The other modality: Auditory stimuli in language switching

Mathieu Declerck, Denise N. Stephan, Iring Koch and Andrea M. Philipp

Institute of Psychology, RWTH Aachen University, Aachen, Germany

Authors' Note

Correspondence concerning this article should be addressed to Mathieu Declerck, Aix-Marseille Université, Centre St. Charles, 3 place Victor Hugo, 13331 Marseille, France. Email: mathieu.declerck@blri.fr.

Abstract

Language switching studies typically implement visual stimuli and visual language cues to trigger a concept and a language response, respectively. In the present study we set out to generalize this to another stimulus modality by investigating language switching with auditory stimuli next to visual stimuli. The results showed that switch costs can be obtained with both auditory and visual stimuli. Yet, switch costs were relatively larger with visual stimuli than with auditory stimuli. Both methodological and theoretical implications of these findings are discussed.

(83 words)

Keywords:
Language switching; Auditory stimuli; Visual stimuli; Stimulus modality

(overall word count: 3567 words)

One of the main tasks to investigate language control, a process that restricts bilingual production to the intended language, is the language switching task (e.g., Green, 1998). Although rigorous research has been conducted with this task over the last few decades, little has changed in the way it has been implemented. One of the factors that has been kept similar along both production and comprehension-based language switching studies, is its reliance on the visual modality to trigger concepts and languages (for a recent review, see Bobb & Wodniecka, 2013). In the present study, we aimed at generalizing this prior research to another stimulus modality by examining a novel sound-naming version of the language switching task. Moreover, we contrasted this new auditory language switching task with a more traditional visual language switching task.

Language switching

Production-based language switching typically consists of naming a visually presented language-unspecific stimulus, like a picture or digit, in the instructed language (e.g., Costa & Santesteban, 2004; Declerck, Koch, & Philipp, 2012; Philipp, Gade, & Koch, 2007; Prior & Gollan, 2013). Moreover, since generally two languages are used in language switching, the language assignment is usually instructed by visual language cues (e.g., colored squares) that are presented prior to or simultaneous with the stimulus (e.g., Costa & Santesteban, 2004; Declerck et al., 2012; Philipp et al., 2007; Prior & Gollan, 2013).

The use of two languages also means that there are two types of transitions between trials: a repetition of the previously used language (repetition trials) and a switch to another language (switch trials). Typically, worse performance is observed in switch trials than repetition trials (e.g., Costa & Santesteban, 2004; Declerck, Koch, & Philipp, in press; Philipp et al., 2007; Prior & Gollan, 2013). This performance difference is termed “switch costs” and is considered to be a marker for language control (e.g., Green, 1998).

Auditory vs. visual modality in language processing

While the visual stimulus modality is important for language through written language, there is also a strong connection between language and the auditory stimulus modality through speech. Hence, it is well worth investigating whether switch costs can also be assessed with this stimulus modality. Moreover, several lines of research indicate that language switching could be different with auditory and visual stimuli.

Several models of language control (e.g., Declerck et al., in press; Green, 1998; Schwieter & Sunderman, 2008) assume that the functional locus of language control is located prior to phonology, at the lexical-semantic level, which encompasses meaning and syntactic information. Next to the large body of evidence that shows that semantic information is modality specific (for a review, see, e.g., Barsalou, 1999), there are studies that indicate that there are differences in lexical-semantic processing between auditory and visual stimuli (e.g., Gomes, Ritter, Tartter, Vaughan, & Rosen, 1997; Holcomb & Neville, 1990).

For example, Holcomb and Neville (1990), found that semantic priming was larger, began at an earlier stage, and lasted longer with auditory stimuli than with visual stimuli in a lexical decision task. Gomes and colleagues (1997) further tested this for nouns and verbs. Their results were in line with those of Holcomb and Neville, in that they also found stronger semantic priming with auditory stimuli. Based on these differences in lexical-semantic processing with both stimulus modalities, a switch cost difference with auditory and visual stimuli might be expected.

