The minimum requirements of language control: Evidence from sequential predictability effects in language switching

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Abstract

The current study systematically examined the influence of sequential predictability of languages and concepts on language switching. To this end, two language switching paradigms were combined: to measure language switching with a random sequence of languages and/or concepts, a language switching paradigm was used that implements visual cues and stimuli. The second paradigm implements a fixed sequence of languages and/or concepts to measure predictable language switching. Four experiments that used these two paradigms showed that switch costs were smaller when both the language and concept were predictably known, whereas no overall switch cost reduction was found when just the language or concept was predictable. These results indicate that knowing both language and concept (i.e., response) can resolve language interference. However, interference resolution does not start solely based on the knowledge of which concept or language one has to produce. We discuss how existent models need to be revised to accommodate for these results.

(153 words)

Bilinguals rarely produce words in a language different from the target language during natural language production (Poulisse, 2000; Poulisse & Bongaerts, 1994). The process that makes sure that bilinguals stay within the target language is called bilingual language control (e.g., Green, 1998). Put differently, language control is necessary to ensure that a bilingual selects words in the correct language in order to produce the intended verbal output. An important experimental approach to investigate language control is language switching (e.g., Christoffels, Firk & Schiller, 2007; Costa & Santesteban, 2004; Green, 1998; Meuter & Allport, 1999; Philipp & Koch, 2009).

Basic language switching characteristics

Language switching paradigms

In the current study, we implemented two language switching paradigms or a hybrid of these two paradigms. The first is the cued language switching paradigm, which is very prominent in the language switching literature (e.g., Costa & Santesteban, 2004; Declerck, Koch & Phillip, 2012; Meuter & Allport, 1999; Philipp, Gade & Koch, 2007). This task consists of naming a visually presented object or digit (see Figure 1) in the same language as the previous trial (repetition trial) or in another language as the previous trial (switch trial). The language assignment during cued language switching is derived from visually presented language cues (e.g., different color squares for different languages). These language cues are either presented prior to or simultaneous with a stimulus. Hence, due to the visually presented stimulus, which triggers the desired response, a random language sequence and concept sequence can be implemented.

---- Please insert Figure 1 about here ----

The second language switching paradigm is the recently developed sequence-based language switching paradigm (Declerck, Philipp & Koch, 2013). Contrary to the cued language switching paradigm, in the sequence-based language switching paradigm, both the language sequence and concept sequence are endogenously triggered. For the concept sequence, this means that concepts follow an overlearned sequence, such as weekdays or numbers, or the participants have to learn a new fixed concept sequence prior to the experiment. The required language is also memory-based in that it changes after every second trial (i.e., alternating language sequence; L1-L1-L2-L2-L1 etc.; see e.g., Festman, Rodriguez-Fornells & Münte, 2010; Jackson, Swainson, Mullin, Cunnington & Jackson, 2004). Since both the concept sequence and language sequence are memory-based, no visual stimuli are needed in the sequence-based language switching paradigm. For Figure 1 this means that the sequence-based language switching paradigm does not require the top two panels (i.e., visible cues and stimuli), but can elicit the required response based on purely endogenous triggers. Since no visual signal is given which instructs the participants to produce a response, an auditory response-signal is implemented that indicates that the next concept can be named in the correct language.

Because both the language sequence and concept sequence are predictable, participants can prepare for the upcoming trial in the sequence-based language switching paradigm. Yet, this is typically not the case in cued language switching. This entails that with cued language switching participants are generally unaware of which concept and language will be required in the next trials (i.e., an unpredictable language sequence and concept sequence)[1].

In the current study, we made use of both language switching paradigms to investigate the role of language and concept predictability in bilingual language control. More specifically, we independently manipulated the predictability of the language sequence and of the concept sequence during language switching. On an empirical level, these results would inform us about the effects of preparing different aspects of a word in language switching. Theoretically, these results help specify the specific roles that language and concept play during language control. This is of major theoretical interest since language control models have assumed that part of language control is solely based on language information, while further interference resolution occurs when both language and concept are known (see below).

Markers of language control in language switching

In both of these language switching paradigms, the relevant language either repeats or switches to another language and in both paradigms responses are slower when switching between languages than when the same language has to be repeated (e.g., Costa & Santesteban, 2004; Declerck et al., 2013; Linck, Schwieter & Sunderman, 2012; Meuter & Allport, 1999; Philipp et al., 2007). The performance difference found between these two types of trials is known as “switch costs” and is assumed to be a marker for language control (e.g., Christoffels et al., 2007; Green, 1998).

Another marker for language control, namely “mixing costs” (e.g., Christoffels et al., 2007; Declerck et al., 2013), can be obtained by contrasting the performance between pure language blocks, in which only one language is relevant, and mixed language blocks, in which participants switch between two (or more) relevant languages. Typically, better performance is observed during pure language blocks than during mixed language blocks, thus constituting mixing costs (e.g., Christoffels et al., 2007; Declerck et al., 2013; Gollan & Ferreira, 2009; Wang, Kuhl, Chen & Dong, 2009).

However, according to some theoretical accounts, switch costs and mixing costs are mainly markers for language interference rather than for active “executive” language control (e.g., Allport, Styles & Hsieh, 1994). This entails that any difference in switch costs or mixing costs could solely refer to a difference in language interference. In contrast, language control is assumed to be a process of language interference resolution (e.g., Green, 1998). Hence, a more informative marker for language control are preparatory effects on switch costs or mixing costs, since these allow for advanced (i.e., preparatory) interference resolution (e.g., Verhoef, Roelofs & Meyer, 2009). During preparation, the participants can exploit knowledge about the to-be-produced response which should result in interference resolution. Yet, there are surprisingly few language switching studies that have investigated preparatory processes, especially when compared against the large proportion of task switching studies that focused on preparatory processes (e.g., Altmann, 2004; Logan & Bundesen, 2003; Mayr & Kliegl, 2003; Meiran, 1996; Monsell & Mizon, 2006; Rogers & Monsell, 1995). Furthermore, as we describe below, those language switching studies that did investigate preparation effects found an inconsistent pattern of results across studies.

Note that preparation can be examined in several different ways (for a review of preparation processes in a switching paradigm, see Kiesel et al., 2010). In the language switching literature this has been investigated by manipulating either time-based preparation or predictability-based preparation.

For example, by manipulating the time interval between language cue and stimulus, Costa and Santesteban (2004) showed that language switch costs are smaller when language preparation time increases. Yet, a smaller switch cost difference due to language preparation time was not observed by Philipp et al. (2007). Furthermore, Macnamara et al. (1968) also did not find any time-based preparation effect on mixing costs, suggesting that language preparation effects are not very robust in language switching. This inconsistent pattern across different studies (Costa & Santesteba, 2004; Macnamara et al., 1968; Philipp et al., 2007) makes further examination of the role of language preparation in language switching essential.

Next to time-based language preparation, Macnamara et al. (1968) also investigated the effect of language predictability on language switching by contrasting performance in blocks with a predictable language sequence with that in an unpredictable language sequence. The data of Macnamara et al. (1968) revealed that a predictable language sequence reduces mixing costs compared to an unpredictable language sequence and thus demonstrates a predictability-based reduction of language mixing costs.

Finally, Declerck et al. (2013) introduced the already described sequence-based language switching paradigm, in which predictability could be exploited to prepare the upcoming response. Yet, the main aim of this study was to investigate whether switch costs would be elicited when both the language and concept sequence are predictable (i.e., when the response can be prepared). According to reconfiguration models (e.g., Mayr & Kliegl, 2003; Rogers & Monsell, 1995; Rubinstein, Meyer & Evans, 2001; for reviews, see Monsell, 2003; Kiesel et al., 2010; Vandierendonck, Liefooghe & Verbruggen, 2010), a substantial reduction of switch costs, or even elimination of switch costs, should be observed when abundant time is given and both the concepts and languages are predictable. Still, Declerck et al. (2013) did find significant switch costs using the sequence-based language switching paradigm, which uses a predictable language and concept sequence. To assure that the participants exploited the predictable language sequence and concept sequence, response preparation was examined by manipulating the inter-trial interval while using a predictable language and concept sequence. Hence, this study manipulated time-based preparation while the languages and concepts could be prepared on the basis of predictability. The results showed that a longer time to prepare for both language and concept leads to smaller switch costs, which indicates a time-based preparation benefit when both concept and language, and thus the response, can be prepared.

However, because of the manipulation of response preparation time in Declerck et al. (2013), we cannot be sure about which mechanisms actually caused the smaller switch costs. Put differently, the switch costs could be reduced because of a longer preparation time with the predictable language sequence, because of a longer preparation time with the predictable concept sequence, or because of a combination of both the predictable language sequence and concept sequence (i.e., predictable response sequence). So, the differential influence of language and concept preparation has not been examined when both are predictable.

It will be apparent by now that some studies have looked into the impact of language preparation on switch costs and mixing costs (Costa & Santesteba, 2004; Macnamara et al., 1968; Philipp et al., 2007) and preparation of both language and concept on switch costs

(Declerck et al., 2013). Yet, no language switching studies have sought to isolate the influence of concept preparation in a language switching setting. This line of research could be crucial, since it is assumed that concepts activate the target lemma and its translation-equivalent lemma. Hence, some interference between lemmas could be resolved by concept preparation. Yet, this does not necessarily pertain to language interference. Furthermore, some models have opted for differential strengths in the connection between concepts and their respective first language (L1) and second language (L2) lemmas (e.g., Kroll & Stewart, 1994). Hence, any influence of concept predictability could be different between languages.

Models of control

The results of language switching studies that examined preparation processes can be used to specify the assumptions made by models of control. One influential language control model, named the inhibitory control model (ICM; Green, 1998), assumes that language control mainly consists of persisting, reactive inhibition of the non-target language. Language interference resolution (i.e., inhibition) occurs at two functional processing stages according to the ICM (see Figure 2). First off, the ICM assumes that language interference resolution occurs between language schemas, which are “mental devices” that are implemented to achieve task-specific goals. In turn, these language schemas affect language tags, which inhibit the lemmas of the other language. Yet, according to the ICM the language tags are not altered until the concepts have activated their lemmas. So, any language interference between translation-equivalent lemmas will not be resolved until the concept is known. However, some interference resolution can occur between the language schemas prior to knowing the concepts.

---- Please insert Figure 2 about here ----

It is interesting to note that the ICM assumes that control occurs in a similar fashion as in the proactive interference model (Allport, Styles & Hsieh, 1994), which is a model derived from the task switching literature. On the other hand, its assumptions regarding the functional locus of control processes are in line with another model of the task switching literature, namely the reconfiguration model (e.g., Mayr & Kliegl, 2003; Rogers & Monsell, 1995; Rubinstein, Meyer & Evans, 2001). The reconfiguration model also assumes two stages of control processes (i.e., two stages of reconfiguration). The first stage consists of a reconfiguration to the goal of the new task (i.e., language in the current study) and can be executed before the presentation of the stimulus. Part of the reconfiguration can thus be accounted for by this first stage. A second reconfiguration stage follows during stimulus presentation (i.e., concept in the current study), which requires the task rules to be activated. Taken together, according to the reconfiguration model, language switch costs indicate, at least to some degree, the time needed to reconfigure to a novel language with a specific concept. How these models relate to the current study will be discussed in the next section.

Outline of the present study

To address the assumptions of the ICM (and those of the reconfiguration model), we aimed at a systematic investigation of sequential predictability of languages and/or concepts in language switching. In four experiments, using a hybrid of the cued language switching paradigm and the sequence-based language switching paradigm, the effect of language predictability and concept predictability was investigated (see Figure 3 for an overview of the predictability manipulations of each experiment).

---- Please insert Figure 3 about here ----

In Experiment 1, language switching with a predictable language sequence was contrasted with language switching with a random language sequence, while the concept sequence was predictable in both conditions. Hence, this experiment should give us an idea on the role of languages when information about the concepts is also provided. In Experiment 2, a predictable sequence of concepts was contrasted with a random sequence of concepts, while the language sequence was predictable in both conditions. This experiment explores the role of concepts when information about the languages is also provided. According to the ICM, language interference resolution can be completed between lemmas, after both the language and concept are known. Hence, smaller switch costs should be found when both the language and concept are known relative to when only one of these is known.

Experiment 3 contrasted a predictable language sequence with a random language sequence, while the concept sequence was unpredictable in both conditions. This experiment investigated the sole influence of languages without any information about the concepts. According to the ICM, smaller switch costs should be elicited when only the language sequence is predictable contrary to when the language sequence and the concept sequence are both unpredictable, because the ICM assumes that some language interference resolution occurs between language schemas.

Finally, in Experiment 4, a predictable sequence of concepts was contrasted with a random sequence of concepts, while the language sequence was unpredictable in both conditions, which allowed us to investigate the sole influence of concepts without any information about the languages. Since the ICM assumes that language control starts with the two languages influencing each other, we could assume to find no switch cost difference between the two conditions in this experiment.

