,19) = 7.34, p < .05$, $\eta^2_G = .065$. Naming latencies were faster at SOA 0 ms, but this main effect of SOA was only marginally significant in the analysis by participants, $F_1(1,31) = 4.06, p = .053$, $\eta^2_G = .005$, $F_2(1,19) = 11.60, p < .01, \eta^2_G = .037$. None of the other effects were significant, all $F$s $< 1$.

Effects from object-related distractors. For naming latencies, there was a main effect of relatedness, indicating longer naming latencies in the related compared to the unrelated
condition, but this effect only approached significance in the analysis by items, $F_1(1, 31) = 9.80, \ p < .01, \ \eta^2_G = .006, \ F_2(1, 19) = 3.65, \ p = .071, \ \eta^2_G = .034$. Furthermore, there was a main effect of SOA reflecting faster naming latencies at SOA 0 ms, $F_1(1, 31) = 9.84, \ p < .01, \ \eta^2_G = .012, \ F_2(1, 19) = 16.27, \ p < .01, \ \eta^2_G = .068$. None of the other effects reached significance, all $ps > .148$.

Taken together, these results suggest that the planning scope at the abstract-lexical level was not reduced in the presence of a concurrent verbal working memory task. In other words, the utterance-final element (i.e., the object) was still included within the planning scope. However, one cannot entirely rule out that the persistence of the object-related semantic interference effect across load conditions came about merely because of the experimental procedure employed thus far. Specifically, one could argue that by presenting only the subject of the to-be-produced utterance, speakers had to retrieve the entire utterance as a chunk from memory, thus inevitably activating the abstract-lexical information of the object. If this were true, any object-related effects could not be attributed to abstract-lexical advance planning proper, but instead would only reflect the automatic activation of the memory chunk if the planning of the sentence is required. To test this alternative hypothesis, Experiment 4 was conducted.
Table 4

*Mean naming latencies (in ms) and error rates (in %) broken down by SOA, primed element, and relatedness for Experiment 3.*

<table>
<thead>
<tr>
<th></th>
<th>SOA</th>
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<th></th>
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<th></th>
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<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 ms</td>
<td>150 ms</td>
<td>0 ms</td>
<td>150 ms</td>
<td>0 ms</td>
<td>150 ms</td>
<td>0 ms</td>
<td>150 ms</td>
<td>0 ms</td>
<td>150 ms</td>
<td>0 ms</td>
<td>150 ms</td>
<td>0 ms</td>
<td>150 ms</td>
<td>0 ms</td>
<td>150 ms</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>E%</td>
<td>M</td>
<td>E%</td>
<td>M</td>
<td>E%</td>
<td>M</td>
<td>E%</td>
<td>M</td>
<td>E%</td>
<td>M</td>
<td>E%</td>
<td>M</td>
<td>E%</td>
<td>M</td>
<td>E%</td>
</tr>
<tr>
<td>Subject-related</td>
<td>1253</td>
<td>16.1</td>
<td>1286</td>
<td>15.0</td>
<td>(45)</td>
<td>(1.7)</td>
<td>(46)</td>
<td>(1.8)</td>
<td>(44)</td>
<td>(1.6)</td>
<td>(45)</td>
<td>(1.5)</td>
<td>(44)</td>
<td>(1.6)</td>
<td>(45)</td>
<td>(1.5)</td>
</tr>
<tr>
<td>Subject-unrelated</td>
<td>1193</td>
<td>15.2</td>
<td>1230</td>
<td>15.2</td>
<td>(44)</td>
<td>(1.6)</td>
<td>(45)</td>
<td>(1.5)</td>
<td>(44)</td>
<td>(1.6)</td>
<td>(45)</td>
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<td>(44)</td>
<td>(1.6)</td>
<td>(45)</td>
<td>(1.5)</td>
</tr>
<tr>
<td>Difference</td>
<td>60</td>
<td>0.9</td>
<td>55</td>
<td>-0.2</td>
<td>(18)</td>
<td>(1.4)</td>
<td>(17)</td>
<td>(2.0)</td>
<td>(18)</td>
<td>(1.4)</td>
<td>(17)</td>
<td>(2.0)</td>
<td>(18)</td>
<td>(1.4)</td>
<td>(17)</td>
<td>(2.0)</td>
</tr>
<tr>
<td>Object-related</td>
<td>1221</td>
<td>18.1</td>
<td>1286</td>
<td>19.8</td>
<td>(43)</td>
<td>(2.1)</td>
<td>(48)</td>
<td>(2.1)</td>
<td>(45)</td>
<td>(1.9)</td>
<td>(47)</td>
<td>(1.8)</td>
<td>(45)</td>
<td>(1.9)</td>
<td>(47)</td>
<td>(1.8)</td>
</tr>
<tr>
<td>Object-unrelated</td>
<td>1188</td>
<td>15.9</td>
<td>1239</td>
<td>17.7</td>
<td>(45)</td>
<td>(1.9)</td>
<td>(47)</td>
<td>(1.8)</td>
<td>(45)</td>
<td>(1.9)</td>
<td>(47)</td>
<td>(1.8)</td>
<td>(45)</td>
<td>(1.9)</td>
<td>(47)</td>
<td>(1.8)</td>
</tr>
<tr>
<td>Difference</td>
<td>33</td>
<td>2.2</td>
<td>47</td>
<td>2.2</td>
<td>(15)</td>
<td>(2.2)</td>
<td>(16)</td>
<td>(1.8)</td>
<td>(15)</td>
<td>(2.2)</td>
<td>(16)</td>
<td>(1.8)</td>
<td>(15)</td>
<td>(2.2)</td>
<td>(16)</td>
<td>(1.8)</td>
</tr>
</tbody>
</table>

*Note.* Standard error of the mean (SE) is given in brackets. Positive difference scores reflect semantic interference. Superscripts indicate significance: † $p < .10$ (marginally significant), * $p < .05$, ** $p < .01$, *** $p < .001$.  

50 Own Experiments
Experiment 4 was conducted to rule out the possibility that the object-related semantic interference effects obtained in Experiments 1--3 came about because of the experimental procedure rather than abstract-lexical advance planning proper. Because participants were familiarised with complete scenes containing a subject and an object, it is feasible that when they had to produce the sentence upon subject presentation during the experiment, a memory trace was activated which automatically included the object, regardless of it being planned on the abstract-lexical level prior to speech onset. That is, in line with the speech-error model by Garrett (1975, 1980), an abstract scene representation must be created, i.e., the lexical items must be specified, before utterance onset, and it is possible that this is a mechanism resistant to load imposed on working memory. In other words, one could argue that the scenes which the participants had to learn at the beginning of each experiment were then memorised as chunks, resulting in automatic activation of both noun phrases upon visual presentation of the subject. Notably, Cowan (2001) showed that up to four such chunks can be held in working memory.

The interference effects observed throughout Experiments 1--3 thus might therefore not reflect abstract-lexical advance planning, which would render the conclusion that abstract-lexical advance planning does not rely on verbal (and for that matter, visuospatial) working memory invalid.

One way of testing this possibility is to alter the required utterance format. Instead of producing the whole sentence, participants were asked to only produce the inflected verb form of the previously learnt scene (e.g., “las” [read]) upon subject presentation. Thus, none of the elements primed with the auditory distractors were part of the required utterance. Oppermann et al. (2010) conducted an analogous experiment for the phonological level and did not find any evidence for the phonological activation of the subject and object of the utterance. Likewise, the reasoning of the current experiment was that if the memory trace established during the familiarisation and practice phase causes semantic interference from related distractors, these semantic interference effects from object-related distractors should still be obtained even if the noun phrases need not be articulated. On the other hand, if the paradigm used in the previous experiments really is an index of abstract-lexical advance planning, no effects should be observed because the elements primed by the distractors (i.e., the subject and the object of the scene) are not included in the required utterance (i.e., the inflected verb).
Methods

Participants

32 native speakers of German (24 female; mean age = 22.7, SD = 4.6, range = 18-36), most of them students from the University of Leipzig, participated in exchange for course credit or a monetary reimbursement of 8 €.

Materials, Design, Apparatus, & Procedure

Experiment 4 was completely identical to Experiment 1, with the only difference that during the two experimental blocks, participants were asked to produce the inflected verb of the sentence (e.g., “las” [read]) instead of the entire sentence. However, during familiarisation and the practice blocks they produced the entire sentences as well.

Results and Discussion

Working Memory Task

On average, participants made 7.1 % (SE = 0.8) errors in the visuospatial task and 9.7 % (SE = 1.0) errors in the verbal task, both of which were executed as single tasks. This difference was statistically reliable, t(31) = 2.43, p < .05. However, because this experiment solely focused on the speech production task instead of comparing it to specific load conditions, this difference is not considered to be critical.

Sentence Production Task

The raw data were treated as in the previous experiments. 342 observations (6.7 %) were marked as erroneous and 110 observations (2.1 %) as outliers. Separate analyses were performed for distractors that were related or unrelated to the subject or object, respectively. Again, averaged naming latencies were submitted to analyses of variance (ANOVAs) involving the fixed variables relatedness (semantically related vs. unrelated) and SOA (0 ms vs. 150 ms). Table 5 displays mean naming latencies and error rates broken down by SOA, primed element, and relatedness.

Effects from subject-related distractors. There was an interaction of SOA and relatedness, indicating a trend towards semantic interference from related distractors at SOA 150 ms as opposed to no effect at SOA 0 ms, $F_1(1,31) = 4.60, p < .05, \eta^2_g = .005$, $F_2(1,19) = 7.46, p < .05, \eta^2_g = .014$. Subsequent t-tests showed that this interference effect was reliable in the analysis by participants only, $t_1(31) = 3.40, p < .01, t_2(19) = 1.51, p = .148$. 
In the analysis of error rates, there was a weak trend towards higher error rates in the related condition, which was only marginally significant in the analysis by items and did not become significant in the analysis by participants, $F_1(1,31) = 2.71, \ p = .110, \ \eta^2_G = .009, F_2(1,19) = 4.17, \ p = .055, \ \eta^2_G = .015$. None of the other effects were significant, all $ps > .185$.

**Effects from object-related distractors.** There were no significant effects both in the analysis of naming latencies and error rates, all $ps > .150$.

The results from Experiment 4 clearly show that the semantic interference effects obtained in the previous experiments are not a result of a memory trace activating the lexical entries. Specifically, the absence of any object-related effect supports the claim that the effects from the previous experiments can be attributed to advance planning processes.