Next to differences in lexical-semantic processing, it has been proposed that different control processes are evoked by auditory and visual stimulus modalities in more general cognitive control (Costa, Medeiros-Ward, Halper, Helm, & Maloney, 2012), which language control is assumed to be a part of (e.g., Green, 1998; Prior & Gollan, 2013). In the study of Costa and colleagues (2012), participants had to respond to visual stimuli (shape identification) or auditory stimuli (letter identification), depending on a cue. The results showed that switch costs were found when switching to either task and thus for both visual and auditory stimuli. Yet, switch costs were only reduced due to task preparation with a visual stimulus and not with auditory stimuli (however, see Lukas, Philipp, & Koch, 2010). Since preparation-based reduction of switch costs is assumed to be due to endogenous control processes, this finding was seen as evidence that visual stimuli elicit endogenous, goal-driven control processes, whereas auditory stimuli might simply trigger an "alerting" effect. The study of Costa et al. (2012), thus, suggests that control processes differ depending on the stimulus modality. Based on this finding, we suppose that also language switch costs could be affected by the stimulus modality.

The present study

To investigate whether switch costs can be obtained with our novel sound-naming version of the language switching task, and to examine whether there is a difference between auditory and visual input during language switching, we constructed a language switching task that used language-unspecific auditory and visual stimuli, which would present comparable bottom-up cues for the concepts. To further reduce any amount of auditory or visual features in the current study, apart from the stimuli, an alternating language sequence was used (e.g., Declerck et al., in press; Declerck, Philipp, & Koch, 2013) instead of visual language cues (e.g., Costa & Santesteban, 2004; Philipp et al., 2007; Prior & Gollan, 2013). The implementation of an alternating language sequence entails that the target language changes predictably after every second trial, without any additional visual or auditory external cue.

Method

Participants

36 native German participants (17 male) took part and spoke English as their second language (L2). Prior to the experiment they were asked to fill in a questionnaire regarding their age (mean age = 21.4), age of acquisition for English (mean age = 10.3), years of formal

English education (mean age = 8.9), and self-rated level of spoken English, with 1 being very bad and 7 being very good (mean = 5.1) [1].

Apparatus and stimuli

Ten concepts were used in the current experiment (for an overview of these concepts, see Appendix), which had to be produced eight times in English and eight times in German throughout the experiment. The participants were required to name these ten concepts based on a sound that is characteristic for this particular concept (e.g., chirping for the concept *bird* or a shot being fired for the concept *gun*) or on the basis of a visual depiction of the concept (Severens, van Lommel, Ratinckx, & Hartsuiker, 2005). None of the words were cognates and they had on average 1.7 syllables in German and 1.3 syllables in English. Their frequency was on average 43.9 per million for German and 70.5 per million for English (Baayen, Piepenbrock, & Guliker, 1995).

The sounds were recorded with a Zoom H2 Handy Portable Stereo Recorder and presented with a headphone (Speed Link, Full Metal Headset, SL8755). The trials were presented using E-prime. Speech onset of vocal responses was recorded with a voice-key and errors were coded online by the experimenter in a subject file.

Procedure

Prior to the experiment, the instructions were presented both orally and visually, with an emphasis on both speed and accuracy. In the instructions, the participants were told that they would hear a sound or see a picture that represents a certain concept. This concept then had to be named in one of two languages (i.e., German and English).

The manner of indicating the target language for each trial in the current study was chosen to exclude any auditory or visual information. So, a predictable, alternating language sequence was used, in which the required language alternated after every second trial (i.e., L1-L1-L2-L2-L1-L1 or L2-L2-L1-L1-L2-L2). This entails that there was an equal amount of language switches and language repetitions in each language. Furthermore, the starting language alternated from one block to the next and was counterbalanced across participants.

The instructions were followed by a practice block and four experimental blocks of 20 trials each. In these five blocks, either auditory or visual stimuli were presented (i.e., pure stimulus modality blocks). This was followed by another practice block and four experimental blocks of 20 trials each with the other stimulus modality. The order of the auditory blocks and the visual blocks was counterbalanced across participants. Furthermore, at the beginning of each block the participants were informed about the characteristics of the block (i.e., which language they should begin with and the stimulus modality).

Each trial started with an auditory or visual stimulus (1000 ms), depending on the block. After, or during, the stimulus presentation, participants had to produce the appropriate response. The ensuing pause of 600 ms would not be initiated until a response was registered, after which the subsequent stimulus would be presented.