Furthermore, we were also interested in investigating two methodological aspects of language switching, which differ between the cued language switching paradigm and the sequence-based language switching paradigm. This led us to also investigate the effect of visual language cues and visual presentations of concepts (i.e., digits) on language switching in Experiments 1 and 2 respectively (see Figure 4 for an overview of the manipulations of visual availability of language cue and stimulus in Experiments 1 and 2). In Experiment 1, language switching with visual language cues was contrasted with language switching without visually presented language cues, while the language sequence and concept sequence was predictable in both conditions. Hence, this experiment should give us an idea about the role of explicit, visual language cues in language switching. In Experiment 2, the concepts could be either visually presented (i.e., digits) or participants had to solely rely on the memorized sequence of concepts, while the language sequence and concept sequence was predictable in both conditions. This experiment examines the role of visually presented concepts in language switching with predictable sequences.

---- Please insert Figure 4 about here ----

Experiment 1

The goal of Experiment 1 was two-fold. The first goal was to investigate whether language switch costs would decrease by manipulating language predictability (i.e., cued random language sequence vs. cued alternating language sequence), while the concept sequence was predictable in all conditions (see top panel of Figure 3). With a cued alternating language sequence, the participants had to switch to another language after two trials with the same language. Since this language sequence was predictable, it should have enabled the participants to prepare for upcoming trials. During cued random language sequences, on the other hand, no such predictability-based language preparation was possible.

The ICM assumes that language interference resolution occurs solely due to information from the target language (i.e., between language schemas) and when both language and concept information are known (i.e., between translation-equivalent lemmas). Yet, no assumption has been put forward in the ICM that solely concept information should reduce language interference. So, based on the ICM, switch costs should be smaller when both language and concept are predictable than when only the concept is predictably known.

The second goal was to determine the influence of availability of visual language cues on switch costs (see top panel of Figure 4). Prior task switching research has shown that cue processing on its own can contribute to switch costs (for a recent review on the effect of cues in task switching, see Jost, De Baene, Koch & Brass, 2013). The question remains whether this is also the case in language switching. To this end, the presence of visual language cues was manipulated while the language sequence was predictable (see also Koch, 2003).

Method

Participants. 24 native German participants took part and spoke English as their second language (19 female, mean age = 22.5). Prior to the experiment they were asked to fill in a questionnaire about when they started learning English, how many years of formal English education they had, how many other languages they know and how high they rated their own level of spoken English[2], with 1 being very bad and 7 being very good (see Table 1).

---- Please insert Table 1 about here ----

Apparatus and concepts. The to-be-produced concepts consisted of the numbers one to five. The participants were required to produce these five numbers, from memory (i.e., no visual indication of the numbers was presented), in the appropriate serial order (see appendix for all response sequences).

The experiment was presented using E-prime. Speech onset of vocal responses was recorded with a voice-key and the entire experiment was recorded with a Zoom H2 Handy Portable Stereo Recorder. Errors were coded online by the experimenter in a subject file and the recorded speech files were consulted for accuracy.

Procedure. Prior to the experiment the instructions were presented both orally and visually, with an emphasis on both speed and accuracy. These instructions were followed by one of the three experimental conditions (with a counterbalanced order across participants). In the alternating language sequence condition, participants were informed about which language they should begin with at the beginning of each block. This was followed by a fixation cross (+), presented in the centre of the screen, which stayed visible throughout the entire block. After hearing an auditory response-signal (a tone of 50 ms), the participants had to produce one of the five numbers from memory, which was followed by a “pacing-interval”, constituting the time between the previous response-onset and the current response-signal, of 1500 ms. The next response-signal would not be presented until a response was recorded. The responses had to be produced in the correct serial order, starting with the concept referring to "1", as well as in the correct language (German or English). During this condition, the participants were required to alternate languages after every second trial (e.g., L1-L1-L2-L2-L1-L1 or L2-L2-L1-L1-L2-L2).

The cued alternating language sequence condition followed the same structure as the alternating language sequence condition, apart from the additional (i.e., redundant) presentation of a visual language cue (color cue: green or blue rectangle; 160 × 106 pixels), which was presented in the centre of the screen simultaneous with each auditory response-signal. The language cue remained on the screen until a response was registered.

Finally, in the cued random language sequence condition, the language sequence was random, with only the language cues to indicate which language had to be used. The language cues also appeared simultaneously with the response-signal in this condition and remained on the screen until a response was registered.

Each condition consisted of four blocks of 20 trials each, which followed each other and were presented after two practice blocks, also consisting of 20 trials each. During the alternating language and cued alternating language sequence, half of the blocks started with English and half with German, and the sequence of blocks was counterbalanced across participants. In the cued random language sequence and cued alternating language sequence, the participants were aided by a card, indicating the color-cue to language assignment. The assignment of color-cue to language was held constant throughout the experiment and was counterbalanced across participants.

Note that, for the conditions using an alternating language sequence, repeating the concept sequence four times in each block and the language sequence requiring a language switch after every second trial results in perfect counterbalancing of language, language sequence, and serial position in the number sequence. That is, each number was named equally often in each language and equally frequent on switch trials and repetition trials in each block. Similar restrictions were put on the cued random language sequence.

Design. We defined two non-orthogonal contrasts. First, we compared language switching with (i.e., cued alternating language sequence) and without a predictable language sequence (i.e., cued random language sequence) in the *language predictability contrast*. Note that the concept sequence was predictable throughout.

Secondly, we compared language switching with (i.e., cued alternating language sequence) and without visually presented language cues (i.e., alternating language sequence) in the *visual language cue contrast*. Note that here languages and concepts were both predictable throughout.

That is, in the *language predictability contrast* the within-subjects independent variables were language (German vs. English), language transition (switch vs. repetition), and language predictability (cued random language sequence vs. cued alternating language sequence), whereas in the *visual language cue contrast* the latter was language cue presentation (alternating language sequence vs. cued alternating language sequence). The dependent variables were reaction time (RT) and error rate.

Results and Discussion

The first trial of each block and the error trials, which constituted the production of a wrong concept and/or production in the wrong language, were excluded from RT analyses, as were trials following an error trial. Furthermore, RTs in all trials were z-transformed, and trials with a z-score of -2/+2 were discarded as outliers. Taking these criteria into account, a total of 13% of the RT data was excluded.

---- Please insert Table 2 about here ----

Language predictability contrast: Cued random language sequence vs. cued alternating language sequence. An analysis of variance (ANOVA) of the RT data revealed a significant effect of language ($F(1, 23) = 5.29$; $p < .05$; $\eta_p^2 = .187$), with English responses

(546 ms; see Table 2) being slower than German responses (537 ms), and a significant effect of language transition ($F(1, 23) = 46.92$; $p < .001$; $\eta_p^2 = .671$), with switch trial responses (568 ms) being slower than repetition trial responses (514 ms), indicating language switch costs of 54 ms. Furthermore, the main effect of language predictability was also significant ($F(1, 23) = 29.44$; $p < .001$; $\eta_p^2 = .561$), with responses in the cued random language sequence (626 ms) being slower than in the cued alternating language sequence (458 ms). The latter effect shows that language predictability reduces RT and thus was used to prepare for the upcoming trial.

Importantly, also the interaction between language predictability and language transition was significant ($F(1, 23) = 12.18$; $p < .01$; $\eta_p^2 = .346$), with larger switch costs during the cued random language sequence (80 ms; see Figure 5) than during the cued alternating language sequence (27 ms). Separate t-tests revealed that switch costs were significant for both the cued random language sequence ($t(23) = 5.68$; $p < .001$) and the cued alternating language sequence ($t(23) = 4.30$; $p < .001$). The reduction in switch costs found in this analysis suggests that knowing both language and concept reduces language switching interference, relative to only knowing the concept.

The interaction between language and language transition ($F(1, 23) = 3.68$; ns. ; $\eta_p^2 = .138$) was not significant, but there was a trend towards larger switch costs for German (65 ms) than English (41 ms), which represents a phenomenon found in several other studies (e.g., Macizo, Bajo & Paolieri, 2012; Meuter & Allport, 1999; Philipp et al., 2007; for reviews on asymmetrical switch costs, see Bobb & Wodniecka, 2013; Koch, Gade, Schuch & Philipp, 2010). These asymmetrical switch costs have several interpretations, from reactive inhibition (e.g., Green, 1998), a difference in interference across different trial types (Verhoef et al., 2009), to response availability (Finkbeiner, Almeida, Janssen & Caramazza, 2006). None of the other interactions (Fs < 1) were significant.

The error data revealed no significant main effect of language ($F(1, 23) = 1.60$; ns.; $\eta_p^2 = .065$), language transition ($F(1, 23) = 2.94$; ns.; $\eta_p^2 = .113$), or language predictability (F(1,

23) = 1.66; ns.; η_p^2 = .067). The interaction between language and language transition (F(1, 23) = 2.62; ns.; η_p^2 = .102) was not significant, like all the other interactions (Fs < 1).

---- Please insert Figure 5 about here ----

Visual language cue contrast: Alternating language sequence vs. cued alternating language sequence. An ANOVA of the RT data revealed no significant effect of language (F(1, 23) = 3.22; ns.; η_p^2 = .123), but there was a trend towards English (459 ms) being slower than German (451 ms). The effect of language transition was significant (F(1, 23) = 22.02; p < .001; η_p^2 = .489), with switch trials (468 ms) being slower than repetition trials (441 ms), indicating language switch costs of 27 ms. Importantly, the main effect of language cue presentation was not significant (F(1, 23) = 0.03; ns.; η_p^2 = .001).

None of the two-way interactions (Fs < 1) and the three-way interaction were significant (F(1, 23) = 2.36; ns.; η_p^2 = .093). This means that, contrary to task switching studies (e.g., Koch, 2003; for a recent review, see Jost et al., 2013), the current study did not provide evidence for an influence of additional, redundant language cues on switch costs (see Figure 5), which suggests that there is a difference in cue processing between task switching and language switching. Supporting evidence for this claim was found by Philipp and Koch (2009), who used a 2:1 cue-to-language mapping (i.e., two cues per language) and found opposite cue-based results to what is generally found in the task switching literature (e.g., Gade & Koch, 2008; Mayr & Kliegl, 2003).

The error data revealed a main effect of language (F(1, 23) = 5.75; p < .05; η_p^2 = .200), with more errors in English (0.2%) than German (0.1%), and of language transition (F(1, 23) = 10.47; p < .01; η_p^2 = .313), with more errors in switch trials (0.2%) than in repetition trials (0.0%). The effect of language cue presentation (F < 1) was not significant. The interaction between language and language transition was not significant (F(1, 23) = 4.00; ns.; η_p^2 = .148), but did reveal a trend towards larger switch costs during German trials (0.2%) than during English trials (0.1%). None of the other interactions were significant (Fs < 1).

Summary. The visual language cue contrast showed no switch cost difference between language switching with or without visual language cues when both language and concept were predictable. Contrary to some studies in task switching (e.g., Koch, 2003), this indicates that redundant language cues do not seem to contribute a great deal to switch costs.

On the other hand, the language predictability contrast showed smaller switch costs with a predictable language and concept sequence when compared with language switching with solely a predictable concept sequence. This finding indicates that being able to prepare both language and concept (i.e., the response) can reduce language interference to a higher extent relative to preparing just the concept.

In the following experiment we aimed to test whether a similar switch cost reduction would be found when comparing language and concept predictability against just language predictability. This is of special interest, since the ICM assumes that advanced (i.e., preparatory) language interference resolution can occur when both language and concept are predictable (i.e., between language schemas and lemmas) and when only the language sequence is predictable (i.e., between language schemas). So, language interference resolution is possible in both condition according to the ICM. In Experiment 1, on the other hand, language interference resolution was only possible when both language and concept were predictable, and not when only the language sequence was predictable.

Experiment 2

Experiment 2 also had two goals. The first goal was to investigate the role of concepts in language switching, while information about the languages was available (see second panel of Figure 3). To this end, the predictability of the concept sequence was manipulated in a language switching setting (i.e., random digit sequence vs. fixed digit sequence), while the language sequence was predictable in both conditions. In one condition (i.e., fixed digit sequence condition), the participants knew which concept would have to be activated in the upcoming trial, giving them the ability to prepare the response of the upcoming trial. In the random digit sequence condition, no prior indication was given on which concept would be required, so that no preparation of concepts or responses was possible.

The ICM assumes that further language interference resolution can occur after language schemas between translation-equivalent lemmas. However, the latter need to be activated by their concept first. This entails that, according to the ICM, switch costs should be smaller when both language and concept are predictable relative to when only the language is predictable, since the former would allow for language interference resolution between translation-equivalent lemmas, whereas the latter would allow language interference resolution between language schemas. Hence, this is of special interest since the ICM assumes that advanced (i.e., preparatory) interference resolution can occur in both conditions, whereas this was not the case in Experiment 1.