It should be noted that there was a trend towards a subject-related interference effect at SOA 0 ms. One explanation for this is that the visual presentation of the agent might have boosted the activation of the subject noun even though it did not have to be produced (cf. Morsella & Miozzo, 2002). However, because the effect was not reliable statistically and does not play a decisive role in the conclusions drawn from Experiments 1–3, it is not considered any further.
Table 5

*Mean reaction times (in ms) and error rates (in %) broken down by SOA, primed element, and relatedness for Experiment 4.*

<table>
<thead>
<tr>
<th>SOA</th>
<th>0 ms</th>
<th>150 ms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>E%</td>
</tr>
<tr>
<td></td>
<td>866</td>
<td>7.8</td>
</tr>
<tr>
<td>Subject-related</td>
<td>(24)</td>
<td>(1.5)</td>
</tr>
<tr>
<td>Subject-unrelated</td>
<td>873</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td>(24)</td>
<td>(1.0)</td>
</tr>
<tr>
<td>Difference</td>
<td>-7</td>
<td>2.0ns/†</td>
</tr>
<tr>
<td></td>
<td>(13)</td>
<td>(1.3)</td>
</tr>
<tr>
<td>Object-related</td>
<td>852</td>
<td>6.6</td>
</tr>
<tr>
<td></td>
<td>(20)</td>
<td>(1.3)</td>
</tr>
<tr>
<td>Object-unrelated</td>
<td>863</td>
<td>6.6</td>
</tr>
<tr>
<td></td>
<td>(20)</td>
<td>(1.5)</td>
</tr>
<tr>
<td>Difference</td>
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<td>0.0</td>
</tr>
<tr>
<td></td>
<td>(7)</td>
<td>(1.3)</td>
</tr>
</tbody>
</table>

*Note.* Standard error of the mean (SE) is given in brackets. Positive difference scores reflect semantic interference. Superscripts indicate significance: † *p* < .10 (marginally significant), *p* < .05, ** *p* < .01, *** *p* < .001.
Interim Summary: The Flexibility of Abstract-Lexical Advance Planning

The first four experiments contrasted the influence of a cognitive load on the planning scope of abstract-lexical advance planning. Figure 7 provides an overview of the results from Experiments 1–3, depicting performance in the respective working memory task(s) (upper panel, in % error) as well as distractor effects on naming latencies (middle panel) and error rates (lower panel) in the sentence production task.

In terms of performance in the working memory task, single-task performance in both the visuospatial or verbal task was comparable across participant groups. Moreover, working memory task performance was substantially worse in the dual-task situation (i.e., when it was performed concurrently with the sentence production task) than in the single-task situation. Furthermore, there was an interaction of working memory task modality (visuospatial vs. verbal) and test situation (single- vs. dual-task), $F(1,62) = 34.25, p < .001, \eta^2_p = .05$, showing that verbal working memory performance was disrupted more strongly than performance in the visuospatial working memory task when performed in the dual-task situation.

With regard to overall naming latencies and error rates in the sentence production task, a similar impact from the working memory task is visible. Compared to the no load condition (Experiment 1: 937 ms and 13.8 % errors, unrelated conditions only), a concurrent visuospatial task increased error rates (Experiment 2: 972 ms and 18.4 %), and a concurrent verbal working memory task substantially increased naming latencies and—to a lesser extent—error rates (Experiment 3: 1213 ms and 16.0 %). Thus, the more similar dual-task situation (verbal working memory task with sentence production) resulted in a stronger performance decline in both tasks than the less similar dual-task situation (visuospatial working memory task with sentence production). Both effects, i.e., the presence of dual-task interference in the two tasks (cf. Cowan, 1995, 2001, 2005) as well as the stronger interference with more similar tasks (cf. Baddeley, 1986; Baddeley & Hitch, 1974; Baddeley & Logie, 1999; Wickens, 2008), are in line with current theoretical accounts of working memory performance.

When looking at the size of the advance planning scope, distractors semantically related to the final element of the required utterance consistently yielded semantic interference effects, indicating that the entire sentence had been planned ahead on the abstract-lexical level prior to speech onset regardless of concurrent cognitive load (visuospatial or verbal, respectively). To compare the size of the observed effects across experiments, an ANOVA including the factor load modality (none vs. visuospatial vs. verbal) was performed. The three-
way interaction load modality × relatedness × SOA was neither significant for the subject nor the object of the utterance (all $F$s < 1), indicating that the size of the semantic interference effects was comparable across Experiments 1–3. Furthermore, there was no interaction of load modality and relatedness (all $p$s > .35).

Finally, Experiment 4 ruled out the possibility that the persistence of the object-related effects under cognitive load could be attributed to the experimental procedure employed: No object-related effect was obtained when only the inflected verb of the previously learnt utterance had to be produced.

Taken together, Experiments 1--4 demonstrated that the abstract-lexical planning scope includes both the initial and the final element of a simple sentence, and this holds also in the presence of a visuospatial or verbal working memory load, respectively. Verbal working memory and processes involved in abstract-lexical advance planning thus do not appear to share a common cognitive system; if they did, the verbal working memory task should have abolished the semantic interference effect for the object of the sentence. In other words, the presence of a concurrent cognitive load does not narrow the size of the abstract-lexical planning scope in sentence production, which provides evidence that planning at this processing level and working memory do not share a common cognitive resource. These findings are in line with those reported by Wagner et al. (2010) and Martin et al. (2014).
Figure 7. Overview of Experiments 1–3: working memory performance and distractor effects on naming latencies and error rates in sentence production. The sentence production task was performed as a single task in Experiment 1 and as a dual task in Experiments 2 and 3. Positive scores on distractor effects (middle and lower panel) reflect semantic interference from related distractors.
Experiment 5: Phonological Advance Planning Without Cognitive Load

The second set of experiments tested whether the scope of advance planning at the phonological level would be equally resistant to influences from a concurrent cognitive load. Experiment 5 was a replication of Oppermann et al. (2010, Experiment 1). As in the previous experiments, after having learnt the material set, participants saw the agent of a scene and had to produce the according sentence while ignoring auditory distractors phonologically related or unrelated to the subject or object of the utterance. Given that the pattern of phonological activation observed by Oppermann et al. (2010) proves to be replicable, subject-related facilitation and object-related interference was expected, indicating that both the initial and final element of the utterance were phonologically activated prior to speech onset.

Methods

Participants

32 native speakers of German (29 female, mean age = 23.3, SD = 3.1, range = 18-29), most of them students from the University of Leipzig, participated in exchange for course credit or a monetary reimbursement of 8 €.

Materials

For the sentence production task, twenty line drawings of simple scenes depicting a subject performing a simple action on or with an object were used. For each subject and object, a phonologically related distractor that shared the initial consonant or consonant cluster and the adjacent vowel with, and had the same number of syllables and syllabic structure as the subject's or object's name was selected (e.g., distractor “mölk” for target “Mönch” [monk] or distractor “buf” for target “Buch” [book]). As in Oppermann et al. (2010), phonotactically legal non-words instead of real words were used as distractors. When producing gender-marked noun phrases, a discrepancy between the grammatical gender of target and distractor can result in gender congruency effects (e.g., Schriefers, 1993), which in turn might contaminate the phonological effects that are the subject of interest in this and the following experiments.

Unrelated control conditions were created by reassigning the distractors to different subjects (for the subject-related distractors) or objects (for the object-related distractors); see Appendix B for a complete list of the materials. The auditory distractors were spoken by a female native speaker of German and varied in duration from 529 ms to 968 ms with an aver-
age of 731 ms ($SD = 122$ ms). All auditory materials were digitized at a sampling rate of 48 kHz for presentation during the experiment. An additional set of five scenes with corresponding distractors served as practice and warm-up trials.

For the working memory task, the same materials as in the previous experiments were used.

**Design, Apparatus, & Procedure**

The experimental design, apparatus, and procedure were identical to Experiment 1, with the exception that phonologically related vs. unrelated distractors at SOAs 150 ms and 300 ms were compared. The two SOAs were used because they had provided reliable subject- and object-related phonological effects compared to an earlier SOA (see Oppermann et al., 2010, Experiment 1).

Due to experimenter error, only one respective working memory task was tested during the experiment for the first 24 participants. Following an attempt to retest these participants, 16 out of 24 volunteered to participate in a quasi-second experimental session in which the working memory task which had not yet been taken was conducted. Participants 25 to 32 conducted the experiment as described.

**Results and Discussion**

**Working Memory Task**

Error rates for the visuospatial working memory task and the verbal working memory task, both of which were performed as single tasks within participants, amounted to 9.3% ($SE = 1.0$) and 8.8% ($SE = 0.9$), respectively. These values did not differ, $t < 1$.

**Sentence Production Task**

The raw data of the sentence production task were treated and analysed as in the previous experiments. According to these criteria, 719 observations (14.0%) were marked as erroneous and 53 observations (1.0%) as outliers. Statistical analyses involved the two fixed variables relatedness (phonologically related vs. unrelated) and SOA (150 ms vs. 300 ms). Table 6 displays mean naming latencies and error rates broken down by SOA, primed element, and relatedness.

**Effects from subject-related distractors.** There was a main effect of relatedness, indicating shorter naming latencies with related distractors than with unrelated distractors,
F₁(1,31) = 43.70, p < .001, η²₁ = .023, F₂(1,19) = 23.92, p < .001, η²₂ = .165. The main effect of SOA was significant as well, reflecting shorter naming latencies at SOA 300 ms than at SOA 150 ms, F₁(1,31) = 5.67, p < .05, η²₁ = .011, F₂(1,19) = 16.82, p < .01, η²₂ = .058. Moreover, relatedness and SOA interacted, F₁(1,31) = 25.04, p < .001, η²₁ = .012, F₂(1,19) = 20.56, p < .001, η²₂ = .082. Subsequent t-tests revealed that the facilitation effect was significant at SOA 150 ms, t₁(31) = 6.81, p < .001, t₂(19) = 5.99, p < .001, but not at SOA 300 ms, t₁(31) = 1.88, p = .069, t₂(19) = 1.47, p = .157.

In the analysis of error rates, only the interaction of relatedness and SOA was significant, albeit at a trend level only in the analysis by items, F₁(1,31) = 6.81, p < .05, η²₁ = .026, F₂(1,19) = 3.02, p = .099, η²₂ = .050. Subsequent t-tests revealed that there was a trend towards fewer errors with related distractors than with unrelated distractors at SOA 150 ms, t₁(31) = 1.86, p = .073, t₂(19) = 2.00, p = .060, but not at SOA 300 ms, ps > .214. None of the other effects was significant, ps > .316.

**Effects from object-related distractors.** Relatedness was not significant, ps > .251. There was a main effect of SOA, indicating shorter naming latencies at SOA 300 ms than at SOA 150 ms, F₁(1,31) = 13.77, p < .01, η²₁ = .028, F₂(1,19) = 19.96, p < .001, η²₂ = .108. Relatedness and SOA interacted, F₁(1,31) = 6.65, p < .05, η²₁ = .003, F₂(1,19) = 4.30, p = .052, η²₂ = .021. Subsequent t-tests revealed longer naming latencies with related distractors at SOA 150 ms only, which, however, was at a trend level only in the analysis by items, t₁(31) = 2.65, p < .05, t₂(19) = 1.97, p = .064.

In the analysis of error rates, relatedness was only significant in the analysis by participants, reflecting more errors with related than with unrelated distractors, F₁(1,31) = 5.26, p < .05, η²₁ = .025, F₂(1,19) = 2.91, p = .104, η²₂ = .041. The main effect of SOA was significant in the analysis by participants, but at a trend level only in the analysis by items, suggesting more errors at SOA 150 ms, F₁(1,31) = 4.86, p < .05, η²₁ = .028, F₂(1,19) = 3.81, p = .066, η²₂ = .046. Finally, relatedness and SOA interacted, F₁(1,31) = 10.39, p < .01, η²₁ = .040, F₂(1,19) = 11.13, p < .01, η²₂ = .065, and subsequent t-tests revealed that more errors from related distractors were found at SOA 150 ms only, t₁(31) = 4.54, p < .001, t₂(19) = 1.97, p < .01; for SOA 300 ms, ps > .687.
Table 6
Mean naming latencies (in ms) and error rates (in %) broken down by SOA, primed element, and relatedness for Experiment 5.