Design

An analysis of variance (ANOVA) was calculated for reaction time (RT) and error rates, with the within-subjects independent variables stimulus modality (auditory vs. visual stimulation), language (German vs. English), and language transition (switch vs. repetition). A different ANOVA was calculated for subjects (F1) and items (F2) to generalize our finding over subjects and items. Furthermore, posterior probabilities were calculated (Masson, 2011), which allowed us to identify support for the alternative hypothesis in a graded, non-binomial manner. The values obtained with posterior probabilities range from .50-.75, indicating weak evidence, from .75-.95, indicating positive evidence, from .95-.99, indicating strong evidence, and from .99-1, indicating very strong evidence.

Results

The first trial of each block, error trials (which constituted the production of a wrong concept and/or production in the wrong language), and trials following an error, were excluded from RT analyses. Furthermore, for the calculation of RT outliers, RTs in all trials were z-transformed per participant and trials with a z-score equal to or exceeding -2/+2 were discarded as outliers. Taken together, this resulted in the exclusion of 4.2% of the data for RT analyses.

An ANOVA of the RT data revealed a significant effect of stimulus modality, $F1(1, 35) = 269.187$, $p < .001$, $\eta_p^2 = .89$, $p(H_1|D) = 1$; $F2(1, 9) = 171.88$, $p < .001$, $\eta_p^2 = .95$, $p(H_1|D) = 1$, with longer RTs with auditory stimulation (1503 ms) than with visual stimulation (1052 ms), of language, $F1(1, 35) = 36.07$, $p < .001$, $\eta_p^2 = .51$, $p(H_1|D) = 1$; $F2(1, 9) = 4.78$, $p = .057$, $\eta_p^2 = .35$, $p(H_1|D) = 1) = .99$, with slower responses during German trials (1334 ms) than during English trials (1221 ms) [2], and of language transition, $F1(1, 35) = 70.04$, $p < .001$, $\eta_p^2 = .67$, $p(H_1|D) = 1$; $F2(1, 9) = 53.28$, $p < .001$, $\eta_p^2 = .86$, $p(H_1|D) = 1$, with slower responses during switch trials (1333 ms) than during repetition trials (1222 ms).

In addition, there was a non-significant trend in the interaction between language and language transition, $F1(1, 35) = 4.10$, $p = .051$, $\eta_p^2 = .11$, $p(H_1|D) = .55$; $F2(1, 9) = 1.31$, $p = .283$, $\eta_p^2 = .13$, $p(H_1|D) = .66$, with larger English (132 ms) than German switch costs (91 ms). The interaction between stimulus modality and language and the three-way interaction were also not significant, $F\text{s} < 1$.

Interestingly, there was also no significant interaction between stimulus modality and language transition, $F1(1, 35) = 2.18$, $p = .149$, $\eta_p^2 = .06$, $p(H_1|D) = .33$; $F2(1, 9) = 3.35$, $p = .100$, $\eta_p^2 = .27$, $p(H_1|D) = .98$. This indicates that language switch costs can be found with auditory and visual stimuli and that there is no modality-specific difference in switch costs. However, due to the very large RT difference between responses with auditory and visual stimuli, it is difficult to compare switch costs for both stimulus modalities directly. Thus, we calculated proportional switch costs to compare language switch costs with auditory vs. visual stimulation. Proportional switch costs were calculated by dividing the mean switch cost RT by mean repetition trial RT. An ANOVA was then conducted with the independent within-subject variables stimulus modality and language and proportional switch costs as dependent variable. These results indicate a significant switch cost difference between auditory and visual stimulation, $F1(1, 35) = 12.98$, $p < .01$, $\eta_p^2 = .27$, $p(H_1|D) = .98$; $F2(1, 9) = 9.75$, $p < .05$, $\eta_p^2 = .52$, $p(H_1|D) = 1$, with smaller switch costs elicited by auditory stimulation (performance is decreased by 6.8% in switch trials relative to repetition trials) than with visual stimulation (13.9% proportional switch costs; see Figure 1). This analysis of proportional switch costs also revealed smaller switch costs for German than English (7.9% vs. 12.8%), $F1(1, 35) = 8.16$, $p < .01$, $\eta_p^2 = .19$, $p(H_1|D) = .88$; $F2(1, 9) = 3.37$, $p = .099$, $\eta_p^2 = .27$, $p(H_1|D) = .98$ [3]. The interaction between stimulus modality and language was not significant, *F*s < 1.