Similar to Experiment 1, where the influence of visual language cues on language switching was investigated, the second goal was to investigate whether a visual trigger of the concepts would influence language switching (see second panel of Figure 4). Having the concepts visually present in the form of a digit should reduce working memory load. Hence, this experiment would allow for an investigation of working memory load on switch costs.

Method

Participants. 24 native German participants took part and spoke English as their second language (18 female, mean age = 22.2). A questionnaire, identical to that in Experiment 1, was given to the participants prior to the actual experiment (see Table 1).

Apparatus and concepts. The apparatus was identical to those used in the previous experiment. Similar to Experiment 1, the participants were instructed to produce the numbers 1-5. However, these numbers had to be produced either in a random or in a fixed order (see appendix for all responses). Furthermore, the numbers could either be visually presented (300 × 300 pixels) and/or memory-based.

Procedure. The procedure was similar to that used in Experiment 1. However, there were some differences with respect to the language sequence, concept sequence, and the availability of language cues and digits.

Similar to Experiment 1, there were three conditions. In the memory-based number sequence, the concepts followed a fixed sequence, which means that they were triggered from memory. In the fixed digit sequence, the concepts also followed a fixed sequence, but digits were also visually presented simultaneous with the response signal. The visually presented digit remained on the screen until a response was registered. Finally in the random digit sequence, the digits were presented in a random fashion, so that the concept was only triggered by a visual digit.

The former two conditions, which both used a fixed sequence of concepts, each used a different fixed sequence to prevent transfer effects or learning effects from one condition to another in our within-subjects design. Hence, two mixed (i.e., non-overlearned) sequences were constructed (see appendix for the order of numbers in both sequences). The assignment of sequence to condition was counterbalanced across participants. Additionally, each digit appeared equally frequent in both languages and equally frequent in switch trials and repetition trials in each condition (this is also the case for the random digit sequence).

Furthermore, we implemented an alternating language sequence for each of the three conditions. Half of the blocks started with English and half with German, and the sequence of blocks was counterbalanced across participants.

Design. We defined two non-orthogonal contrasts. First, we compared language switching with (i.e., fixed digit sequence) and without predictable concepts (i.e., random digit sequence) in the concept predictability contrast. Note that the language sequence was predictable throughout.

In the second contrast, we compared language switching with (i.e., fixed digit sequence) vs. without visible digits (i.e., memory-based number sequence) in the *visual digit contrast.* Note that here languages and concepts were both predictable throughout.

That is, in the *concept predictability contrast* the within-subjects independent variables were language (German vs. English), language transition (switch vs. repetition), and concept predictability (random digit sequence vs. fixed digit sequence), whereas in the *visual digit contrast* the latter was digit presentation (fixed digit vs. memory-based number). The dependent variables were RT and error rate.

Results and Discussion

We used identical outlier criteria and error definitions as in Experiment 1, which resulted in the exclusion of 14% of the RT data.

---- Please insert Table 3 about here ----

Concept predictability contrast: Random digit sequence vs. fixed digit sequence. An ANOVA of the RT data revealed a significant effect of language ($F(1, 23) = 18.00$; $p < .001$; $\eta_p^2 = .439$), with English responses (557 ms; see Table 3) being slower than German responses (525 ms), and a significant effect of language transition ($F(1, 23) = 32.78$; $p < .001$; $\eta_p^2 = .588$), with switch trial responses (566 ms) being slower than repetition trial responses (516 ms), indicating language switch costs of 50 ms. Furthermore, the main effect of concept predictability was also significant ($F(1, 23) = 20.70$; $p < .001$; $\eta_p^2 = .474$), with responses in the random digit sequence (580 ms) being slower than those in the fixed digit sequence (502 ms). The latter effect indicates that concept predictability reduces RT and thus was used to prepare for the upcoming trial.

Importantly, the interaction between concept predictability and language transition was significant ($F(1, 23) = 6.44$; $p < .05$; $\eta_p^2 = .219$), with larger switch costs during the random digit sequence (66 ms; see Figure 6) than during the fixed digit sequence (35 ms). Separate t-tests revealed that switch costs were significant for both the random digit sequence

($t(23) = 5.82$; $p < .001$) and the fixed digit sequence ($t(23) = 3.47$; $p < .01$). The reduction of switch costs with a predictable language and concept sequence, relative to when only the language sequence was predictable, provides evidence that knowing both the language and concept reduces language switching interference. This finding is in line with the results of Experiment 1.

Both the interaction between concept predictability and language and the three-way interaction (*F*s < 1) were not significant. The interaction between language and language transition was significant ($F(1, 23) = 9.10$; $p < .01$; $\eta_p{}^2 = .284$), with larger switch costs for German (64 ms) than for English (39 ms).

The error data revealed a main effect of language ($F(1, 23) = 6.46$; $p < .05$; $\eta_p{}^2 = .219$), with more errors elicited in German (1.3%) than in English (0.8%), which indicates a speed accuracy trade off (i.e., German responses were less accurate and faster than English responses). The main effect of language transition was also significant ($F(1, 23) = 20.31$; $p < .001$; $\eta_p{}^2 = .469$), with switch trials (1.6%) being more erroneous than repetition trials (0.4%). The main effect of concept predictability ($F(1, 23) = 1.00$; ns.; $\eta_p{}^2 = .042$) was not significant.

The interaction between language and language transition ($F(1, 23) = 3.00$; ns.; $\eta_p{}^2 = .115$) was not significant, but (like in the RT) there was a trend towards larger switch costs for German (1.5%) than for English (0.9%). The interaction between concept predictability and language transition ($F < 1$) was also not significant. However, the interaction between concept predictability and language was significant ($F(1, 23) = 6.46$; $p < .05$; $\eta_p{}^2 = .219$), with a higher number of errors in the random digit sequence (1.6%) than the fixed digit sequence in German trials (0.9%), and a reverse pattern with English trials, with a higher amount of errors in the fixed digit condition (0.9%) than the random digit sequence (0.6%). The three-way interaction ($F(1, 23) = 8.85$; $p < .01$; $\eta_p{}^2 = .278$) was also significant, with larger switch costs in the random digit sequence (2.2%) than in the fixed digit sequence (0.9%) during German trials, whereas in the English trials the fixed digit sequence (1.3%) had larger switch costs than the random digit sequence (0.5%). Separate t-test showed that there was a significant difference in switch costs between the fixed digit sequence and random digit sequence in the German trials ($t(23) = 2.25$; $p < .05$), but not in the English trials ($t(23) = 1.77$; ns.). The latter finding indicates that switch costs are even more reduced in L1 than L2 due to concept predictability. Possible explanations for this three-way interaction will be discussed in the General Discussion.

---- Please insert Figure 6 about here ----

Visual digit contrast: Fixed digit sequence vs. memory-based number sequence. An ANOVA of the RT data revealed a significant effect of language ($F(1, 23) = 5.45$; $p < .05$; $\eta_p^2 = .192$), with English responses (532 ms) being slower than German responses (509 ms), and a significant effect of language transition ($F(1, 23) = 20.50$; $p < .001$; $\eta_p^2 = .471$), with switch trials (545 ms) being slower than repetition trials (497 ms), indicating language switch costs of 48 ms. The main effect of digit presentation was not significant ($F(1, 23) = 1.76$; ns.; $\eta_p^2 = .071$).

The interaction between digit presentation and language transition was significant ($F(1, 23) = 4.37$; $p < .05$; $\eta_p^2 = .160$), with larger switch costs during the memory-based number sequence (60 ms) than during the fixed digit sequence (35 ms). Separate t-tests revealed that switch costs were significant for both the memory-based number sequence ($t(23) = 4.36$; $p < .001$) and the fixed digit sequence ($t(23) = 3.47$; $p < .01$). Additionally, the interaction between language and language transition was significant ($F(1, 23) = 7.10$; $p < .05$; $\eta_p^2 = .236$), with larger switch costs for German (65 ms) than for English (30 ms), whereas the interaction between digit presentation and language and the three-way interaction were not significant (Fs < 1). The decrease in switch costs due to digit presentation suggests that working memory load plays a role during language switching. Declerck et al. (2013) came to the same conclusion when they found smaller switch costs with overlearned sequences than with newly learned concept sequences.

The ANOVA of the error data revealed a main effect of language transition ($F(1, 23) = 12.79$; $p < .01$; $\eta_p^2 = .357$), with switch trials (1.6%) being more erroneous than repetition trials (0.4%), whereas language and digit presentation (Fs < 1) were not significant, and neither was the interaction between digit presentation and language ($F(1, 23) = 1.04$; ns.; $\eta_p^2 = .043$) or any of the other two-way interactions (Fs < 1). The three-way interaction ($F(1, 23) = 3.68$; ns.; $\eta_p^2 = .138$) was not significant, but showed a trend towards larger switch costs in the memory-based number sequence (1.2%) than in the fixed digit sequence (0.9%) during German trials, whereas in English trials the fixed digit sequence (1.3%) had larger switch costs than the memory-based number sequence (0.2%).

Summary. In the visual digit contrast, where the influence of redundant visual stimuli was investigated, smaller switch costs were observed when the digits were visually presented than when they were not visually presented, when both language and concept sequence were predictable. We interpreted this as an influence of working memory load on language switching.

The concept predictability contrast also showed a switch cost difference: smaller switch costs were observed with a predictable language and concept sequence when compared with language switching with solely a predictable language sequence. This indicates that being able to prepare both language and concept (i.e., the response) can reduce language interference to a higher extent relative to preparing just the language. Moreover, the results also indicate that L1 switch costs are reduced to a higher extent than L2 switch costs due to both language and concept sequence being predictable.

Whereas the findings of Experiments 1 and 2 have focused on the combination of language and concept predictability, Experiment 3 set out to investigate whether solely language predictability also influences switch costs.

Experiment 3

In Experiment 3, the influence of predictability of the language sequence was examined (i.e., cued random language sequence vs. cued alternating language sequence), while the concept sequence was unpredictable in both conditions (see third panel of Figure 3). This is a similar set-up to that of Experiment 1, except that in Experiment 1 the concept sequence was predictable in both conditions. According to the ICM, some language interference can be resolved at the level of language schemas, so that language predictability should reduce switch costs.

Method

Participants. 24 native German participants took part and spoke English as their second language (21 female, mean age = 23.3). A questionnaire, identical to that in Experiment 1, was given to the participants prior to the actual experiment (see Table 1).

Apparatus and concepts. The apparatus was identical to that of the previous experiments. Similar to the random digit sequence in Experiment 2, the participants were instructed to produce number words in a random order, as indicated by the visually presented digits (1-5).

Procedure. The procedure was similar to that used in Experiment 1. However, in the current experiment the concept sequence was random and thus indicated by visually presented digits. Furthermore, only two conditions were implemented, namely the cued alternating language sequence (i.e., predictable language sequence) and the cued random language sequence (i.e., random language sequence).

Design. The within-subjects independent variables were language (German vs. English), language transition (switch vs. repetition), and language predictability (cued alternating language sequence vs. random language sequence). The dependent variables were RT and error rate.

Results and discussion

We used identical outlier criteria and error definitions as in Experiment 1, which resulted in the exclusion of 11% of the RT data.

---- Please insert Table 4 about here ----

An ANOVA of the RT data revealed a significant effect of language ($F(1, 23) = 16.70$; $p < .001$; $\eta_p^2 = .421$), with English responses (619 ms; see Table 4) being slower than German responses (592 ms), and a significant effect of language transition ($F(1, 23) = 75.72$; $p < .001$; $\eta_p^2 = .767$), with switch trial responses (638 ms) being slower than repetition trials responses (573 ms), indicating language switch costs of 65 ms. Furthermore, the main effect of language predictability was also significant ($F(1, 23) = 20.88$; $p < .001$; $\eta_p^2 = .476$), with responses produced in the cued random language sequence (627 ms) being slower than those produced in the cued alternating language sequence (584 ms). The latter result shows that the predictable language sequence reduced RT and thus was used to prepare for the upcoming trial, even though the responses themselves were not predictable.

The interaction between language and language transition was significant ($F(1, 23) = 8.17$; $p < .01$; $\eta_p^2 = .262$), with larger switch costs for German (81 ms) than for English (49 ms), whereas the other two-way interactions (Fs < 1) and the three-way interaction ($F(1, 23) = 1.02$; ns.; $\eta_p^2 = .043$) were not significant. The non-significant interaction between language transition and language predictability entails that language predictability, without any knowledge of the concepts, did not influence language switch costs (switch costs of 68 ms in the cued alternating language sequence vs. 61 ms in the cued random language sequence; see Figure 7), which is not in line with the specific prediction derived from the ICM.

The error data revealed a main effect of language ($F(1, 23) = 10.62$; $p < .01$; $\eta_p^2 = .316$), with more errors in German (0.6%) than in English (0.3%), which indicates a speed-accuracy trade-off for the language effect. The main effect of language transition was also significant ($F(1, 23) = 4.60$; $p < .05$; $\eta_p^2 = .167$), with more errors in switches (0.6%) than in repetitions (0.3%), whereas the main effect of language predictability ($F < 1$) was not significant. The interaction between language and language transition was significant (F(1, 23) = 6.15; $p < .05$; $\eta_p^2 = .211$), with larger switch costs in German (0.5%) than in English (0.1%). However, none of the other interactions were significant (Fs < 1).