<table>
<thead>
<tr>
<th>SOA</th>
<th>150 ms</th>
<th>300 ms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>E%</td>
</tr>
<tr>
<td>Subject-related</td>
<td>726</td>
<td>12.7</td>
</tr>
<tr>
<td>(31)</td>
<td>(2.2)</td>
<td>(31)</td>
</tr>
<tr>
<td>Subject-unrelated</td>
<td>815</td>
<td>17.2</td>
</tr>
<tr>
<td>(31)</td>
<td>(2.0)</td>
<td>(29)</td>
</tr>
<tr>
<td>Difference</td>
<td>-89***/***</td>
<td>-4.5†/†</td>
</tr>
<tr>
<td>(13)</td>
<td>(2.4)</td>
<td>(8)</td>
</tr>
<tr>
<td>Object-related</td>
<td>823</td>
<td>19.2</td>
</tr>
<tr>
<td>(31)</td>
<td>(1.7)</td>
<td>(34)</td>
</tr>
<tr>
<td>Object-unrelated</td>
<td>795</td>
<td>12.7</td>
</tr>
<tr>
<td>(29)</td>
<td>(1.6)</td>
<td>(31)</td>
</tr>
<tr>
<td>Difference</td>
<td>27†/†</td>
<td>6.6***/*</td>
</tr>
<tr>
<td>(10)</td>
<td>(1.4)</td>
<td>(10)</td>
</tr>
</tbody>
</table>

Note. Standard error of the mean (SE) is given in brackets. Positive difference scores reflect phonological interference, and negative difference scores reflect phonological facilitation. Superscripts indicate significance: † p < .10 (marginally significant), * p < .05, ** p < .01, *** p < .001.

Overall, Experiment 5 replicated the pattern obtained by Oppermann et al. (2010) and is in line with the graded-activation account (Jescheniak et al., 2003): Distractors phonologically related to the subject of the target utterance facilitated the naming response compared to the unrelated condition, while distractors phonologically related to the object (i.e., the utterance-final element) interfered with the naming response. The interference effect in naming latencies only approached significance in the analysis by items. However, it should be taken into account that in this experiment, the effect was distributed across both dependent variables (i.e., longer naming latencies and more errors in the related condition), which might have weakened an observable effect on naming latencies.
In the present experiments, the phonological effects were affected differently by the SOA manipulation. While Oppermann et al. (2010) found subject-related facilitation at SOA 150 ms and object-related interference at SOA 300 ms, respectively, both effects were confined to the first SOA in the present experiment. This might be explained due to the increased training phase prior to the experimental blocks, which decreased overall naming latencies compared to Oppermann et al.’s study and might thus have altered the temporal dynamics of the planning process. Regardless of this SOA shift, Experiment 5 showed that both the initial and the final element of a simple sentence were activated on the phonological level. This finding was considered the baseline for the subsequent experiments: Analogous to Experiments 2 and 3, Experiments 6 and 7 investigated to what extent the established phonological advance planning scope might be affected by a concurrent visuospatial or verbal working memory load, respectively.
Experiment 6: Phonological Advance Planning Under Visuospatial Load

In Experiment 6, a concurrent visuospatial WM task was added to the sentence production task. The critical question was whether the phonological interference effect for the object noun would persist. If not, this would suggest that the concurrent visuospatial WM task had reduced the scope of advance planning at the phonological level.

Methods

Participants

32 native speakers of German (26 female; mean age $= 22.6, SD = 2.5, range = 18-27) participated in exchange for course credit or a monetary reimbursement of 8 €. One participant was replaced according to the criterion explained in Experiment 1.

Materials, Design, Apparatus, & Procedure

The materials, design, apparatus, and procedure were identical to Experiment 2, with the exception that the phonologically related or unrelated distractors from Experiment 5 and the corresponding SOAs 150 ms and 300 ms were used.

Results and Discussion

Working Memory Task

Error rates for the visuospatial working memory task substantially increased in the dual-task situation (i.e., when the task was performed concurrently with the sentence production task) compared to the single-task situation, $t(31) = 11.60, p < .001$. In the single task, participants made 7.3% errors ($SE = 0.8$), as opposed to 17.5% ($SE = 1.3$) in the dual task.

Sentence Production Task

The raw data of the sentence production task were treated as in the previous experiments. Thus, 669 observations (13.1%) were marked as erroneous and 36 observations (0.7%) as outliers. Table 7 displays mean naming latencies and error rates broken down by SOA, primed element, and relatedness.

Effects from subject-related distractors. In the analysis of naming latencies, there was only a main effect of relatedness, indicating shorter naming latencies with related distractors
than with unrelated distractors, $F_1(1,31) = 13.36, p < .01, \eta^2_G = .007, F_2(1,19) = 12.46, p < .01, \eta^2_G = .101$.

For error rates, there was a trend towards a main effect of relatedness reflecting less errors in the related condition, but this effect was not significant in the analysis by participants and only at a trend level in the analysis by items, $F_1(1,31) = 2.26, p = .143, \eta^2_G = .007, F_2(1,19) = 3.52, p = .076, \eta^2_G = .019$. None of the other effects in the analysis of naming latencies and error rates was significant, all $ps > .248$.

**Effects from object-related distractors.** For naming latencies, there was a main effect of relatedness, indicating longer naming latencies with related than with unrelated distractors, $F_1(1,31) = 16.78, p < .001, \eta^2_G = .004, F_2(1,19) = 5.94, p < .05, \eta^2_G = .048$. Moreover, the effect of SOA was significant in the analysis by items, but not by participants, reflecting shorter naming latencies at SOA 300 ms, $F_1 < 1, F_2(1,19) = 4.63, p < .01, \eta^2_G = .010$.

In the analysis of error rates, there was a main effect of relatedness, indicating more errors from related than from unrelated distractors, $F_1(1,31) = 6.25, p < .05, \eta^2_G = .024, F_2(1,19) = 5.29, p < .05, \eta^2_G = .058$. None of the other effects in the analysis of naming latencies and error rates was significant, all $Fs < 1$.

Overall, Experiment 6 showed that despite a concurrent visuospatial working memory load, both subject and object nouns were activated at the phonological level: As in Experiment 5, distractors phonologically related to the subject noun facilitated the naming response whereas distractors phonologically related to the object noun interfered with the naming response. Analogous to what was shown in Experiment 2 (i.e., the persistence of the abstract-lexical planning scope under visuospatial load), adding a concurrent visuospatial working memory task also did not affect the phonological planning scope up to the utterance-final element. Experiment 7 tested whether this also holds true when a concurrent verbal working memory task is introduced.
Table 7

Mean reaction times (in ms) and error rates (in %) broken down by SOA, primed element, and relatedness for Experiment 6.

<table>
<thead>
<tr>
<th></th>
<th>SOA</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>150 ms</td>
<td>300 ms</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subject-related</td>
<td>848</td>
<td>848</td>
<td></td>
</tr>
<tr>
<td>E%</td>
<td>10.8</td>
<td>12.2</td>
<td></td>
</tr>
<tr>
<td>Subject-unrelated</td>
<td>(39)</td>
<td>10.8</td>
<td></td>
</tr>
<tr>
<td>E%</td>
<td>(1.6)</td>
<td>(1.8)</td>
<td></td>
</tr>
<tr>
<td>Subject-related</td>
<td>891</td>
<td>877</td>
<td></td>
</tr>
<tr>
<td>E%</td>
<td>12.5</td>
<td>13.8</td>
<td></td>
</tr>
<tr>
<td>Subject-unrelated</td>
<td>(36)</td>
<td>12.5</td>
<td></td>
</tr>
<tr>
<td>E%</td>
<td>(1.7)</td>
<td>(1.8)</td>
<td></td>
</tr>
<tr>
<td>Difference</td>
<td>-43**/*</td>
<td>-29**/*</td>
<td></td>
</tr>
<tr>
<td>E%</td>
<td>(14)</td>
<td>(12)</td>
<td></td>
</tr>
<tr>
<td>Object-related</td>
<td>895</td>
<td>880</td>
<td></td>
</tr>
<tr>
<td>E%</td>
<td>15.9</td>
<td>15.3</td>
<td></td>
</tr>
<tr>
<td>Object-unrelated</td>
<td>(38)</td>
<td>15.9</td>
<td></td>
</tr>
<tr>
<td>E%</td>
<td>(2.6)</td>
<td>(1.9)</td>
<td></td>
</tr>
<tr>
<td>Difference</td>
<td>25†/ns</td>
<td>29**/*</td>
<td></td>
</tr>
<tr>
<td>E%</td>
<td>(13)</td>
<td>(19)</td>
<td></td>
</tr>
</tbody>
</table>

Note. Standard error of the mean (SE) is given in brackets. Positive difference scores reflect phonological interference, and negative difference scores reflect phonological facilitation. Superscripts indicate significance: † p < .10 (marginally significant), * p < .05, ** p < .01, *** p < .001.
Experiment 7: Phonological Advance Planning Under Verbal Load

Experiment 7 differed from Experiment 6 only in that the visuospatial working memory task was replaced by the verbal working memory task. The critical question again was whether the phonological interference effect for the object noun would persist when the verbal working memory task was performed concurrently with the sentence production task. If not, this would suggest that the concurrent verbal working memory task had reduced the scope of advance planning at the phonological level.

Methods

Participants

32 native speakers of German (25 female; mean age = 23.4, SD = 3.0, range = 19-29) participated in exchange for course credit or a monetary reimbursement of 8 €. Two participants were replaced according to the error criterion set in Experiment 1.

Materials, Design, Apparatus, & Procedure

The materials, design, and apparatus were identical to Experiment 5, and the procedure was identical to Experiment 3.

Results and Discussion

Working Memory Task

Again, error rates for the verbal working memory task substantially increased in the dual-task situation (i.e., when the task was performed concurrently with the sentence production task) compared to the single-task situation, $t(31) = 19.00, p < .001$. In the single task, participants made 8.2 % (SE = 0.8) errors, as opposed to 27.4 % (SE = 1.4) in the dual task.

Sentence Production Task

The raw data were treated as in the previous experiments, leading to the removal of 889 erroneous responses (17.4 %) and 49 outliers (1.0 %). Table 8 displays mean reaction times and error rates broken down by SOA, primed element, and relatedness.

Effects from subject-related distractors. In the analysis of naming latencies, there was a main effect of relatedness, showing shorter naming latencies with related distractors than with unrelated distractors, $F_1(1,31) = 22.48, p < .001$, $\eta^2_G = .018$, $F_2(1,19) = 30.57, p < .001,$
η²G = .132. The main effect of SOA reflecting shorter naming latencies at SOA 150 ms than at 300 ms was significant in the analysis by items, but only approached significance in the analysis by participants, $F_1(1,31) = 3.11$, $p = .088$, $\eta^2_G = .007$, $F_2(1,19) = 7.13$, $p < .05$, $\eta^2_G = .041$. There was also a trend for an interaction of relatedness and SOA, although confined to the analysis by items, reflecting a descriptively larger facilitation effect at SOA 150 ms, $F_1(1,31) = 1.48$, $p = .252$, $\eta^2_G = .001$, $F_2(1,19) = 4.48$, $p < .05$, $\eta^2_G = .017$.

In the analysis of error rates, there were no significant effects, all $p$s > .106.

**Effects from object-related distractors.** In the analysis of naming latencies, there was only a trend for a main effect of SOA, which was reliable in the analysis by items only and indicated shorter naming latencies at SOA 150 ms, $F_1(1,31) = 2.13$, $p = .155$, $\eta^2_G = .007$, $F_2(1,19) = 10.69$, $p < .01$, $\eta^2_G = .048$. There were no further significant effects both in the analysis of naming latencies and error rates, all $p$s > .112.

Although there was no effect from object-related distractors in this experiment, it cannot be ignored that at least descriptively, there was a trend towards interference at SOA 150 ms (17 ms). Thus, to countercheck the reliability of the null effect obtained in the ANOVA, I additionally performed a Bayesian analysis (Masson, 2011; Wagenmakers, 2007). This analysis estimates the likelihood of the null hypothesis $H_0$ or the alternative hypothesis $H_1$ being true with respect to the collected data. In this case, it revealed positive evidence for the null hypothesis being true (for participants, $p(H_0|D) = .81$; for items, $p(H_0|D) = .80$), confirming the conclusion that there indeed was no reliable interference effect.

For the first time in this series of experiments, the effect from distractors related to the object noun disappeared. This could be taken as evidence that the concurrent verbal working memory load has effectively reduced the scope of phonological advance planning. However, such a conclusion might be premature, given that naming latencies in Experiment 7 were substantially longer than in the experiments which had shown object-related interference effects. Therefore, one might argue that the SOAs under which the effect was observed in Experiment 5 (SOA 150 ms) and Experiment 6 (SOAs 150 ms and 300 ms) were not suitable to detect the effect in Experiment 7. This possibility was tested in Experiment 8.
Table 8
Mean naming latencies (in ms) and error rates (in %) broken down by SOA, primed element, and relatedness for Experiment 7.

<table>
<thead>
<tr>
<th></th>
<th>SOA</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>150 ms</td>
<td>300 ms</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>E%</td>
<td>M</td>
<td>E%</td>
</tr>
<tr>
<td>Subject-related</td>
<td>968</td>
<td>14.2</td>
<td>1020</td>
<td>18.1</td>
</tr>
<tr>
<td></td>
<td>(42)</td>
<td>(1.5)</td>
<td>(44)</td>
<td>(2.1)</td>
</tr>
<tr>
<td>Subject-unrelated</td>
<td>1044</td>
<td>17.8</td>
<td>1069</td>
<td>17.0</td>
</tr>
<tr>
<td></td>
<td>(39)</td>
<td>(2.1)</td>
<td>(42)</td>
<td>(1.6)</td>
</tr>
<tr>
<td>Difference</td>
<td>-76 <em><strong>/</strong></em></td>
<td>-3.6 †/†</td>
<td>-50 *<em>/</em></td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>(19)</td>
<td>(1.9)</td>
<td>(15)</td>
<td>(1.8)</td>
</tr>
<tr>
<td>Object-related</td>
<td>1043</td>
<td>19.1</td>
<td>1070</td>
<td>17.8</td>
</tr>
<tr>
<td></td>
<td>(41)</td>
<td>(2.2)</td>
<td>(43)</td>
<td>(1.9)</td>
</tr>
<tr>
<td>Object-unrelated</td>
<td>1026</td>
<td>18.4</td>
<td>1075</td>
<td>16.4</td>
</tr>
<tr>
<td></td>
<td>(40)</td>
<td>(1.9)</td>
<td>(43)</td>
<td>(2.4)</td>
</tr>
<tr>
<td>Difference</td>
<td>17</td>
<td>0.6</td>
<td>-6</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>(17)</td>
<td>(2.1)</td>
<td>(17)</td>
<td>(2.4)</td>
</tr>
</tbody>
</table>

Note. Standard error of the mean (SE) is given in brackets. Positive difference scores reflect phonological interference, and negative difference scores reflect phonological facilitation. Superscripts indicate significance: † p < .10 (marginally significant), * p < .05, ** p < .01, *** p < .001.
Experiment 8: Phonological Advance Planning Under Verbal Load With Different SOAs

In order to rule out the possibility that the longer naming latencies in Experiment 7, compared to Experiments 5 and 6, were responsible for the absence of the effect from object-related distractors in Experiment 7, Experiment 8 was conducted. It was an exact replication of Experiment 7 with the only difference that the SOAs were adjusted to compensate for the naming latency shift. Thus, instead of SOAs 150 ms and 300 ms, SOAs 300 ms and 450 ms were tested. Should the interference effect from object-related distractors also be absent at these SOAs, this would corroborate the conclusion that indeed the scope of advance phonological planning can be reduced by a concurrent verbal working memory load.

Methods

Participants

32 native speakers of German (22 female; mean age = 23.0, SD = 3.7, range = 18-30) participated. Two participants were replaced according to the error criterion set in Experiment 1, and another three were replaced because their performance in the verbal working memory task in the dual-task situation was at chance level.

Materials, Design, Apparatus, & Procedure

The materials, design, and apparatus were identical to Experiment 7, except that SOAs 300 ms and 450 ms were tested (instead of 150 ms and 300 ms).

Results and Discussion

Working Memory Task

Again, error rates for the verbal working memory task substantially increased in the dual-task situation (i.e., when the task was performed concurrently with the sentence production task) compared to the single-task situation, \( t(31) = 22.03, p < .001 \). In the single task, participants made 8.7 % errors \( (SE = 0.8) \), as opposed to 32.0 % \( (SE = 1.3) \) in the dual task.
Sentence Production Task

The raw data were treated as in the previous experiments. Thus, 872 erroneous responses (17.0%) and 38 outliers (0.9%) were removed. Table 9 displays mean naming latencies and error rates broken down by SOA, primed element, and relatedness.

Effects from subject-related distractors. In the analysis of naming latencies, there was a main effect of relatedness, indicating shorter naming latencies with related distractors than with unrelated distractors, $F_1(1,31) = 17.57, p < .001, \eta^2_G = .005, F_2(1,19) = 6.04, p < .05, \eta^2_G = .069$. The main effect of SOA was significant in the analysis by items only, reflecting a trend towards faster naming latencies at SOA 300 ms, $F_1 < 1, F_2 = 9.71, p < .01, \eta^2_G = .040$. The interaction of relatedness and SOA was significant in the analysis by participants only, $F_1(1,31) = 5.54, p < .05, \eta^2_G = .001, F_2 < 1$. Subsequent $t$-tests revealed that the facilitation effect from related distractors was reliable at SOA 300 ms, $t_1(31) = 4.83, p < .001, t_2(19) = 2.70, p < .05$, but not at SOA 450 ms, $ps > .063$.

In the analysis of error rates, none of the effects was significant, all $ps > .091$.

Effects from object-related distractors. In the analysis of naming latencies, there was no effect of relatedness and no interaction of relatedness and SOA, all $ps > .300$.

In the analysis of error rates, the main effect of relatedness was marginally significant in the analysis by participants, but not significant by items, $F_1(1,31) = 3.81, p = .060, \eta^2_G = .013, F_2(1,19) = 2.48, p = .132, \eta^2_G = .039$. None of the other effects were significant, all $Fs < 1$.

As for Experiment 7, a Bayesian analysis on the effect from object-related distractors was performed. This again provided positive evidence for the null hypothesis being true (for participants, $p(H_0|D) = .80$; for items, $p(H_0|D) = .81$), confirming the conclusion that there was no interference effect.

In summary, Experiment 8 also did not provide evidence for the phonological activation of the object, although the SOAs had been adjusted to compensate for the substantially longer naming latencies in Experiment 7 compared to Experiments 5 and 6. This pattern gives additional support to the notion that the size of the phonological advance planning scope can be affected when a verbal working memory task is performed concurrently with the sentence production task. As a final test, Experiment 9 investigated the influence of a concurrent verbal working memory load within participants.
Table 9

Mean reaction times (in ms) and error rates (in %) broken down by SOA, primed element, and relatedness for Experiment 8.

<table>
<thead>
<tr>
<th></th>
<th>300 ms</th>
<th></th>
<th>450 ms</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>E%</td>
<td>M</td>
<td>E%</td>
</tr>
<tr>
<td>Subject-related</td>
<td>1030</td>
<td>15.6</td>
<td>1075</td>
<td>14.1</td>
</tr>
<tr>
<td></td>
<td>(58)</td>
<td>(2.0)</td>
<td>(66)</td>
<td>(2.1)</td>
</tr>
<tr>
<td>Subject-unrelated</td>
<td>1099</td>
<td>16.6</td>
<td>1103</td>
<td>13.8</td>
</tr>
<tr>
<td></td>
<td>(57)</td>
<td>(2.4)</td>
<td>(65)</td>
<td>(2.1)</td>
</tr>
<tr>
<td>Difference</td>
<td>-69***</td>
<td>-0.9</td>
<td>-28†/ns</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>(14)</td>
<td>(1.7)</td>
<td>(15)</td>
<td>(1.9)</td>
</tr>
<tr>
<td>Object-related</td>
<td>1062</td>
<td>16.7</td>
<td>1082</td>
<td>16.6</td>
</tr>
<tr>
<td></td>
<td>(59)</td>
<td>(2.6)</td>
<td>(59)</td>
<td>(2.3)</td>
</tr>
<tr>
<td>Object-unrelated</td>
<td>1074</td>
<td>13.6</td>
<td>1084</td>
<td>13.9</td>
</tr>
<tr>
<td></td>
<td>(58)</td>
<td>(2.2)</td>
<td>(56)</td>
<td>(1.9)</td>
</tr>
<tr>
<td>Difference</td>
<td>-12</td>
<td>3.1</td>
<td>-3</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>(14)</td>
<td>(2.0)</td>
<td>(13)</td>
<td>(2.3)</td>
</tr>
</tbody>
</table>

*Note. Standard error of the mean (SE) is given in brackets. Positive difference scores reflect phonological interference, and negative difference scores reflect phonological facilitation. Superscripts indicate significance: † p < .10 (marginally significant), * p < .05, ** p < .01, *** p < .001.*
Experiment 9: Testing the Influence of Verbal Load on Phonological Advance Planning Within Participants

A major caveat of the previous experiments is that load modality (i.e., no load vs. visuospatial load vs. verbal load) was implemented as a between-subjects factor. While this was done mainly for pragmatic reasons (a single session testing one load modality already lasted close to one and a half hours, and conducting experiments across several experimental sessions raises the issue of the influence of practice effects on the obtained results), it is possible that the somewhat unclear relationship between the no-load condition (Experiment 5) and the verbal load condition (Experiments 7 and 8) might have come about precisely due to this aspect of the experiments. After all, comparing several different groups under different load conditions might lead to premature conclusions. That is, the participant group tested in Experiment 5 might actually show an object-related interference effect even under verbal load, and likewise the participant groups tested in Experiments 7 and 8 might not show such an effect even without a concurrent load. In fact, the naming latency differences between the object-related and unrelated condition (i.e., what is considered to be the phonological distractor effect) only differed by 10 ms between Experiment 5 (SOA 150 ms) and Experiment 7 (SOA 150 ms). However, only the effect in Experiment 5 proved to be statistically reliable.

To back the claim that the phonological planning scope is indeed reduced under a verbal load, a direct within-participants contrast between these two conditions (i.e., phonological advance planning without load, SOA 150 ms vs. phonological advance planning under verbal load, SOA 150 ms) was required. Such a contrast would show to what extent the same speakers plan ahead both with and without a concurrent verbal load. If the hypothesis that the object is activated on the phonological level prior to speech onset without load but not under verbal load is correct, this should result in a significant interaction of load modality (none vs. verbal) and object-relatedness (phonologically related vs. unrelated).