---- Please insert Figure 7 about here ----

Summary. Experiment 3 revealed no switch cost difference between language switching with vs. without a predictable language sequence when the concept sequence is unpredictable. This indicates that being able to just prepare the upcoming language does not reduce language interference to a higher extent relative to not being able to prepare either language or concept.

That is, whereas the findings of Experiments 1 and 2, where the combination of language and concept predictability was investigated, did show an influence on switch costs, no such predictability effect was found on switch costs when only the language was predictable in Experiment 3. In the final experiment (i.e., Experiment 4), we set out to investigate whether this is also the case for concept predictability.

Experiment 4

To investigate whether some interference resolution can occur on the basis of concept predictability alone, without accompanying language predictability, we compared performance in a condition in which only the concept sequence was predictable (i.e., fixed digit sequence) with that in a condition where neither concept nor language was predictable (i.e., random digit sequence; see last panel of Figure 3). According to the ICM, no difference in switch costs should be obtained due to this manipulation because interference resolution does not occur until the target language is known.

Method

Participants. 24 native German participants took part and spoke English as their second language (15 female, mean age = 23.2). A questionnaire, identical to that in Experiment 1, was given to the participants prior to the actual experiment (see Table 1).

Apparatus and concepts. The apparatus and concepts were similar to those used in the random digit sequence and the fixed digit sequence of Experiment 2. Unlike Experiment 2, however, only one fixed concept sequence was implemented (see appendix for all response sequences).

Procedure. The procedure was similar to that used in Experiment 2. However, in the current experiment, the languages followed an unpredictable sequence and thus were always triggered by language cues. Furthermore, only two conditions were implemented, namely the fixed digit sequence (i.e., predictable concept sequence) and the random digit sequence (i.e., random concept sequence).

Design. The within-subjects independent variables were language (German vs. English), language transition (switch vs. repetition), and concept predictability (random digit sequence vs. fixed digit sequence). The dependent variables were RT and error rate.

Results and Discussion

We used identical outlier criteria and error definitions as in Experiment 1, which resulted in the exclusion of 13% of the RT data.

---- Please insert Table 5 about here ----

An ANOVA of the RT data revealed a significant effect of language ($F(1, 23) = 5.53$; $p < .05$; $\eta_p^2 = .194$), with higher RT for English responses (675 ms; see Table 5) than for German responses (651 ms), and a significant effect of language transition ($F(1, 23) = 140.13$; $p < .001$; $\eta_p^2 = .859$), with slower switch trial responses (689 ms) than repetition trial responses (637 ms), indicating language switch costs of 52 ms. Furthermore, the main effect of concept predictability was not significant ($F(1, 23) = 4.23$; ns.; $\eta_p^2 = .071$), even though there was a trend towards slower responses in the random digit sequence (671 ms) than in the fixed digit sequence (655 ms).

The interaction between language and language transition was not significant ($F(1, 23) = 1.64$; ns.; $\eta_p^2 = .067$), as were the interactions between concept predictability and language transition ($F(1, 23) = 2.66$; ns.; $\eta_p^2 = .104$) and between concept predictability and language ($F < 1$). However, the three-way interaction was significant ($F(1, 23) = 4.36$; $p < .05$; $\eta_p^2 = .159$), with larger switch costs in the random digit sequence (78 ms) than in the fixed digit sequence (43 ms) during German trials, whereas there was only a small switch cost difference between the random digit sequence (42 ms) and fixed digit sequence (46 ms) during English trials. Separate t-tests revealed that the switch cost reduction with a predictable concept sequence was significant for German trials ($t(23) = 2.55$; $p < .05$), whereas it was unsignificant for English trials ($t(23) = 0.30$; ns.). Thus, without a predictable language sequence, there is no overall influence of concept predictability on switch costs (see Figure 8), but there is such an effect in L1 (German). This is similar to the result found in Experiment 2, where we also found a larger decrease in L1 switch costs due to concept predictability. Possible explanations for this three-way interaction and the one found in Experiment 2 will be discussed in the General Discussion.

The error data revealed a main effect of language ($F(1, 23) = 5.84$; $p < .05$; $\eta_p^2 = .203$), with more errors in German responses (0.8%) than in English responses (0.4%), which indicates a speed-accuracy trade-off for the effect of language. The main effect of language transition was also significant ($F(1, 23) = 8.46$; $p < .01$; $\eta_p^2 = .269$), with more errors in switch trials (0.8%) than in repetition trials (0.4%), whereas the main effect of concept predictability ($F < 1$) was not significant. The interactions between language and language transition ($F(1, 23) = 2.32$; ns.; $\eta_p^2 = .091$), concept predictability and language transition ($F(1, 23) = 1.80$; ns.; $\eta_p^2 = .073$), concept predictability and language ($F(1, 23) = 1.56$; ns.; $\eta_p^2 = .064$), and the three-way interaction ($F(1, 23) = 1.81$; ns.; $\eta_p^2 = .073$) were not significant.

---- Please insert Figure 8 about here ----

Summary. Experiment 4 revealed that only L1 switch costs are reduced with a predictable concept sequence as compared to no predictability at all. This finding indicates that concept predictability does play some role during language control, but that this influence may depend on the strength of the association between concept and lemma.

General Discussion

In the present study, we set out to investigate preparation processes in language switching in order to examine the specific influence of language and concept on language control. To this end, we aimed at manipulating language predictability and concept predictability independently from each other. Experiment 1 and 2 revealed smaller switch costs when both language and concept sequences were predictable than when only the language sequence (Experiment 1) or the concept sequence (Experiment 2) was predictable. Furthermore, Experiment 2 showed that this predictability-based reduction was larger for L1 switch costs than L2 switch costs. Experiment 3 and 4 revealed similar switch costs when comparing language switching with a predictable language sequence (Experiment 3) or a predictable concept sequence (Experiment 4) against language switching with an unpredictable language and concept sequence. However, although there was no general effect of concept predictability on switch costs, the data of Experiment 4 did reveal a concept predictability-based reduction of L1 switch costs.

In the following, we first discuss the data with respect to the influence of preparation on language switching and the theoretical implications. Then we consider whether preparation effects obtained in language switching studies converge with those obtained in task switching. Finally, we propose a modification of the ICM, which can account for our findings and those of previous studies.

Predictability and language control

The results obtained in this study can specify the assumptions of the ICM (Green, 1998) that were described in the introduction. According to this model, language control starts between language schemas, which influence language tags once lemmas have been activated by their corresponding concept. In turn, these language tags influence the activation of lemmas, including the target lemma and its translation-equivalent lemma, resolving any interference between the two translation-equivalent lemmas. Put differently, some language control processes can start when knowing which language to produce in (i.e., interference resolution between language schemas). Yet, the lemmas are only influenced after they have been activated by their respective concepts (i.e., interference resolution between lemmas).

The results of Experiment 1 and 2 demonstrate that when both the language sequence and concept sequence are predictable, switch costs are reduced relative to when only the language sequence or the concept sequence is predictable. This finding provides evidence that language control benefits from the combined information about the upcoming language and concept (i.e., response). Thus, the findings of Experiments 1 and 2 are in line with the ICM.

Declerck et al. (2013) found similar evidence by manipulating preparation time with a predictable sequence of languages and concepts, which led to a decrease in switch costs when preparation time was longer. However, the current study indicates that the decrease in switch costs, due to both a predictable language and concept sequence, was arguably not solely the result of language predictability or concept predictability alone, but because of the combination of both. This distinction was not possible in Declerck et al. (2013) since the language sequence and concept sequence were not manipulated independently from each other, unlike in the present study. Furthermore, since more time elapsed in the long preparation time condition than in the short preparation time condition, the decrease of switch costs in Declerck et al. (2013) could also have been due to time-based decay processes (for a discussion of task-set decay see Horoufchin et al., 2011; Rogers & Monsell, 1995) rather than based on active preparation. This could not have been the case in the current study, since the time between response onset and the next trial was identical for both conditions in Experiments 1 and 2.

In Experiments 3, we found no language predictability effect on switch costs when the concept sequence was unpredictable. This finding is contrary to the assumption postulated by the ICM, which supposes that language control can start between the two language schemas prior to knowing the concept. Yet, there was an overall predictability-based reduction or RT, which indicates that the predictable language sequence was used to prepare the upcoming trial. The absence of a language predictability effect on switch costs is even more surprising since Macnamara et al. (1968) did find an effect of language predictability on mixing costs. Yet, this might be due to a difference between mixing costs and switch costs. Previous research has shown that an asymmetry in performance costs across languages can differ between mixing costs and switch costs (Christoffels, Firk & Schiller, 2007; Declerck et al., 2013; Gollan & Ferriera, 2009; Wang, Kuhl, Chen & Dong, 2009). Furthermore, Declerck et al. (2013) found that different stimulus types (i.e., weekdays vs. numbers) also have a different impact on mixing costs and switch costs. Differences between these two markers have also been reported in the task switching literature (e.g., Goffaux, Phillips, Sinai & Pushkar, 2006; Koch, Prinz & Allport, 2005; Mayr, 2001). Hence, it could be that these two measures respond differently to predictability effects.

The inconsistent pattern of results across studies on language predictability (Macnamara et al., 1968; the current study) resembles the inconsistency of the pattern of results found by studies that investigated the effect of language preparation time in language switching. For example, whereas the study of Costa and Santesteban (2004) revealed that longer language preparation time causes smaller switch costs, no such effect was found by Philipp et al. (2007). Thus, it might be that knowing the target language is not a guarantee to start language interference resolution processes. Yet, the question remains why some language switching studies find an effect of preparation on switch costs and others do not.

Note that Verhoef et al. (2009) also investigated time-based preparation on switch costs.Yet, these authors did not report the overall preparation effect on switch costs. They reported a larger switch cost asymmetry with short than long preparation time. Similar to the study of Costa and Santesteban (2004), Verhoef et al. (2009) also manipulated the cue-to-stimulus interval (CSI), with the RSI being variable. Hence, regardless of the type of preparation effect (i.e., time-based or predictability-based), it appears as if the only two studies that found an influence of preparation on switch costs (Costa & Santesteban, 2004; Verhoef et al., 2009) implemented a variable response-to-stimulus interval (RSI). In contrast, those studies that did not find an influence of preparation on language switch costs (Philipp et al., 2007; the current study) implemented a constant RSI. This leads us to believe that language control could be affected by processes associated with temporal variability across trials, such as hypothetical decay processes (e.g., Horoufchin et al., 2011; Rogers & Monsell, 1995; for a similar argument, see Declerck et al., 2012).

In turn, this would mean that the active language preparation process does not have a large impact on switch costs. It could very well be that the previously activated language passively decays over time and thus led to smaller switch costs in those studies that found a preparation effect (Costa & Santesteban, 2004; Verhoef et al., 2009). Since, prior evidence for active language preparation effects (Costa & Santesteban, 2004; Verhoef et al., 2009) can be explained by decay processes, it could be assumed that language interference resolution does not occur between language schemas. This would entail that interference resolution would mainly occur between language tags or lemmas in the ICM (see Guo, Ma & Liu, 2013, for a similar claim with respect to inhibition).

So far, the role of concept predictability has not been examined in a language switching setting. Hence, the results obtained in Experiment 4 are of empirical and theoretical interest. Experiment 4 demonstrated that concept predictability alone can reduce switch costs, but only for L1. A similar result was found in Experiment 2, which revealed that concept predictability, when the language sequence is predictable, influences L1 switch costs more than L2 switch costs.

These two similar results could be explained by an idea proposed by Kroll and Stewart (1994), who assumed that concepts have a stronger connection to L1 lemmas than to L2 lemmas (for reviews on this model see, Brysbaert & Duyck, 2010; Kroll, van Hell, Tokowicz & Green, 2010). In the current set-up, this would mean that when a concept can be prepared (i.e., concept activation), the L1 lemma will receive a higher amount of activation than the translation-equivalent L2 lemma. This effect should mainly influence switch trials in which between-language interference is higher than in repetition trials. Thus, switching languages with the concepts already activated should be easier from L2 to L1 than from L1 to L2, since the L1 lemmas are activated more, prior to the language control process, and thus should be easier to select.

An alternative explanation for the larger predictability-based reduction of L1 switch costs relative to L2 switch costs could be that the participants learned the concept sequence in their L1. We did not instruct the participants to do so, but it seems plausible for them to learn the sequence in their L1. This would have a similar effect as proposed in the previous paragraph, with each predictable concept activating the respective L1 lemmas more strongly than L2 lemmas. When L2 production is required during a predictable concept sequence, a translation process would be engaged. However, at least a slight reduction in switch costs should have been observed in the English trials as well, since we used a large number of practice trials, which implemented both German and English trials. Yet, no such effect arose in the English trials of Experiment 4 (see Table 5). Furthermore, a recent study on semantic modulation during the production of memory-based words (Declerck, Stephan & Philipp, 2014) suggests that not L1 or L2 responses are stored when working with memory-based words in a bilingual setting, but a more abstract representation, which mainly represents conceptual information. Hence, we do not think that storing the concepts as L1 words alone can account for a larger concept predictability-based reduction of L1 switch costs than L2 switch.