Methods

Participants

32 native speakers of German (25 female; mean age = 23.2, SD = 3.6, range = 18-30) participated in exchange for course credit or a monetary reimbursement of 8 €.
Design, Apparatus, & Procedure

The design, apparatus, and procedure were identical to Experiment 7, with the following exceptions: First, only SOA 150 ms was tested. At this SOA, the statistical null effect under verbal load was descriptively the largest (i.e., 17 ms in Experiment 7); thus, if there is a chance to obtain an object-related effect even under verbal load, it should be most likely to find it in this time window, based on the data from the previous experiments.

Furthermore, the sentence production both without and with a concurrent verbal working memory task was tested within participants, yielding an experimental block requesting sentence production as a single task as well as another experimental block requesting sentence production in the presence of the verbal working memory task. The order of these experimental blocks was counterbalanced across participants.

Results and Discussion

Working Memory Task

Again, dual-task performance was substantially worse compared to single-task performance, \( t(31) = 13.06, p < .001 \). On average, participants made 9.2 % errors (\( SE = 1.3 \)) in the single task, but 29.1 % (\( SE = 1.5 \)) in the dual task.

Sentence Production Task

The raw data were treated as in the previous experiments. Thus, 699 erroneous responses (13.7 %) and 68 outliers (1.3 %) were removed. Table 10 displays mean naming latencies and error rates broken down by load modality (none vs. verbal), primed element, and relatedness.

**Effects from subject-related distractors.** In the analysis of naming latencies, there was a main effect of load modality, reflecting longer naming latencies in the verbal load condition compared to the no-load condition, \( F_1(1,31) = 59.26, p < .001, \eta^2_G = .212, F_2(1,19) = 599.62, p < .001, \eta^2_G = .726 \). There was a main effect of relatedness, indicating faster naming latencies with related than with unrelated distractors, \( F_1(1,31) = 65.33, p < .001, \eta^2_G = .035, F_2(1,19) = 26.96, p < .001, \eta^2_G = .243 \).

For error rates, there was a main effect of load modality, reflecting fewer errors in the no load condition compared to the verbal load condition, \( F_1(1,31) = 4.11, p = .051, \eta^2_G = .016, F_2(1,19) = 6.55, p < .05, \eta^2_G = .054 \). None of the other effects reached significance, all \( ps > .265 \).
Effects from object-related distractors. In the analysis of naming latencies, there was a main effect of load modality reflecting longer naming latencies under verbal load, \( F_1(1,31) = 60.83, p < .001, \eta^2_G = .196, F_2(1,19) = 245.31, p < .001, \eta^2_G = .585. \) The main effect of relatedness was significant in the analysis by participants only, suggesting that distractors phonologically related to the object interfered with the naming response compared to unrelated distractors, \( F_1(1,31) = 5.63, p < .05, \eta^2_G = .002, F_2(1,19) = 2.42, p = .136, \eta^2_G = .016. \)

None of the other effects reached significance, all \( ps > .078. \)

Experiment 9 failed to provide a verification of the claim made throughout Experiments 5 to 8: While the descriptive results, i.e., the size of the phonological effects, parallel the previously obtained ones, no significant interaction between relatedness and load modality was observed for object-related distractors \( (Fs < 1) . \) Thus, statistically speaking, the 10-ms statistical null effect under verbal load does not differ from the 29-ms interference effect without load (which was significant in the analysis by participants only). The following interim summary as well as the General Discussion will return to this issue.
Table 10

Mean naming latencies (in ms) and error rates (in %) broken down by load modality, primed element, and relatedness for Experiment 9.

<table>
<thead>
<tr>
<th></th>
<th>No load</th>
<th></th>
<th>Verbal load</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>E%</td>
<td>M</td>
<td>E%</td>
</tr>
<tr>
<td>Subject-related</td>
<td>799</td>
<td>10.5</td>
<td>1037</td>
<td>14.5</td>
</tr>
<tr>
<td></td>
<td>(34)</td>
<td>(1.6)</td>
<td>(44)</td>
<td>(1.9)</td>
</tr>
<tr>
<td>Subject-unrelated</td>
<td>891</td>
<td>13.4</td>
<td>1114</td>
<td>14.8</td>
</tr>
<tr>
<td></td>
<td>(40)</td>
<td>(1.9)</td>
<td>(40)</td>
<td>(2.2)</td>
</tr>
<tr>
<td>Difference</td>
<td>-92***/***</td>
<td>-3.0ns/†</td>
<td>-76***/**</td>
<td>-0.3</td>
</tr>
<tr>
<td></td>
<td>(14)</td>
<td>(1.9)</td>
<td>(15)</td>
<td>(2.0)</td>
</tr>
<tr>
<td>Object-related</td>
<td>891</td>
<td>14.1</td>
<td>1103</td>
<td>16.4</td>
</tr>
<tr>
<td></td>
<td>(40)</td>
<td>(1.5)</td>
<td>(42)</td>
<td>(2.4)</td>
</tr>
<tr>
<td>Object-unrelated</td>
<td>862</td>
<td>12.0</td>
<td>1093</td>
<td>13.4</td>
</tr>
<tr>
<td></td>
<td>(37)</td>
<td>(1.3)</td>
<td>(42)</td>
<td>(1.5)</td>
</tr>
<tr>
<td>Difference</td>
<td>29*/ns</td>
<td>2.0</td>
<td>10</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>(13)</td>
<td>(1.8)</td>
<td>(13)</td>
<td>(2.4)</td>
</tr>
</tbody>
</table>

Note. Standard error of the mean (SE) is given in brackets. Positive difference scores reflect phonological interference, and negative difference scores reflect phonological facilitation. Superscripts indicate significance: †p < .10 (marginally significant), *p < .05, **p < .01, ***p < .001.
Interim Summary: The Flexibility of Phonological Advance Planning

Experiments 5–9 explored the scope of advance planning at the phonological level in sentence production under different working memory load conditions. Figure 8 provides an overview of the results from Experiments 5–8, depicting performance in the respective working memory task(s) (upper panel, in % error) as well as distractor effects on naming latencies (middle panel) and error rates (lower panel) in the sentence production task. Parallel to the interim summary of abstract-lexical planning, the following remarks will first focus on the comparison of Experiments 5–7, i.e., the contrast between no load vs. visuospatial load vs. verbal load, and then speak to the two additional experiments conducted (Experiments 8 and 9).

In terms of the performance in the working memory task, single-task performance in both the visuospatial and verbal task was comparable across participant samples. Also, performance was substantially worse in the dual-task situation (i.e., when the respective working memory task was performed concurrently with the sentence production task) compared to the single-task situation. Moreover, performance in the verbal working memory task was disrupted more strongly in the dual-task situation than performance in the visuospatial working memory task, $F(1,62) = 31.10, p < .001, \eta^2_G = .06$, for the interaction of WM task (visuospatial vs. verbal) and test situation (single- vs. dual-task).

With regard to overall naming latencies and error rates from the sentence production task, a similar impact from the working memory task emerged. Compared to the single-task situation (Experiment 5: 777 ms and 13.9 %, unrelated conditions only), a concurrent visuospatial working memory task substantially increased naming latencies (Experiment 6: 872 ms and 12.6 %), and a concurrent verbal WM task increased naming latencies and also error rates to an even larger extent (Experiment 7: 1054 ms and 17.4 %). This overall pattern strongly resembles what was observed in Experiments 1–3. Again, the more similar dual-task situation (verbal working memory task with sentence production) resulted in a stronger performance decline in both tasks than the less similar dual-task situation (visuospatial working memory task with sentence production). This correspondence between Experiments 1–3 and 5–7 is to be expected because the processes leading to different degrees of dual-task interference are determined by the kind and similarity of tasks involved (which were the same in Ex-

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6 The data from Experiment 9 are not shown in this figure because contrary to Experiments 5–9, it tested a load/no-load manipulation within participants.
periments 1–3 and Experiments 5–7) and should not be affected by the types of distractors tapping different processing levels in one of the tasks (which differed across the sets of experiments).

The most important finding from this second set of experiments is that the concurrently performed verbal WM task effectively reduced the scope of advance planning at the phonological level. In the absence of a concurrent cognitive load (Experiment 5), both the initial and the final element of the target utterance were found to be activated on the phonological level, and this planning scope persisted when a visuospatial load was imposed (Experiment 6). However, in the presence of a concurrent verbal load, the planning scope exhibited greater flexibility: Experiments 7 and 8 did not obtain any significant object-related effect for a wide SOA range (150, 300, and 450 ms), suggesting that the planning scope was indeed reduced when the sentence had to be produced under a verbal load. Ideally, this pattern should be substantiated in an interaction of (object) relatedness, SOA (150 ms vs. 300 ms), and load modality (none vs. visuospatial vs. verbal). This interaction, however, turned out to be non-significant for naming latencies, $ps > .25$ and to be only marginally significant in the analysis by participants for error rates, $F_1(2,93) = 2.65, p = .08$, $n^2 = 0.01$, $F_2(2,38) = 3.23, p = .05$, $n^2 = .02$. This might be due to the fact that these experiments target at the online measurement of a highly complex process (production of sentences triggered by incomplete visual input), which is difficult to tackle even without adverse circumstances (e.g., a concurrent working memory load; cf. Bock, 1996). The complexity of the task is manifested in rather long sentence production latencies and increased variability among participants. These factors reduce the chance of obtaining significant higher level interactions, in particular if these involve between-participant comparisons. Unfortunately, employing a within-participant design in Experiment 9 (testing SOA 150 ms only) failed to show an interaction of relatedness and load (none vs. verbal) as well, while, however, replicating the individual effects.

One potential problem that emerges from the within-participants design employed in Experiment 9 is the fact that the order of load modality had to be counterbalanced between participants (i.e., 16 participants started with the no load block and 16 with the verbal load block). While this aspect of the experimental design intends to rule out possible sequence effects, it is not clear to what extent a given sequence (i.e., no load first vs. verbal load first) influences the degree to which the entire sentence is planned ahead or not. For instance, it is possible that participants who started with the no-load block used a strategy which pushed them toward a larger planning scope even in the verbal load block, while the other half of the participants who started out with the (intuitively more difficult) verbal load block did not
employ such an approach. In fact, when looking at the descriptive effects of the two groups, participants who started with the no-load block showed a (non-significant) 15-ms interference effect from object-related distractors under verbal load, while participants who started with the verbal load block only showed a 4-ms difference. Thus, even though a within-experiment design theoretically allows for a better contrast of the different load conditions, the results obtained thereby should be taken with a grain of salt as well.

Compared to planning on the abstract-lexical level, phonological advance planning displayed much more variability. Overall, the results suggest that in contrast to no load or a visuospatial load, a concurrent verbal load effectively reduces the phonological planning scope. However, while the main effect of object-relatedness was indeed not significant in Experiments 7 and 8, conclusions with respect to the susceptibility of phonological advance planning to a verbal working memory load should be drawn cautiously. Descriptively, the size (and polarity) of the object-related effects in Experiments 7 and 8 were found in a comparably large array, ranging from 12 ms facilitation to 17 ms interference. This allows the objection that what these experiments show is not a null effect per se as suggested by the results from the ANOVAs, but rather an average of the undoubtedly greater variance found in these cases. In a similar vein, the failure to find both between- and within-experiment interactions of load modality and object-relatedness emphasise the large variability which might be attributed to other mechanisms. Thus, it is possible that factors which simply were not measured with the current design moderate the extent to which the phonological planning scope can be reduced by a verbal load. Verbal working memory capacity beyond what was measured by the backward digit span, for instance, might be a contributing factor, maintaining the larger planning scope even under verbal load for some speakers while effectively reducing it for others.