Interestingly, a stronger L1 activation than L2 activation is already implemented in the ICM. Yet, this assumption, so far, was mainly used to explain asymmetrical switch costs

(Green, 1998; Meuter & Allport, 1999). Further it was not specified whether this activation difference refers to the lemma level and how it comes into play. Based on the findings of Experiments 2 and 4, we assume that concepts have a stronger connection with L1 lemmas than with L2 lemmas (Kroll & Stewart, 1994). In turn, the increased activation of L1 lemmas would make it easier to select an L1 lemma after an L2 trial than an L2 lemma after an L1 trial. Thus, language control could function as the ICM assumes, with the additional assumption that concept predictability influences lemma selection by an increased L1 lemma activation. That is, interference between translation-equivalent lemmas is biased by the concept predictability towards L1 selection.

If this is the case, we could talk about an L1-oriented language control process instigated by language-unspecific concepts, which begins prior to the language control process on the lemma level. Whereas this idea would not critically change the ICM, it would require a differently weighed connection between the concept level and the translation-equivalent lemmas in this model. A similar architecture was also used in the model of Schwieter and Sunderman (2008) for less proficient L2 learners.

It also bears mentioning that Kroll and Stewart (1994) and Schwieter and Sunderman (2008) assumed that the degree of second language proficiency affects the differently weighed connections from concept to the L1 and L2 lexicon. To this end, we assume that this additional language control process might not affect balanced bilinguals to the same extent as second language learners.

Before we discuss our modifications to the ICM, we first want to take a closer look at the relationship between language switching and task switching, with a special emphasis on preparation effects.

Preparation effects in language switching vs.task switching

In the previous section it was assumed that language control is not instigated solely due to language information. This would mean that, in the context of the ICM, no interference resolution occurs between schemas. Interesting, with respect to schemas in the ICM, is that they can be language oriented or task oriented. Put differently, according to this model, language interference resolution and task interference resolution resemble each other partially, with the main overlap being the schemas. So, if we assume that language interference resolution does not occur between language schemas but on a later stage, then it follows that task control and language control rely on different processes according to the ICM.

In contrast, several studies have assumed a close relationship between task control and language control (e.g., Prior & Gollan, 2011; Thomas & Allport, 2000; Von Studnitz & Green, 1997). This assumption could be tested quite easily by comparing task switching results to those obtained in language switching, since these two paradigms are very similar and measure task control and language control respectively. Correlation analyses have shown that the relationship between language switch costs and task switch costs are rather weak (Calabria et al., 2011, in press; Klecha, 2013; Prior & Gollan, 2013). These results seem to indicate that language switching and task switching do not necessarily measure the same processes[3] (see also Weissberger, Wierenga, Bondi & Gollan, 2012).

So far, no such comparison has been made between preparation effects of language switching and task switching. Yet, the pattern of results across studies shows a clear picture. To this end, we discuss preparation effects that have been studied by both language switching and task switching studies.

One of these is the manipulation of CSI and its effect on switch costs. In task switching, many studies have reported reduced switch costs when CSI increases (e.g., Altmann, 2004; Koch, 2001; Logan & Bundesen, 2003; Mayr & Kliegl, 2003; Meiran, 1996; Monsell & Mizon, 2006). Yet, in language switching, only Costa and Santesteban (2004) reported such a decrease in switch costs, while Philipp et al. (2007) did not find such an effect. What is more, Costa and Santesteban (2004) manipulated CSI across participants, whereas Philipp et al. (2007) manipulated CSI within participants. In contrast, several task switching studies have shown that manipulating CSI between subjects more often does not cause a difference in switch costs, whereas manipulating CSI within subjects does (Altmann, 2004; Koch, 2001; Poljac, de Haan, & van Galen, 2006).

A similar discrepancy is found between language switching and task switching with regard to time-based preparation effects on mixing costs. Whereas preparation time is found to have no effect on language mixing costs (Macnamara et al, 1968), several task switching studies did find smaller mixing costs when preparation time increased (e.g., Rubin & Meiran, 2005; Lawo, Philipp, Schuch & Koch, 2012). These time-based preparation effects on switch costs and mixing costs seem to indicate quite a difference between language switching and task switching.

On the other hand, when investigating the effect of task predictability, typically no effect on switch costs is found (e.g., Gotler, Meiran & Tzelgov, 2003; Heuer, Schmidtke & Kleinsorge, 2001; Koch, 2001; 2005; 2008; Ruthruff, Remington, & Johnston 2001; Sohn & Carlson, 2000). This is compatible with the result of Experiment 3 of the current study, which showed no difference due to solely language predictability. Thus, the predictability effect on language switch costs is in line with the task switching literature.

Taken together, there seems to be a dissimilarity between language switching and task switching when investigating the effect of preparation time on switch costs. This goes even beyond quantitative differences, since the type of manipulation (i.e., between subject or within subject) also seems to differ across switch costs found in task switching and language switching. In contrast, when it comes to investigating preparation on the basis of predictability, language switching and task switching both find no effect on switch costs, even though the overall reaction times decrease when the language/task sequence is predictable. However, not finding an effect does not seem to be grounds to assume that similar processes are at play during language switching and task switching. Hence, similar to the correlation studies, the preparation studies show little evidence for any similarity between language switching and task switching, which provides additional evidence that no interference resolution occurs between language schemas.

A modified inhibitory control model

---- Please insert Figure 9 about here ----

These correlation studies and the overview of preparation effects in language switching and task switching seem incompatible with some of the assumptions of the ICM. Similarly, several of the results of the current study were also not in line with the assumptions postulated by the ICM. Therefore, a modified ICM is proposed to account for the results of this study and those found in other language switching studies, while still trying to stay as close to the original ICM as possible (see Figure 9 for a visual representation of the modified ICM).

First, the connection between the concepts and lemmas are weighed differently for each language, with a stronger connection between concepts and their L1 lemma than between the concepts and their L2 lemma (Kroll & Stewart, 1994; Schwieter & Sunderman, 2008). This is not contrary to the original ICM, since this issue was merely not specified. Yet, the considerable reduction of L1 switch costs relative to L2 switch costs due to concept predictability (Experiments 2 and 4) indicates that this is an important architectural feature that influences language control. Thus, the connection from the concepts to the L1 lemmas is stronger than to the L2 lemmas in Figure 9.

Another difference with the original ICM is that in the modified ICM it is assumed that little to no language interference resolution occurs between language schemas. This assumption is based on the results found in Experiment 3 and Philipp et al. (2007), where no switch cost reduction was found due to language preparation, whereas a general language preparation effect was observed. On the other hand, those studies that did find a language preparation effect on language switch costs (Costa & Santesteban, 2004; Verhoef et al., 2009) might be accounted for by assuming passive decay of competing language schemas, as was discussed previously.

Furthermore, if there was some language interference resolution between language schemas, then this should resemble that of task interference according to the ICM, since these are both partially resolved between schemas. Yet, correlation studies have found a poor relationship between language switch costs and task switch costs (Calabria et al., 2011, in press; Klecha, 2013; Prior & Gollan, 2013). Similarly, preparation effects found in language switching and task switching are not converging.

However, there are still language schemas in this modified model, which represent the mental devices to speak a specific language. The proposed modification simply entails that the schemas of both languages have little direct influence over the activation level of the other language schema. Interference resolution in the modified ICM now occurs between the language tags (see Figure 9), which then inhibit the corresponding lemmas. Since language tags do not come into play until the concepts have been activated, and thus when the entire response is known, language interference resolution between the language tags can account for switch costs to be unaffected by just language preparation (Experiment 3; Philipp et al., 2007a), while also being able to account for a switch cost reduction due to response preparation (Experiments 1 and 2).

These modifications do not change the locus of language control suggested by the original ICM, as between-language interference is still located mainly at the lemma level. However, recent studies have indicated that processes that occur after lemma selection, such as phonological encoding, also influence language switching and thus language control (e.g., Christoffels et al., 2007; Declerck et al., 2012; Filippi et al., in press). As of yet, it still remains an open question whether these processes merely influence lemma selection or whether language control also occurs on those levels, and thus we did not yet include this in the modified ICM.

Conclusion

Exploring a new sequence-based language switching paradigm, we were able to distinguish predictability effects at the level of the languages and at the level of the concepts, which jointly determine the overt vocal response. The results showed that a predictable response (i.e., the combination of language and concept) can reduce switch costs, whereas solely the language or concept being predicable has only a small impact on switch costs. This led to the conclusion that both language and concept are needed to resolve language interference.

Notes

[1] However, preparation is possible in the cued language switching paradigm by increasing the time between the language cue and the stimulus.

[2] Prior research has shown that self-rated scores of second language proficiency are a good indication of second language proficiency (Leblanc & Painchaud, 1985; Ready-Morfitt, 1991).

[3] Some of these studies used different tasks and/or response modalities in the language switching and task switching task. We know from the task switching literature that motor-related processes (e.g., different modalities) can have a big impact on switch costs (e.g., Koch & Philipp, 2005; Philipp, Jolicoeur, Falkenstein & Koch, 2007; Philipp, Weidner, Koch & Fink, 2012; Schuch & Koch, 2003). This is also the case for language switch costs (Christoffels et al., 2007; Declerck et al., 2012; Filippi et al., in press).

References

Allport, A., Styles, E. A., & Hsieh, S. (1994). Shifting attentional set: Exploring the dynamic control of tasks. In C. Umiltà & M. Moscovitch (Eds.), *Attention and Perfomance XV: Conscious and nonconscious information processing* (pp. 421-452). Cambridge, MA: MIT Press.

Altmann, E. M. (2004). The preparation effect in task switching: Carryover of SOA. *Memory & Cognition, 32,* 153-163*.*

Bobb, S. C., & Wodniecka, Z. (2013). Language switching in picture naming: What asymmetric switch costs (do not) tell us about inhibition in bilingual speech planning. *Journal of Cognitive Psychology, 25*, 568-585*.*

Brysbaert, M., & Duyck, W. (2010). Is it time to leave behind the Revised Hierarchical Model of bilingual language processing after fifteen years of service? *Bilingualism: Language and Cognition, 13,* 359-371.

Calabria, M., Branzi, F. M., Marne, P., Hernández, M., & Costa, A. (in press). Age-related effects over bilingual language control and executive control. *Bilingualism: Language and Cognition*.

Calabria, M., Hernández, M., Branzi, F. M., & Costa, A. (2012). Qualitative differences between bilingual language control and executive control: evidence from task-switching. *Frontiers in Psychology, 2*.

Christoffels, I. K., Firk, C., & Schiller, N. O. (2007). Bilingual language control: An event-related brain potential study. *Brain Research, 1147*, 192-208.

Costa, A., & Santesteban, M. (2004). Lexical access in bilingual speech production: Evidence from language switching in highly proficient bilinguals and L2 learners. *Journal of Memory and Language, 50*, 491-511.

Costa, A., Santesteban, M., & Ivanova, I. (2006). How do highly proficient bilinguals control their lexicalization process? Inhibitory and language-specific selection mechanisms are both functional. *Journal of Experimental Psychology: Learning, Memory and Cognition, 32,* 1057-1074.

Declerck, M., Koch, I., & Philipp, A. M. (2012). Digits vs. pictures: The influence of stimulus type on language switching. *Bilingualism: Language and Cognition, 15*, 896-904.

Declerck, M., Philipp, A. M., & Koch., I. (2013). Bilingual control: Sequential memory in language switching. *Journal of Experimental Psychology: Learning, Memory and Cognition, 39*, 1793-1806.

Declerck, M., Stephan, D. N., & Philipp, A. M. (2014). Are memory-based words semantically modulated? Evidence from a monolingual and bilingual semantic blocking task. *Manuscript submitted for publication.*

Festman, J., Rodriguez-Fornells, A., & Münte, T. F. (2010). Individual differences in control of language interference in late bilinguals are mainly related to general executive abilities. *Behavioral and Brain Functions, 6*, 5.

Filippi, R., Karaminis, T., & Thomas, M. S. C. (In press). Bilingual language switching in production: empirical and computational studies. *Bilingualism: Language & Cognition.*

Finkbeiner, M., Almeida, J., Janssen, N., & Caramazza, A. (2006). Lexical selection in bilingual speech production does not involve language suppression. *Journal of Experimental Psychology: Learning, Memory and Cognition, 32*, 1075-1089.

Gade, M., & Koch, I. (2008). Dissociating cue-related and task-related processes in task inhibition: Evidence from using a 2:1 cue-to-task mapping. *Canadian Journal of Experimental Psychology, 62*, 51–55.