The present experiments clearly were not set out to test this possibility. Instead, they provide initial evidence that the phonological planning scope can, but does not have to be reduced by a concurrent verbal load, while it is robust to the influence of a visuospatial load. The next chapter will summarise all findings obtained in the experiments presented here.
Figure 8. Overview of Experiments 5–8: working memory performance and distractor effects on naming latencies and error rates in sentence production. The sentence production task was performed as a single task in Experiment 5 and as a dual task in Experiments 6–8. Positive scores on distractor effects (middle and lower panel) reflect phonological interference from related distractors; negative scores reflect phonological facilitation.
5. **Summary and Conclusions**

The aim of the experiments presented in this thesis was to elucidate the relationship between advance planning processes in sentence production and different working memory components. Two sets of largely parallel experiments investigated to what extent advance planning on the abstract-lexical (Experiments 1–4) and phonological level (Experiments 5–9) can be modulated by a concurrent visuospatial or verbal working memory load. After having presented the results in the previous sections, this final chapter will summarise the findings, link them to the state-of-the-art in the field and point out possible caveats that future research should address.

In Experiment 1, participants produced subject-verb-object sentences while ignoring auditory distractors semantically related or unrelated to the subject or object, i.e., the first or final element, of the utterance. Subject- and object-related interference effects indicated that the entire sentence was planned ahead at the abstract-lexical level before articulation began. In Experiments 2 and 3, a concurrent visuospatial and verbal working memory task was introduced. Performing the sentence production task as a dual task by means of the imposed working memory load increased naming latencies but crucially, the subject- and object-related distractor effects persisted. This suggests that abstract-lexical advance planning was not affected by a cognitive load, regardless of its modality. Experiment 4 was a control experiment in which participants only had to produce the inflected verb instead of the entire sentence; this was conducted to rule out the possibility that the robustness of the semantic interference effects was a result of the experimental design rather than advance planning proper.

Experiments 5–9 were analogous to the first set of experiments, except this time the phonological processing level was manipulated. Under no load (Experiment 5), subject-related facilitation and object-related interference indicated that, at the phonological level, the entire sentence was planned ahead before articulation began. Contrary to the experiments investigating abstract-lexical advance planning, the working memory tasks imposed in Experiments 6–9 revealed a differential pattern. That is, the object-related phonological interference effect persisted under visuospatial load (Experiment 6) but disappeared under verbal load (Experiments 7 and 8). This suggests that phonological advance planning was impaired by the verbal load. Experiment 9 contrasted the difference between a no-load and a verbal
load condition within participants, yielding descriptively the same, albeit statistically inconsistent results.

Taken together, the experiments showed that a concurrent visuospatial working memory task did not affect the size of the advance planning scope both at the abstract-lexical and phonological level. A concurrent verbal working memory task, by contrast, reduced advance planning at the phonological level, but not at the abstract-lexical level. The fact that both the abstract-lexical and phonological planning scopes were preserved under visuospatial load supports the theory that working memory is separable into a distinct visuospatial and verbal subsystem (e.g., Baddeley, 1986; Baddeley & Hitch, 1974; Logie, 1986; Shah & Miyake, 1996). While the abstract-lexical planning scope up to the utterance-final element also held under verbal load, this was not the case for the phonological planning scope. This suggests that in planning a complex utterance, the production system can maintain an abstract-lexical advance planning scope beyond the initial noun phrase despite a highly demanding concurrent task, whereas the phonological advance planning scope is reduced as a consequence of performing a concurrent verbal working memory task.

However, dual-task performance was disrupted to a comparable degree between the two sets of experiments. That is, while error rates in the dual-task situation did increase for the visuospatial task compared to single-task performance, this increase was significantly higher for the verbal working memory task, regardless of which processing level was manipulated in the sentence production task. Overall, this speaks in favour of a general capacity limit of working memory (cf. e.g., Cowan, 2001, 2005) and a greater susceptibility to interference as a function of task similarity (cf. Wickens, 2008).

In terms of the abstract-lexical advance planning scope, the presented results replicate and extend those reported by Wagner et al. (2010). The authors obtained semantic interference effects for the first and second noun phrase of utterances like “the book is next to the monk” both with and without a concurrent verbal working memory task. However, whereas the absolute size of the semantic interference effects in that study increased for both noun phrases with concurrent working memory load compared to sentence production without load (Experiment 1a vs. Experiments 3a and 3b in Wagner et al., 2010), this was not the case in the present study (Experiment 1 vs. Experiment 3). Wagner et al. argued that the increase in distractor effects under conditions of cognitive load might have been due to an increase in task demands. However, one should note that the sentence production task in this thesis was probably more demanding than in the study by Wagner et al. (2010) even without a concurrent load. In their study multi-object displays were used, i.e., the subject and object of an ut-
Summary and Conclusions

The current results can be reconciled less easily with those reported by Slevc (2011), who reported a greater influence of a verbal working memory task (as reflected by a decreased prioritization of given elements) on syntactic planning compared to a spatial working memory task. However, it is worth noting that Experiment 3 by Slevc contains a crucial asymmetry on which the author did not place much emphasis: Although there indeed was a reduction of given-new ordering under verbal load, participants made substantially more mistakes on the memory recall task in the visuospatial condition (19.4 % errors for the visuospatial as opposed to 6.8 % errors for the verbal working memory task). If verbal working memory and lexical retrieval processes as measured by the syntactic variability share a common resource, the reduced use of given-new ordering in the sentence production task should be accompanied by an analogous decline in accuracy in the verbal, but not in the visuospatial working memory task. Thus, it is questionable to what extent the verbal working memory-specific effect reported by Slevc (2011) can be directly related to both the design and results this thesis. Possibly the experimental design by Slevc allowed for a greater prioritisation of the verbal working memory material.

Another possible criticism is that the verbal working memory task administered here might have been too phonological in nature, thus only causing an overlap of phonological, but not abstract-lexical processing resources. Studies from patients with brain lesions (e.g., Martin & He, 2004; Martin & Romani, 1994; Martin, Shelton, & Yaffee, 1994) as well as experimental and imaging studies (e.g., Crosson et al., 1999; Shivde & Anderson, 2011) have put forward the idea that verbal working memory can be divided into a phonological and a semantic subsystem, in contrast to Baddeley and Hitch’s conception of the phonological loop comprising the phonological codes of verbal elements only (Baddeley, 1986; Baddeley & Hitch, 1974; Baddeley & Hitch, 1994). Therefore, it is feasible that the planning scope at the abstract-
lexical level might be modulated if a different, more semantic verbal working memory load is introduced, while it is uninfluenced by the primarily phonological verbal working memory task in the present study. In fact, Wagner et al. (2010) did find a reduction of the abstract-lexical planning scope if the participants had to adapt their utterance format to some conceptual feature of the message elements. Although the load imposed by such a task cannot be attributed to verbal working memory per se, it does provide first evidence that imposing a cognitive load that is not phonological can actually affect the size of the abstract-lexical planning scope. However, Martin et al. (2014) directly contrasted the influence of a phonological and a semantic working memory task (participants decided whether a probe word rhymed with previously memorised items or belonged to the same category, respectively) on semantic-syntactic advance planning and did not find an effect of either of those working memory tasks on the planning scope. This provides further evidence that advance planning on a lexical level might indeed be more robust to interference.

The finding that the phonological advance planning scope is restricted by a verbal, but not a visuospatial load further extends recent research on the flexibility of phonological advance planning. Oppermann et al. (2010) showed that speakers reduce their phonological planning scope if the production task is more demanding. Specifically, in their study the phonological planning scope extended to the utterance final element in simple SVO sentences (in a situation with predefined word order for all utterances; analogous to Experiment 5), but was reduced to the middle element when speakers had to adjust their utterance format (SOV vs. VSO) anew for each utterance. While this provided first support for a flexible adaptation of phonological planning processes to immediate task demands, the current experiments demonstrate that this flexibility seems to apply particularly to situations in which these task demands draw on specific processing resources utilised for phonological advance planning. However, as mentioned in the Interim Summary of Experiments 5−9, this conclusion should be treated with caution. The reduction of the phonological planning scope as indicated by a disappearance of the object-related interference effect in this work could only be shown for individual experiments and did not stand up to more elaborate statistical scrutiny; both between- and within-participant analyses did not yield a significant interaction of load modality (none vs. verbal) and relatedness (phonologically related vs. unrelated to the object of the sentence). Future work extending this line of research should therefore aim at disentangling potential factors which influence this variability for individual speakers.

To sum up, by contrasting the influence of different working memory loads on different levels of advance planning, this thesis provides first evidence for the involvement of verbal
working memory in phonological but not abstract-lexical advance planning as well as for the independent functioning of visuospatial working memory processes altogether. Chapter 2 mentioned that the distributional properties of naturally occurring word and exchange errors led to the idea that the scope of advance planning during abstract-lexical/grammatical encoding is notably larger than the scope of advance planning during phonological encoding (Garrett, 1975, 1980). A number of recent laboratory studies (Oppermann et al., 2010; Schnur et al., 2006) exploring online sentence production, however, showed that the scope of phonological advance planning may as well extend beyond the initial noun phrase. This discrepancy between speech errors—which usually originate from manually collected speech error corpora observing natural speech—and online data likely has something to do with the circumstances under which speech errors are produced. In standard sentence production experiments in laboratory settings, participants repeatedly produce the same predefined sentence leaving only a minimum of both lexical and structural degrees of freedom (cf. Bock, 1996). In contrast, in everyday life, humans are often engaged in other activities while speaking, and some of these concurrent activities might have a stronger impact on phonological advance planning as opposed to abstract-lexical planning, which is in line with the conclusions drawn from the experiments presented.
Zusammenfassung

Theoretischer Hintergrund

Der Großteil der alltäglichen gesprochenen Sprache findet statt, während wir gleichzeitig noch eine andere kognitive Tätigkeit ausführen, z. B. uns eine zuvor eingeprägte Wegbeschreibung oder die Telefonnummer aus einer Anzeige merken. Ziel dieser Arbeit war es, zu untersuchen, inwiefern solche zusätzlichen kognitiven Aufgaben die Art, wie wir unsere Äußerungen vorbereiten, beeinflussen. Dabei wurde getestet, (a) ob die Größe der Vorausplanungsspanne auf der abstrakt-lexikalischen und phonologischen Ebene durch eine zusätzliche ausgeführte Arbeitsgedächtnisaufgabe beeinträchtigt wird, und (b) ob dies in Abhängigkeit der Modalität jener Arbeitsgedächtnisaufgabe (visuell-räumlich vs. verbal) differenziell geschieht.