Goffaux, P., Phillips, N. A., Sinai, M., & Pushkar, D. (2006). Behavioural and electrophysiological measures of task switching during single and mixed-task conditions. *Biological Psychology, 72*, 278-290.

Gollan, T. H., & Ferreira, V. S. (2009). Should I stay or should I switch? A cost-benefit analysis of voluntary language switching in young and aging bilinguals. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *35*, 640-665.

Gotler, A., Meiran, N., & Tzelgov, J. (2003). Nonintentional task set activation: Evidence from implicit task sequence learning. *Psychonomic Bulletin & Review, 10*, 890–896.

Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism: Language and Cognition, 1*, 213-229.

Guo, T., Ma, F., & Liu, F. (2013). An ERP study of inhibition of non-target languages in trilingual word production. *Brain and Language*, *127*, 12-20.

Heuer, H., Schmidtke, V., & Kleinsorge, T. (2001). Implicit learning of sequences of tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*, 967–983.

Horoufchin, H., Philipp, A. M., & Koch, I. (2011). The dissipating task-repetition benefit in task switching: Task-set decay or temporal distinctiveness? *Journal of Experimental Psychology: Human Perception and Performance, 37*, 455-472.

Jackson, G. M., Swainson, R., Mullin, A., Cunnington, R., & Jackson, S. R. (2004). ERP correlates of a receptive language-switching task. *The Quarterly Journal of Experimental Psychology, 57*, 223-240.

Jost, K., De Baene, W., Koch, I., & Brass, M. (2013). A review of the role of cue processing in task switching. *Zeitschrift für Psychologie, 221*, 5-14.

Kiesel, A., Wendt, M., Jost, K., Steinhauser, M., Falkenstein, M., Philipp, A. M., & Koch, I. (2010). Control and interference in task switching - A review. *Psychological Bulletin, 136*, 849-874.

Klecha, A. (2013). Language and task switching in Polish-English bilinguals. *Psychology of Language and Communication, 17*, 17-36.

Koch, I. (2001). Automatic and intentional activation of task sets. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 27*, 1474-1486.

Koch, I. (2003). The role of external cues for endogenous advance reconfiguration in task switching. *Psychonomic Bulletin & Review, 10*, 488-492.

Koch, I. (2005). Sequential task predictability in task switching. *Psychonomic Bulletin & Review, 12*, 107-112.

Koch, I. (2008). Instruction effects in task switching. *Psychonomic Bulletin & Review, 15*, 448-452.

Koch, I., Gade, M., Schuch, S., & Philipp, A. M. (2010) Task inhibition in task switching: A review. *Psychonomic Bulletin & Review, 17*, 1-14.

Koch, I., Prinz, W., Allport A. (2005). Involuntary retrieval in alphabet-arithmetic tasks: Task-mixing and task-switching costs. *Psychological Research, 69*, 252-261.

Koch, I., & Philipp, A. M. (2005). Effects of response selection on the task repetition benefit in task switching. *Memory & Cognition*, *33*, 624–634.

Kroll, J. F., Bobb, S. C., Misra, M., & Guo, T. (2008). Language selection in bilingual speech: Evidence for inhibitory processes. *Acta Psychologica, 128*, 416-430.

Kroll, J. F., van Hell, J. G., Tokowicz, N., & Green, D. W. (2010). The Revised Hierarchical Model: A critical review and assessment. *Bilingualism: Language and Cognition, 13*, 373-381.

Kroll, J. F., & Stewart, E. (1994). Category interference in translation and picture naming: Evidence for asymmetric connections between bilingual memory representations. *Journal of Memory and Language, 33*, 149-174.

Lawo, V., Philipp, A. M., Schuch, S., & Koch, I. (2012). The role of task preparation and task inhibition in age-related task-switching deficits. *Psychology and Aging, 27*, 1130-1137.

Leblanc, R. , & Painchaud, G. (1985). Self-assessment as a second-language placement instrument. *TESOL Quarterly, 19*, 673–686.

Linck, J. A., Schwieter, J. W., & Sunderman, G. (2012). Inhibitory control predicts language switching performance in trilingual speech production. *Bilingualism: Language and Cognition, 15*, 651-662.

Logan, G. D., & Bundesen, C. (2003). Clever homunculus: Is there an endogenous act of control in the explicit task-cuing procedure? *Journal of Experimental Psychology: Human Perception and Performance, 29*, 575–599.

Macizo, P., Paolieri, D., & Bajo, T. (2012). Language switching and language competition. *Second Language Research. 28,* 131-149.

Macnamara, J., Krauthammer, M., & Bolgar, M. (1968). Language switching in bilinguals as a function of stimulus and response uncertainty. *Journal of Experimental Psychology, 78*, 208-215.

Mayr, U. (2001). Age differences in the selection of mental sets: the role of inhibition stimulus ambiguity, and response-set overlap. *Psychology and Aging, 16*, 96-109.

Mayr, U., & Kliegl, R. (2003). Differential effects of cue changes and task changes on task-set selection costs. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*, 362-372.

Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*, 1423–1442.

Meuter, R. F. I., & Allport, A. (1999). Bilingual language switching in naming: Asymmetrical costs of language selection. *Journal of Memory and Language*, *40*, 25-40.

Monsell, S., & Mizon, G. A. (2006). Can the task-cuing paradigm measure an endogenous task-set reconfiguration process? *Journal of Experimental Psychology: Human Perception and Performance, 32*, 493–516.

Philipp, A. M., & Koch, I. (2009). Inhibition in language switching: What is inhibited when switching between languages in naming tasks? *Journal of Experimental Psychology: Learning, Memory and Cognition, 35*, 1187-1195.

Philipp, A. M., Gade, M., & Koch, I. (2007a). Inhibitory processes in language switching: Evidence from switching language-defined response sets. *European Journal of Cognitive Psychology, 19*, 395-416.

Philipp, A. M., Jolicoeur, P., Falkenstein, M., & Koch, I. (2007b). Response selection and response execution in task switching: Evidence from a go-signal paradigm. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*, 1062–1075.

Philipp, A. M., Weidner, R., Koch, I., & Fink, G. R. (2012). Differential roles of inferior frontal and inferior parietal cortex in task switching: Evidence from stimulus-categorization switching and response-modality switching. *Human Brain Mapping, 34, 1910*–1920.

Poljac, E., de Haan, A., & van Galen, F. P. (2006). Current task activation predicts general effects of advance preparation in task switching. *Experimental Psychology, 53*, 260–267.

Poulisse, N. (2000). Slips of the tongue in first and second language production. *Studia Linguistica, 54*, 136-149.

Poulisse, N., & Bongaerts, T. (1994). First language use in second language production. *Applied Linguistics, 15*, 36-57.

Prior, A., & Gollan, T. H. (2011). Good language-switchers are good task-switchers: Evidence from Spanish-English and Mandarin-English bilinguals. *Journal of the International Neuropsychological Society, 17*, 682-691.

Prior, A., & Gollan, T. H. (2013). The elusive link between language control and executive control: A case of limited transfer. *Journal of Cognitive Psychology, 25*, 622-645.

Ready-Morfitt, D. (1991). *The role and limitations of self-assessment in testing and research.* Unpublished manuscript, University of Ottawa, Ottawa, Canada.

Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124,* 207-231.

Rubin, O., & Meiran, N. (2005). On the origins of the task mixing cost in the cuing task-switching paradigm. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*, 1477–1491.

Rubinstein, J. S., Meyer, D. E., & Evans, J. E. (2001). Executive control of cognitive processes in task switching. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 763-797.

Ruthruff, E., Remington, R. W., & Johnston, J. C. (2001). Switching between simple cognitive tasks: The interaction of top-down and bottom-up factors. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 1404–1419.

Schuch, S., & Koch, I. (2003). The role of response selection for inhibition of task sets in task shifting. *Journal of Experimental Psychology: Human Perception and Performance, 29*, 92-105.

Schwieter, J. W., & Sunderman, G. (2008). Language switching in bilingual speech production: In search of the language-specific selection mechanism. *The Mental Lexicon, 3,* 214–238.

Sohn, M.-H., & Carlson, R. A. (2000). Effects of repetition and foreknowledge in task-set reconfiguration. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*, 1445–1460.

Thomas, M. S. C., & Allport, A. (2000). Language switching costs in bilingual visual word recognition. *Journal of Memory and Language, 43,* 44-66.

Vandierendonck, A., Liefooghe, B., & Verbruggen, F. (2010). Task switching: Interplay of reconfiguration and interference control. *Psychological Bulletin, 136*, 601-626.

Verhoef, K. M. W., Roelofs, A., & Chwilla, D. J. (2009). Role of inhibition in language switching: Evidence from event-related brain potentials in overt picture naming. *Cognition*, *110*, 84-99.

Verhoef, K. M. W., Roelofs, A., & Chwilla, D. J. (2010). Electrophysiological evidence for endogenous control of attention in switching between languages in overt picture naming. *Journal of Cognitive Neuroscience, 22*, 1832–1843.

Von Studnitz, R. E., & Green, D. W. (1997). Lexical desicion and language switching. *International Journal of Bilingualism*, *1*, 3-24.

Wang, Y., Kuhl, P. K., Chen, C., & Dong, Q. (2009). Sustained and transient language control in the bilingual brain. *NeuroImage*, *47*, 414-422.

Weissberger, G. H., Wierenga, C. E., Bondi, M. W., & Gollan, T. H. (2012). Partially over-lapping mechanisms of language and task control in young and older bilinguals. *Psychology and Aging*, 27, 959-974.

Table 1. Overview of demographic information of the participants of Experiments 1-4. The information consists of the average of English age of acquisition, the average years of formal English education, a self-rated score of spoken English from 1-7, with 1 being very bad and 7 being very good, and an average of known languages (not including the mother language).

Experiment	Age of acquisition	Formal English education	Self-rated score of spoken English	Known foreign languages
Experiment 1	10.4	8.8	5.2	2.0
Experiment 2	9.8	9.1	4.5	2.3
Experiment 3	10.0	9.2	4.8	1.9
Experiment 4	10.5	8.8	5.1	1.9

Table 2. Overall RT in ms and percentage of errors (PE) of Experiment 1 (SD in parenthesis) as a function of language transition (repetition vs. switch), language (German vs. English) and language predictability (cued *random* language sequence vs. *cued* alternating language vs. *alternating* language sequence).

		Language					
		German			English		
		Language predictability					
		random	cued	alternating	random	cued	alternating
RT	Switch	667 (26)	472 (50)	456 (27)	664 (29)	470 (42)	473 (27)
	Repetition	572 (25)	437 (43)	437 (24)	600 (26)	451 (43)	440 (20)
PE	Switch	0.3 (0.1)	0.2 (0.1)	0.3 (0.1)	0.2 (0.1)	0.1 (0.1)	0.2 (0.1)
	Repetition	0.1 (0.1)	0.1 (0.0)	0.1 (0.0)	0.2 (0.1)	0.1 (0.0)	0.0 (0.0)

Table 3. Overall RT in ms and percentage of errors (PE) of Experiment 2 (SD in parenthesis) as a function of language transition (repetition vs. switch), language (German vs. English) and concept predictability (*random* digit sequence vs. *fixed* digit sequence vs. *memory*-based number sequence).

		Language					
		German			English		
		Concept predictability					
		random	fixed	memory	random	fixed	memory
RT	Switch	599 (27)	514 (28)	570 (44)	627 (26)	524 (26)	571 (45)
	Repetition	521 (20)	464 (20)	491 (35)	573 (21)	505 (23)	529 (37)
PE	Switch	2.7 (0.5)	1.4 (0.3)	1.6 (0.4)	0.8 (0.2)	1.6 (0.5)	0.7 (0.3)
	Repetition	0.5 (0.2)	0.5 (0.2)	0.4 (0.3)	0.3 (0.2)	0.3 (0.2)	0.5 (0.3)

Table 4. Overall RT in ms and percentage of errors (PE) of Experiment 3 (SD in parenthesis) as a function of language transition (repetition vs. switch), language (German vs. English) and language predictability (cued *random* language sequence vs. *cued* alternating language sequence).

		Language			
		German		English	
		Language predictability			
		random	cued	random	cued
RT	Switch	655 (15)	612 (23)	660 (17)	625 (19)
	Repetition	572 (17)	531 (15)	621 (16)	568 (14)
PE	Switch	0.9 (0.2)	0.8 (0.2)	0.3 (0.1)	0.3 (0.1)
	Repetition	0.4 (0.1)	0.3 (0.2)	0.3 (0.1)	0.2 (0.1)

Table 5. Overall RT in ms and percentage of errors (PE) of Experiment 4 (SD in parenthesis) as a function of language transition (repetition vs. switch), language (German vs. English) and concept predictability (*random* digit sequence vs. *fixed* digit sequence).

		Language			
		German		English	
		Concept predictability			
		random	fixed	random	fixed
RT	Switch	708 (21)	663 (22)	703 (21)	683 (23)
	Repetition	630 (20)	620 (23)	661 (20)	637 (18)
PE	Switch	1.2 (0.2)	1.0 (0.2)	0.5 (0.2)	0.4 (0.2)
	Repetition	0.3 (0.1)	0.8 (0.2)	0.3 (0.1)	0.3 (0.1)

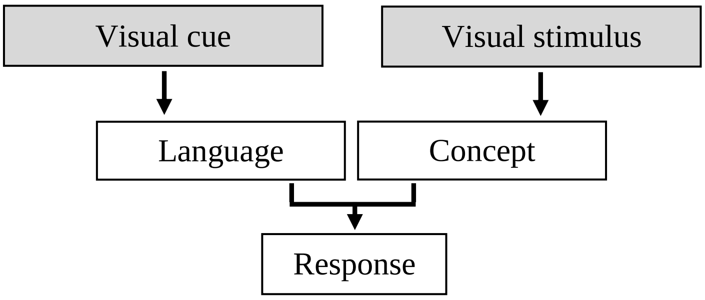
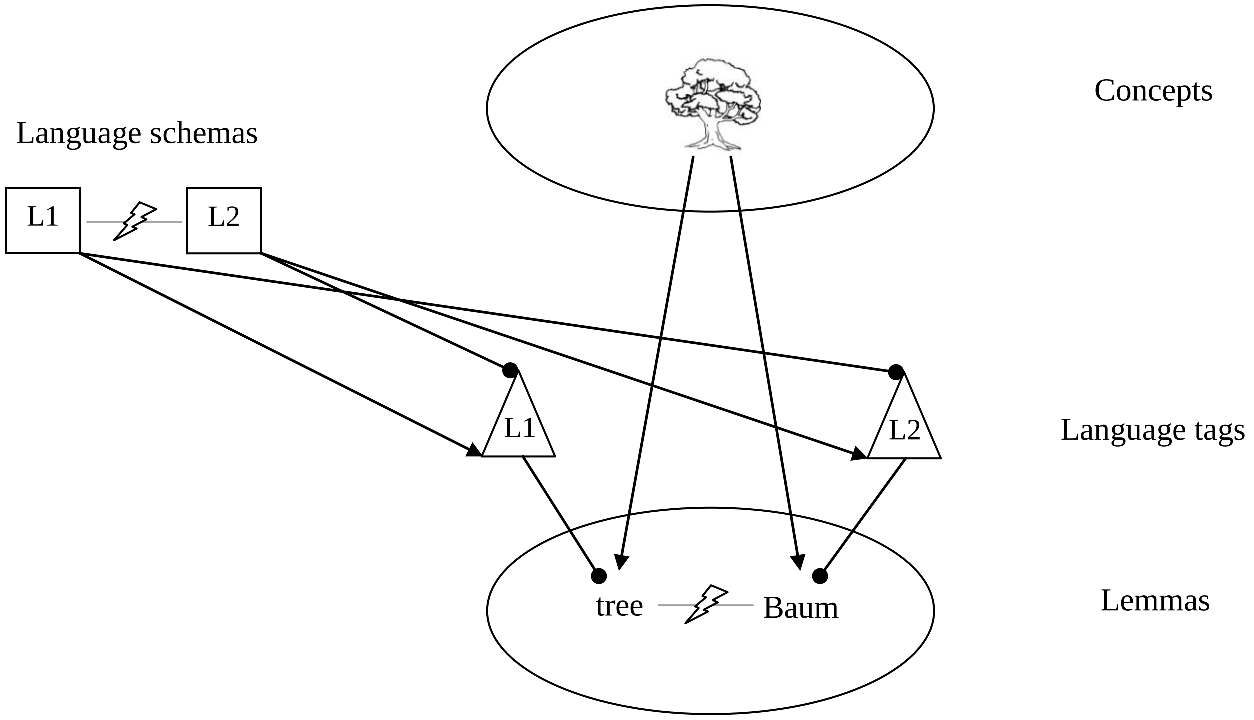
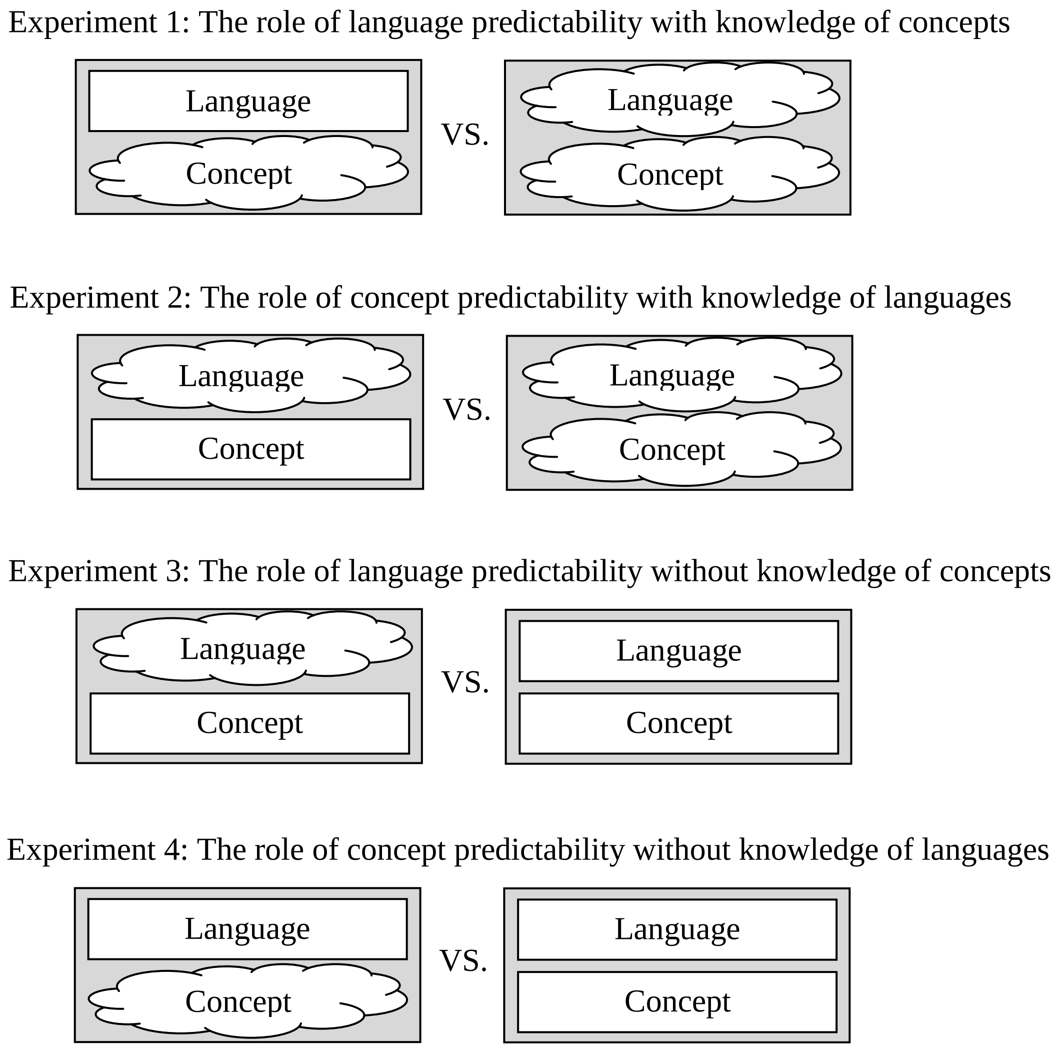


Figure 1. This figure shows a typical progression of a trial during cued language switching: First the visually presented cue and stimulus, respectively, determine the language and concept. The combination of language and concept should then lead to a response. With the sequence-based language switching paradigm the top two panels (i.e., visible cues and stimuli) are bypassed, which leads to a memory-based language sequence and concept sequence, of which the combination then leads to a response.



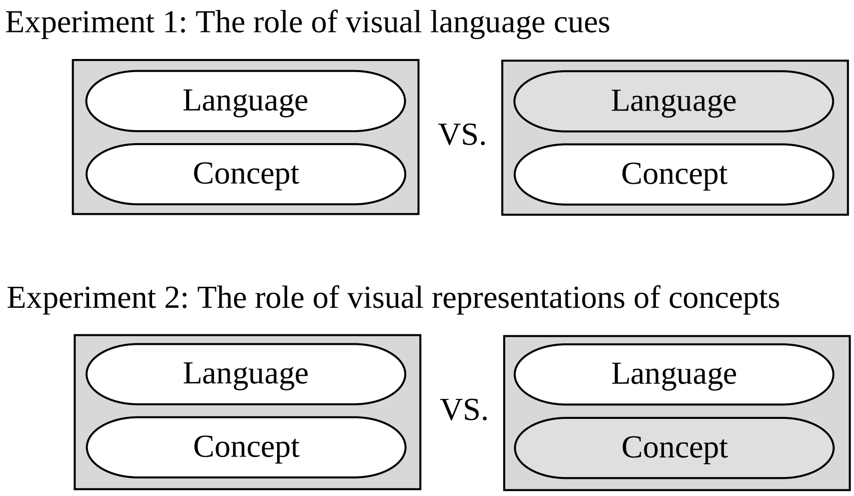
Note: arrow head means activation; circle head means inhibition; lightning bolt means interference resolution; L1 is German in this example and L2 is English.

Figure 2. Visual representation of the inhibitory control model. In this model, language control starts between language schemas, which represent the goal to talk in a certain language. In turn, these language schemas activate their respective language tags and inhibit language tags of other languages. Yet, this only occurs after the concepts have activated their respective lemmas. Finally, the language tags influence the corresponding lemmas, which makes it more likely that the correct lemma will be selected.



Note: Cloud-shape contours indicate a predictable (memorized) sequence; straight contours indicate an unpredictable sequence, with solely externally activated representations.

Figure 3. An overview of the predictability manipulations in all four experiments: the top panel shows the set-up of Experiment 1, with a predictable concept sequence in both conditions and either a predictable or unpredictable language sequence. The second panel shows the set-up of Experiment 2, with a predictable language sequence in both conditions and either a predictable or unpredictable concept sequence. The third panel shows the set-up of Experiment 3, with an unpredictable concept sequence in both conditions and either a predictable or unpredictable language sequence. The last panel shows the set-up of Experiment 4, with an unpredictable language sequence in both conditions and either a predictable or unpredictable concept sequence.



Note: White ellipses indicate a visual representation of language cues or concepts; Grey ellipses indicate no visual representation of language cues or concepts.

Figure 4. An overview of the visibility manipulations in Experiments 1 and 2: the top panel shows the set-up of Experiment 1, with a predictable language sequence and concept sequence in both conditions and either a visible or no visible language cue. The second panel shows the set-up of Experiment 2, with a predictable language sequence and concept sequence in both conditions and either a visible presentation of the concepts or no visible presentation of the concepts.

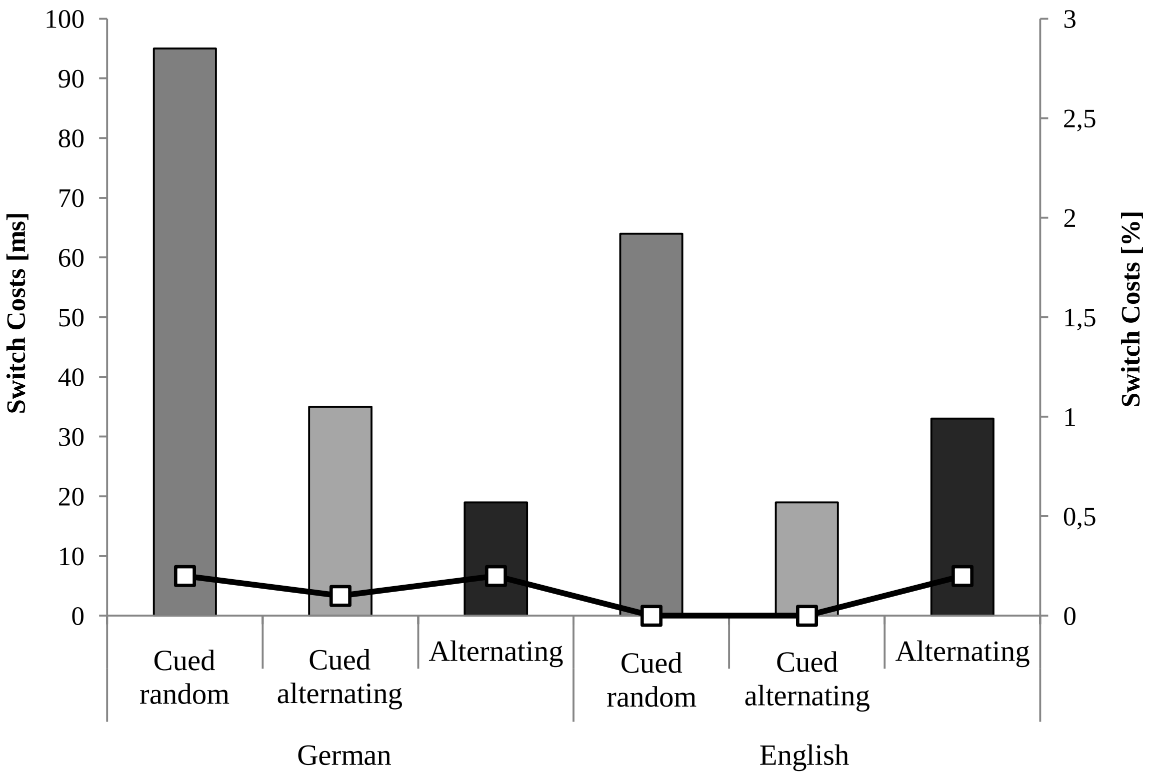


Figure 5. Switch costs in ms (Bars; left axis) and in percentage of errors (Line; right axis) of Experiment 1 as a function of language (German vs. English) and language predictability (*cued random* language sequence vs. *cued alternating* language vs. *alternating* language sequence). In this experiment, the concept sequence was always predictable.