Methode und Hypothesen

Um zu untersuchen, inwiefern sich die Vorausplanung durch eine spezifische Gedächtnisbelastung einschränken lässt, wurde eine Kombination des erweiterten Bild-Wort-Interferenz-Paradigmas (Sprachproduktionsaufgabe) und einer zusätzlichen verbalen oder visuell-räumlichen Arbeitsgedächtnisaufgabe (kognitive Belastungsaufgabe) verwendet. In der Sprachproduktionsaufgabe sahen die Probanden den Agens (z. B. einen Mönch) einer vor-
Zusammenfassung

ab gelernten visuellen Szene und beschrieben, was dieser getan hat, mit einem Subjekt-Verb-Objekt-Satz (z.B. „der Mönch las das Buch“). Zusätzlich wurden auditive Distraktoren präsentiert, die semantisch oder phonologisch relatiert oder unrelatiert zum Subjekt oder Objekt des Satzes waren. Wird diese Satzproduktionsaufgabe ohne eine zusätzliche Arbeitsgedächtnisaufgabe ausgeführt, sind auf Grundlage früherer Befunde sowohl subjekt- als auch objektrelierte Effekte zu erwarten, die zeigen, dass der gesamte Satz sowohl auf der abstrakt-lexikalischen (indiziert durch einen semantischen Distraktoreffekt, vgl. Meyer, 1996; Wagner et al., 2010) als auch auf der phonologischen Ebene (indiziert durch einen phonologischen Distraktoreffekt, vgl. Oppermann et al., 2010, Schnur et al., 2006) vollständig vorausgeplant wurde, bevor die Artikulation beginnt.

Um den Einfluss kognitiver Belastungen auf die Vorausplanungsspanne zu ermitteln, wurden zwei Arbeitsgedächtnisaufgaben getestet, die parallel zur Satzproduktion auszuführen waren. Die Probanden mussten sich vor jedem Satz einen Stimulus merken (vier Punkte in einem 5x5-Gitter in der visuell-räumlichen Bedingung und fünf Ziffern in der verbalen Bedingung). Nach der Produktion des jeweiligen Satzes entschieden die Probanden per Tastendruck, ob ein präsentierter Rekognitions-Stimulus dem zuvor gemerkten entsprach oder nicht.


Experimente

In zwei Sets von Experimenten wurde der Einfluss der beschriebenen Arbeitsgedächtnisaufgaben auf die Vorausplanungsspanne getestet. In den Experimenten 1 bis 4 wurde die abstrakt-lexikalische Repräsentationsebene und in den Experimenten 5 bis 9 die phonologische Repräsentationsebene untersucht. Experiment 1 galt als Referenzexperiment, um die abstrakt-lexikale Vorausplanungsspanne bei der Satzproduktion ohne zusätzliche Arbeitsge-

**Ergebnisse**

Experiment 1 zeigte semantische Interferenzeffekte sowohl für das Subjekt als auch das Objekt des Satzes und replizierte damit frühere Befunde, die suggerieren, dass alle Elemente eines einfachen Satzes auf abstrakt-lexikalischer Ebene vor Äußerungsbeginn vorausgeplant werden können (Meyer, 1996; Wagner et al., 2010). Diese satzweise Vorausplanungsspanne blieb auch bestehen, wenn eine zusätzliche visuell-räumliche (Experiment 2) oder verbale Arbeitsgedächtnisaufgabe (Experiment 3) eingeführt wurde. Experimente 1 bis 3 geben somit keinen Hinweis darauf, dass die abstrakt-lexikale Vorausplanung durch parallel ablaufende Arbeitsgedächtnisprozesse eingeschränkt wird. Es zeigte sich lediglich der zu erwartende Belastungseffekt, d.h. wenn eine zusätzliche Arbeitsgedächtnisaufgabe ausgeführt wurde, stiegen die Benennungslatenzen im Vergleich zur Einzelaufgabe an. Zudem zeigte sich in den jeweiligen Arbeitsgedächtnisaufgaben ein Anstieg der Fehlerraten in der Doppelaufgabensituation im Vergleich zur Einzelaufgabe, welcher zudem für die verbale Arbeitsgedächtnisaufgabe bedeutend größer ausfiel.

Der objektrelatierte semantische Interferenzeffekt verschwand in Experiment 4, in dem nur das flektierte Verb produziert werden sollte. Dieses Kontrollexperiment bestätigt somit, dass die Effekte aus Experimenten 1 bis 3 als Indizes abstrakt-lexikaler Vorausplanung zu betrachten sind und nicht aus der verwendeten experimentellen Prozedur resultierten.

Experiment 5 zeigte einen subjektrelatierten phonologischen Erleichterungseffekt sowie einen objektrelatierten Interferenzeffekt. Dies spricht für eine satzweise phonologische Vo-
Zusammenfassung

rausplanung und repliziert den Befund von Oppermann et al. (2010). Diese phonologischen Effekte änderten sich nicht durch die Einführung der visuell-räumlichen Arbeitsgedächtnisaufgabe (Experiment 6), jedoch durch die verbale Arbeitsgedächtnisaufgabe (Experiment 7): In letzterem Fall verschwand der objektrelationierte Interferenzeffekt, was für die Reduktion der phonologischen Vorausplanungsspanne unter verbaler Belastung spricht. Dieses Muster zeigte sich ebenfalls in Experiment 8, in dem die Distraktoren zusätzlich in einem späteren Zeitsfenster präsentiert wurden, um sicherzugehen, dass sich der Effekt aufgrund der höheren Benennungslatenzen unter verbaler Belastung nicht einfach zeitlich verschoben hatte. Experiment 9 zeigte schließlich—dieses Mal innerhalb von Probanden—erneut einen objektrelationierten Interferenzeffekt, wenn der Satz isoliert produziert wurde, aber keinen Effekt, wenn zusätzlich eine verbale Arbeitsgedächtnisaufgabe bearbeitet werden musste. Hinsichtlich der Performanz in der Arbeitsgedächtnisaufgabe zeigte sich analog zu den ersten Experimenten ein Anstieg der Fehlerraten in der Doppelaufgaben- im Vergleich zur Einzelaufgabensituation, der jedoch erneut bedeutend größer für die verbale Aufgabe ausfiel.

Diskussion

Summary

Theoretical background

In daily life, we often talk while doing other things at the same time, such as memorizing the way to our destination that we just looked up on a map or a telephone number that we just saw in an advertisement. This thesis addressed the question of whether and in which way these additional cognitive tasks affect the way we plan our utterances. More specifically, it was investigated (a) whether the scope of advance planning in sentence production at the abstract-lexical and the phonological level is affected by a concurrently performed working memory task, and, if so, (b) whether it is affected in a differential way, depending on the nature of that concurrent task (verbal vs. visuospatial).

Extant studies which investigated speech production as an isolated task showed that all elements of a simple sentence can be activated at the abstract-lexical and phonological level prior to speech onset (e.g., Meyer, 1996; Oppermann et al., 2010; Schnur et al., 2006; Smith & Wheeldon, 2004). However, only little research has addressed the question to what extent the size of this planning scope on the two processing levels is affected by different concurrent loads. Wagner et al. (2010) showed that advance planning at the abstract-lexical level was reduced by a conceptual, but not a verbal load (see also Martin et al., 2014), whereas Slevc (2011) found a reduction of planning processes by both visuospatial and verbal working memory load. Oppermann et al. (2010) reported that changing the utterance format on a trial-by-trial basis reduced the size of the phonological planning scope. However, a direct contrast between both processing levels and their susceptibility to different cognitive loads has not been done yet.

Methods and hypotheses

To investigate to what extent the advance planning scope is affected by a specific working memory load, a combination of the extended picture-word interference paradigm (sentence production task) and a concurrent verbal or visuospatial working memory load (cognitive load task) was used. In the sentence production task, participants saw the agent of a previously learnt scene (e.g., a monk) and described what this agent had done using a subject-verb-object sentence (e.g., “the monk read the book”). Additionally, auditory distractors were presented, which were semantically or phonologically related or unrelated to the subject or
the object of the sentence. Based on previous findings, both subject- and object-related effects were expected when this sentence production task is executed without a concurrent working memory task. This would show that the entire sentence has been planned ahead both on the abstract-lexical level (indicated by semantic distractor effects, cf. Meyer, 1996; Wagner et al., 2010) and the phonological level (indicated by phonological distractor effects, cf. Oppermann et al., 2010; Schnur et al., 2006) prior to speech onset.

To determine the influence of cognitive load on the advance planning span, two working memory tasks were tested which had to be executed concurrently to the sentence production task. Prior to each sentence, participants had to memorise a stimulus (four dots in a 5-by-5 matrix in the visuospatial condition and five digits in the verbal condition, respectively). After producing the respective sentence, participants decided via button press if a presented recognition probe was identical to the memorized stimulus or not.

Assuming a capacity limit of the cognitive system, introducing a concurrent working memory task should have a detrimental effect both on the speech production and the working memory task. This can be reflected by an increase in naming latencies (speech production) and error rates (working memory), with the latter being greater for the verbal task because it shares more resources with the speech production task. Additionally, an influence of the secondary (working memory) task on the size of the advance planning scope is possible. This should be reflected in an attenuation of the object-related effects both on the abstract-lexical and phonological level.

Experiments

In two sets of experiments, the influence of the described working memory tasks on the advance planning span was investigated. Experiments 1 to 4 tested the abstract-lexical and Experiments 5 to 9 the phonological processing level. Experiment 1 is considered a reference experiment in order to determine the abstract-lexical advance planning span in sentence production in the absence of a concurrent cognitive load. Then the influence of a concurrent visuospatial and verbal working memory task was tested (Experiments 2 and 3). Experiment 4 was a control experiment in which the utterance format was restricted to the inflected verb form, in order to rule out the possibility that the semantic interference effects occur due to the experimental procedure employed. Experiments 5 to 7 were largely parallel to the first three experiments, with the difference that this time the phonological level was manipulated. Experiment 8 was a control experiment to account for substantially longer naming latencies in the
Summary

presence of a verbal load observed in Experiment 7. Finally, Experiment 9 employed a within-participants design to directly investigate the contrast between a no load and a verbal load condition.

Results

Experiment 1 showed semantic interference effects both for the subject and the object of the sentence and thus replicated earlier findings suggesting that all elements are planned ahead on the abstract-lexical level prior to speech onset (Meyer, 1996; Wagner et al., 2010). This advance planning span up to the utterance-final element persisted if a concurrent visuospatial and verbal working memory task was introduced. Experiments 1 to 3 thus provides no evidence that abstract-lexical advance planning is reduced by a concurrently imposed working memory load, regardless of its modality. However, the expected load effect was obtained, i.e., naming latencies increased in the presence of a cognitive load. Furthermore, there was an increase in error rates in both working memory tasks in the dual-task compared to the single-task situation, which, however, was more pronounced for the verbal working memory task.

The object-related semantic interference effect disappeared in Experiment 4 in which only the inflected verb was produced. This control experiment confirms that the effects obtained in Experiments 1 to 3 can be considered indices of abstract-lexical advance planning rather than artifacts resulting from the experimental procedure.

Experiment 5 showed a subject-related phonological facilitation effect and an object-related interference effect. This also indicates phonological advance planning up to the utterance-final element and replicates results by Oppermann et al. (2010). These phonological effects were not affected when introducing a visuospatial working memory task (Experiment 6). However, when a verbal working memory task was added (Experiment 7), the object-related interference effect disappeared, suggesting a reduction of the phonological advance planning span under verbal load. This data pattern was replicated in Experiment 8 in which the distractors were presented in a later time window; this was done to rule out the possibility that the effect had shifted temporally because of the increased naming latencies under verbal load observed in Experiment 7. Finally, in Experiment 9, an object-related interference effect without load and no effect under verbal load were obtained when this contrast was tested within participants. Regarding the performance in the working memory tasks there was an increase of
error rates in the dual task compared to the single task, which, as in the first set of experiments, was larger for the verbal modality.