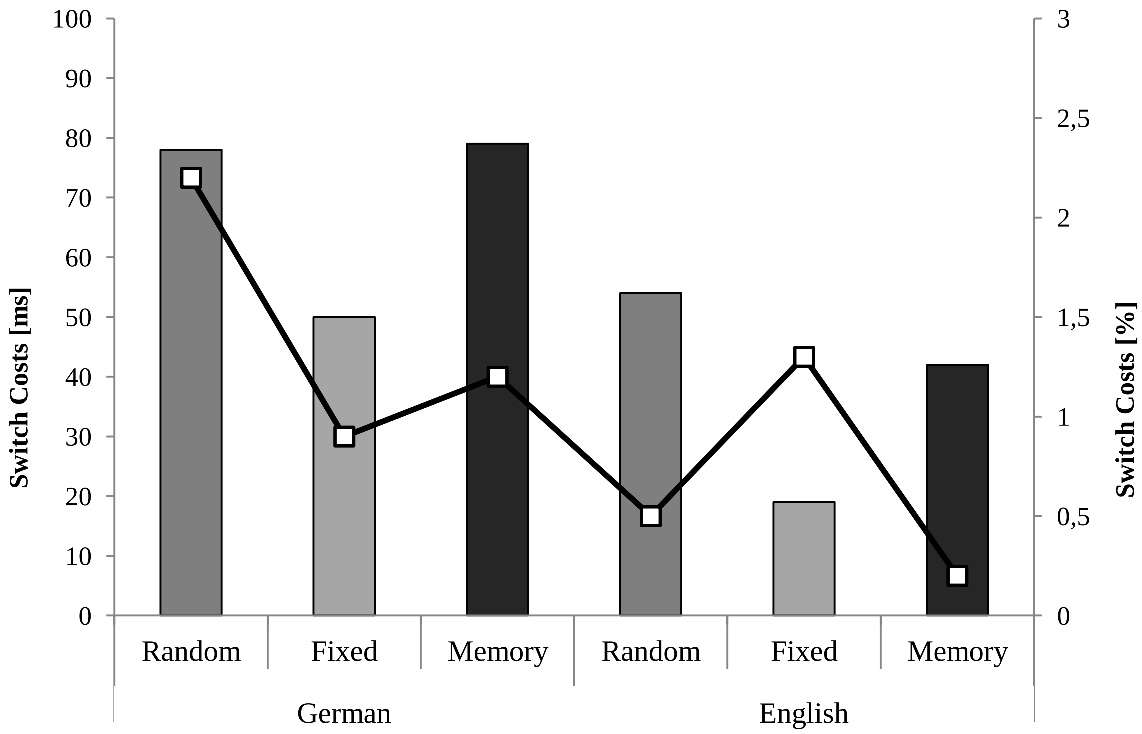


Figure 6. Switch costs in ms (Bars; left axis) and in percentage of errors (Line; right axis) of Experiment 2 as a function of language (German vs. English) and language predictability (*random* digit sequence vs. *fixed* digit sequence vs. *memory*-based number sequence). In this experiment, the language sequence was always predictable.

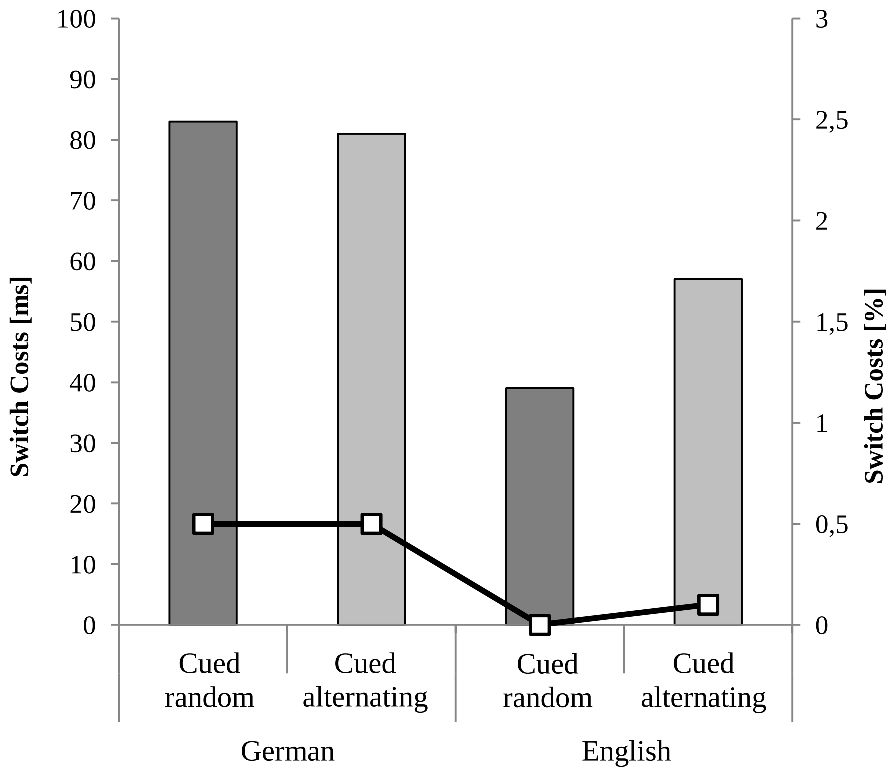


Figure 7. Switch costs in ms (Bars; left axis) and in percentage of errors (Line; right axis) of Experiment 3 as a function of language (German vs. English) and language predictability (*cued random* language sequence vs. *cued* alternating language sequence). In this experiment, the concept sequence was always unpredictable.

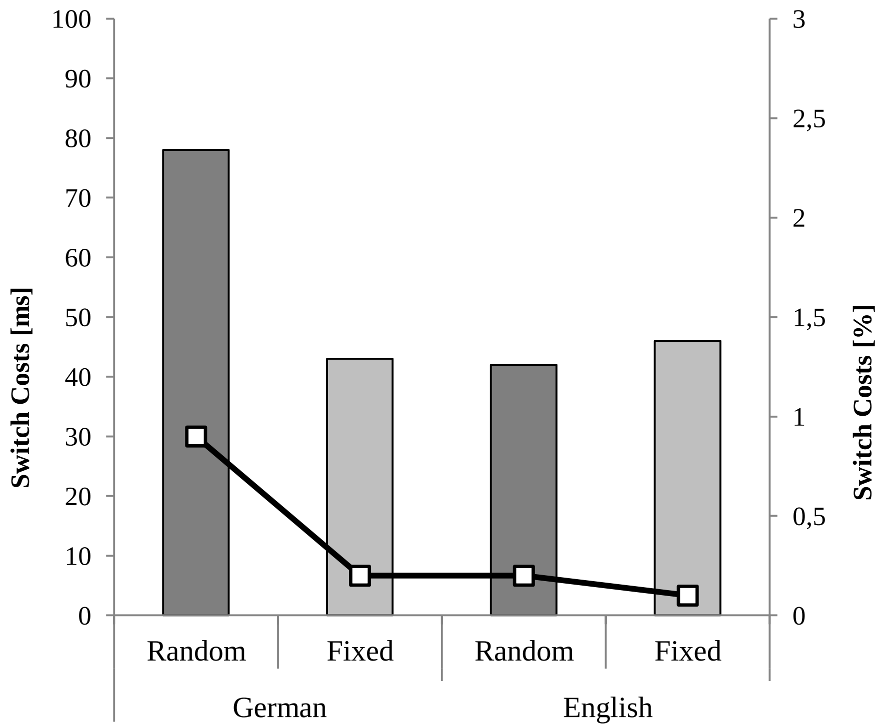
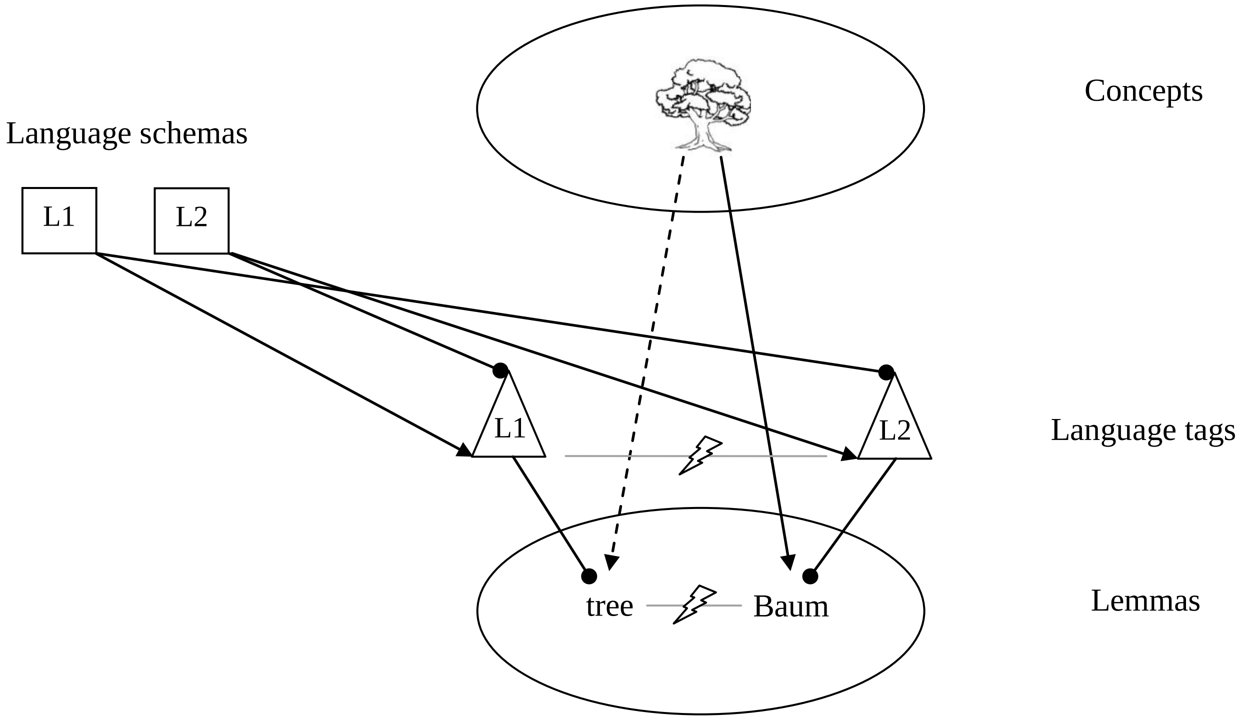


Figure 8. Switch costs in ms (Bars; left axis) and in percentage of errors (Line; right axis) of Experiment 4 as a function of language (German vs. English) and language predictability (*random* digit sequence vs. *fixed* digit sequence). In this experiment, the language sequence was always unpredictable.



Note: arrow head means activation; circle head means inhibition; lightning bolt means interference resolution; full line means larger activation than dotted line. L1 is German in this example and L2 is English.

Figure 9. Visual representation of the modified inhibitory control model. Language control starts when both the language and concept are known in this model. Hence, no interference resolution occurs between the language schemas, which was the case in the original ICM. Similar to the original ICM, the language schemas activate their respective language tags. In turn, the language tags influence each other and then inhibit the lemmas of the other language, which makes it more likely that the correct lemma will be selected. However, prior to the language tags being activated, the concepts activate their respective lemmas, with L1 lemmas being activated to a higher extent than the L2 lemmas by their corresponding concepts.

Appendix.

Fixed response sequences used in Experiments 1, 2 and 4.

	Languages	
	German	English
Experiment 1	eins	one
	zwei	two
	drei	three
	vier	four
	fünf	five
Experiment 2 (sequence a);	vier	four
Experiment 4	drei	three
	fünf	five
	zwei	two
	eins	one
Experiment 2 (sequence b)	fünf	five
	zwei	two
	drei	three
	eins	one
	vier	four