Discussion

Nine experiments showed that advance planning in sentence production (1) encompasses all elements of a simple sentence on the abstract-lexical level, regardless of a concurrent working memory load, and (2) is reduced on the phonological level under verbal load, but not without any or in the presence of a visuospatial load. On the one hand, this suggests that both the utterance-initial and -final element of a sentence must be activated on the abstract-lexical level, and this holds even in the presence of a concurrent visuospatial and verbal working memory load. On the other hand, the phonological advance planning span showed to be more flexible, i.e., when executing a concurrent verbal working memory task, the utterance-final element is not activated consistently any more. This finding suggests that the cognitive processes involved in phonological advance planning and verbal working memory share a common resource, as opposed to those underlying abstract-lexical advance planning, which is in line with the multi-component model of working memory by Baddeley (1986). Furthermore, all experiments introducing a concurrent cognitive load resulted in a lower performance both in the speech production task (measured by overall naming latencies) and the working memory task (measured by error rates) compared to the single-task situation. This is consistent with the notion of a capacity limit of working memory (cf. Cowan, 2001). The fact that the verbal working memory task consistently evoked higher error rates in the dual-task situation compared to the visuospatial working memory task moreover provides evidence that the amount of overlap between two tasks (i.e., sentence production and memorizing verbal elements) influences the extent to which performance decreases (cf. e.g., Baddeley, 1986; Wickens, 2008).
References


List of the experimental scene descriptions and distractors used in Experiments 1–4. English translations are given in brackets.

<table>
<thead>
<tr>
<th>Scene description</th>
<th>Subject-related</th>
<th>Subject-unrelated</th>
<th>Object-related</th>
<th>Object-unrelated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Das Beil spaltet den Kürbis. (The hatchet splits the pumpkin.)</td>
<td>Hammer (hammer)</td>
<td>Dorn (thorn)</td>
<td>Melone (melon)</td>
<td>Tasse (cup)</td>
</tr>
<tr>
<td>Der Besen fegt das Laub. (The broom sweeps the foliage.)</td>
<td>Harke (rake)</td>
<td>Kerze (candle)</td>
<td>Unkraut (weed)</td>
<td>Kalb (calf)</td>
</tr>
<tr>
<td>Der Blitz trifft das Haus. (The lightning strikes the house.)</td>
<td>Funken (spark)</td>
<td>Priester (priest)</td>
<td>Zelt (tent)</td>
<td>Unkraut (weed)</td>
</tr>
<tr>
<td>Der Dieb klaut das Geld. (The thief steals the money.)</td>
<td>Räuber (bandit)</td>
<td>Quirl (whisk)</td>
<td>Schatz (treasure)</td>
<td>Brei (porridge)</td>
</tr>
<tr>
<td>Die Gans trinkt das Wasser. (The goose drinks the water.)</td>
<td>Schwan (swan)</td>
<td>Knabe (lad)</td>
<td>Milch (milk)</td>
<td>Nuss (nut)</td>
</tr>
<tr>
<td>Der Hirte schert das Lamm. (The shepherd shears the lamb.)</td>
<td>Bauer (peasant)</td>
<td>Bagger (digger)</td>
<td>Kalb (calf)</td>
<td>Beet (patch)</td>
</tr>
<tr>
<td>Das Huhn pickt das Korn. (The chicken pecks the grain.)</td>
<td>Taube (pigeon)</td>
<td>Schwester (sister)</td>
<td>Nuss (nut)</td>
<td>Milch (milk)</td>
</tr>
<tr>
<td>Der Junge wirft den Ball. (The boy throws the ball.)</td>
<td>Knabe (lad)</td>
<td>Schwamm (sponge)</td>
<td>Frisbee (frisbee)</td>
<td>Schloss (palace)</td>
</tr>
<tr>
<td>Der Kran hebt die Kiste. (The crane lifts the box.)</td>
<td>Bagger (digger)</td>
<td>Soldat (soldier)</td>
<td>Truhe (chest)</td>
<td>Torte (pie)</td>
</tr>
<tr>
<td>Die Lampe beleuchtet das Zimmer. (The lamp lights the room.)</td>
<td>Kerze (candle)</td>
<td>Säge (saw)</td>
<td>Raum (chamber)</td>
<td>Speck (bacon)</td>
</tr>
<tr>
<td>Die Maus frisst den Käse. (The mouse eats the cheese.)</td>
<td>Ratte (rat)</td>
<td>Harke (rake)</td>
<td>Speck (bacon)</td>
<td>Raum (chamber)</td>
</tr>
<tr>
<td>Das Messer schneidet den Kuchen. (The knife cuts the cake.)</td>
<td>Säge (saw)</td>
<td>Ratte (rat)</td>
<td>Torte (pie)</td>
<td>Truhe (chest)</td>
</tr>
<tr>
<td>German</td>
<td>English</td>
<td>German</td>
<td>English</td>
<td>German</td>
</tr>
<tr>
<td>----------------------------</td>
<td>--------------------------------</td>
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<td>--------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>Der Mixer rührt den Teig.</td>
<td>(The mixer stirs the batter.)</td>
<td>Quirl</td>
<td>Nebel</td>
<td>Brei</td>
</tr>
<tr>
<td>Der Mönch liest das Buch.</td>
<td>(The monk reads the book.)</td>
<td>Priester</td>
<td>Hammer</td>
<td>Zeitung</td>
</tr>
<tr>
<td>Die Mutter tröstet das Baby.</td>
<td>(The mother comforts the baby.)</td>
<td>Schwester</td>
<td>Kanne</td>
<td>Säugling</td>
</tr>
<tr>
<td>Die Nadel sticht den Finger.</td>
<td>(The needle pricks the finger.)</td>
<td>Dorn</td>
<td>Bauer</td>
<td>Daumen</td>
</tr>
<tr>
<td>Der Ritter bewacht die Burg.</td>
<td>(The knight guards the castle.)</td>
<td>Soldat</td>
<td>Schwan</td>
<td>Schloss</td>
</tr>
<tr>
<td>Der Schlauch wässert den Rasen.</td>
<td>(The hose waters the lawn.)</td>
<td>Kanne</td>
<td>Taube</td>
<td>Beet</td>
</tr>
<tr>
<td>Die Wolke verdeckt die Sonne.</td>
<td>(The cloud hides the sun.)</td>
<td>Nebel</td>
<td>Räuber</td>
<td>Mond</td>
</tr>
</tbody>
</table>
Appendix B

List of the experimental scene descriptions and distractors used in Experiments 5–9. English translations are given in brackets.

<table>
<thead>
<tr>
<th>Scene description</th>
<th>Distractors</th>
<th>Subject-related</th>
<th>Subject-unrelated</th>
<th>Object-related</th>
<th>Object-unrelated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Der Blitz trifft das Haus.</td>
<td></td>
<td>Blirt</td>
<td>Galk</td>
<td>Haul</td>
<td>Koscht</td>
</tr>
<tr>
<td>(The lightning strikes the house.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Der Dieb stiehlt das Geld.</td>
<td></td>
<td>Diek</td>
<td>Mäbkull</td>
<td>Geft</td>
<td>Haul</td>
</tr>
<tr>
<td>(The thief steals the money.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Die Gans trinkt das Wasser.</td>
<td></td>
<td>Galp</td>
<td>Huhk</td>
<td>Warrok</td>
<td>Hädim</td>
</tr>
<tr>
<td>(The goose drinks the water.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Der Hirte schert das Lamm.</td>
<td></td>
<td>Hicklu</td>
<td>Jusso</td>
<td>Larr</td>
<td>Brien</td>
</tr>
<tr>
<td>(The shepherd shears the lamb.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Das Huhn pickt das Korn.</td>
<td></td>
<td>Huhk</td>
<td>Mitzik</td>
<td>Koscht</td>
<td>Batz</td>
</tr>
<tr>
<td>(The chicken pecks the corn.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Der Hund jagt die Katze.</td>
<td></td>
<td>Hurp</td>
<td>Mölk</td>
<td>Kago</td>
<td>Zekli</td>
</tr>
<tr>
<td>(The dog chases the cat.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Der Junge wirft den Ball.</td>
<td></td>
<td>Jusso</td>
<td>Noffo</td>
<td>Batz</td>
<td>Tein</td>
</tr>
<tr>
<td>(The boy throws the ball.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Der Kellner bringt den Wein.</td>
<td></td>
<td>Kebmus</td>
<td>Meffot</td>
<td>Weif</td>
<td>Larr</td>
</tr>
<tr>
<td>(The waiter brings the wine.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Die Köchin probiert die Suppe.</td>
<td></td>
<td>Kömmal</td>
<td>Mabof</td>
<td>Sutto</td>
<td>Bemo</td>
</tr>
<tr>
<td>(The cook tastes the soup.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Das Mädchen trägt die Palme.</td>
<td></td>
<td>Mäbkull</td>
<td>Blirt</td>
<td>Pafni</td>
<td>Geft</td>
</tr>
<tr>
<td>(The girl carries the palm.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Der Maler streicht die Wand.</td>
<td></td>
<td>Mabof</td>
<td>Tralsum</td>
<td>Watz</td>
<td>Buf</td>
</tr>
<tr>
<td>(The painter paints the wall.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Die Maus frisst den Käse.</td>
<td></td>
<td>Mauk</td>
<td>Hurp</td>
<td>Kära</td>
<td>Pafni</td>
</tr>
<tr>
<td>(The mouse eats the cheese.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Das Messer schneidet den Kuchen.</td>
<td></td>
<td>Meffot</td>
<td>Diek</td>
<td>Kudil</td>
<td>Fizak</td>
</tr>
<tr>
<td>(The knife cuts the cake.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Der Mixer rührt den Teig. (The mixer stirs the batter.)</td>
<td>Mitzik</td>
<td>Kömmal</td>
<td>Tein</td>
<td>Kago</td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
<td>--------</td>
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<td>------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>Der Mönch liest das Buch. (The monk reads the book)</td>
<td>Mölk</td>
<td>Pfeks</td>
<td>Buf</td>
<td>Weif</td>
<td></td>
</tr>
<tr>
<td>Die Mutter tröstet das Baby. (The mother comforts the baby.)</td>
<td>Muppok</td>
<td>Nalom</td>
<td>Bemo</td>
<td>Kära</td>
<td></td>
</tr>
<tr>
<td>Die Nadel sticht den Finger. (The needle pricks the finger.)</td>
<td>Nalom</td>
<td>Muppok</td>
<td>Fizak</td>
<td>Warrok</td>
<td></td>
</tr>
<tr>
<td>Die Nonne schreibt den Brief. (The nun writes the letter.)</td>
<td>Nofoo</td>
<td>Hicklu</td>
<td>Brien</td>
<td>Watz</td>
<td></td>
</tr>
<tr>
<td>Das Pferd tritt das Zebra. (The horse kicks the zebra.)</td>
<td>Pfeks</td>
<td>Mauk</td>
<td>Zekli</td>
<td>Sutto</td>
<td></td>
</tr>
<tr>
<td>Der Traktor zieht den Hänger. (The tractor pulls the trailer.)</td>
<td>Tralum</td>
<td>Kebmus</td>
<td>Hädim</td>
<td>Kudil</td>
<td></td>
</tr>
</tbody>
</table>
Curriculum Vitae

2011 – 2014  Graduate school „Function of attention in cognition“
Leipzig University
doctoral project supervised by Prof. Dr. Jörg D. Jescheniak

2011  Diploma, Psychology
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Leipzig University

Leipzig University
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Jana Klaus