--Figure 1—

An ANOVA of the error data revealed a main effect of stimulus modality that approached significance, $F1(1, 35) = 3.15$, $p = .084$, $\eta_p^2 = .083$, $p(H_1|D) = .46$; $F2(1, 9) = 4.31$, $p = .068$, $\eta_p^2 = .324$, $p(H_1|D) = .99$, with more errors produced with auditory stimulation (1.1%) than with visual stimulation (0.9%; see Table 1). There was a significant effect of language, $F1(1, 35) = 4.82$, $p < .05$, $\eta_p^2 = .121$, $p(H_1|D) = .63$; $F2(1, 9) = 2.52$, $p = .147$, $\eta_p^2 = .219$, $p(H_1|D) = .93$, with more errors during German responses (1.2%) than during English responses (0.8%), and of language transition, $F1(1, 35) = 6.72$, $p < .05$, $\eta_p^2 = .161$, $p(H_1|D) = .80$; $F2(1, 9) = 6.18$, $p < .05$, $\eta_p^2 = .047$, $p(H_1|D) = 1$, with switch trial responses (1.2%) being more error prone than repetition trial responses (0.8%).

The interaction between modality and language, $F1 < 1$; $F2(1, 9) = 1.06$, $p = .329$, $\eta_p^2 = .106$, $p(H_1|D) = .56$, between language and language transition, $F1 < 1$; $F2(1, 9) = 1.42$, $p = .264$, $\eta_p^2 = .136$, $p(H_1|D) = .70$, and between stimulus modality and language transition, *F*s < 1, were not significant. Similarly, the three-way interaction was not significant, $F1(1, 35) = 2.53$, $p = .121$, $\eta_p^2 = .067$, $p(H_1|D) = .37$; $F2(1, 9) = 2.90$, $p = .123$, $\eta_p^2 = .244$, $p(H_1|D) = .96$.

--Table 1--

Discussion

The present study set out to investigate whether switch costs can be observed with auditory stimuli and whether auditory and visual stimuli elicit a switch cost difference during language switching. While substantial switch costs were obtained with both auditory and visual stimuli, proportional switch costs were significantly smaller with auditory stimuli than with visual stimuli.

The substantial switch costs found with auditory stimuli indicate that language-unspecific sounds are a valid alternative to visual stimuli to trigger a specific concept in language switching. Hence, this result demonstrates that switch costs obtained in a production-based language switching task are a robust finding, which could be generalized to other stimulus modalities.

Finding significant switch costs with auditory stimuli allows for new applications of the language switching paradigm. More specifically, future language switching research can use this novel approach to investigate specific populations, such as visually impaired participants (e.g., blind participants). It also allows prospective language switching research to trigger specific concepts when no visual stimulation is desired.

Next to the significant switch costs with auditory stimulation, a relative switch cost difference between auditory and visual stimuli was also observed in the current study. Since prior research has indicated that lexical-semantic processing is different with auditory and visual stimuli (e.g., Gomes et al., 1999; Holcomb & Neville, 1990), we could interpret the proportionally larger switch costs with visual stimuli than with auditory stimuli as evidence for a role of lexical-semantic processing during language switching. This would be in line with most models of language control (e.g., Declerck et al., in press; Green, 1998; Schwieter & Sunderman, 2008).

More specifically, since semantic priming covers a wider time range with auditory stimulation than with visual stimulation (Holcomb & Neville, 1990), one could assume that lexical-semantic processing takes longer with auditory stimuli than with visual stimuli. Hence, it could be deduced that the inherently longer lexical-semantic processing with auditory stimuli allows for enhanced language control because it implicitly affects the inter-stimulus interval, which could be used for preparation because the language sequence was predictable. Based on previous language switching studies that investigated preparation (cf. Costa & Santesteban, 2004; Declerck et al., in press), we can deduce that smaller switch costs with auditory than visual stimuli should be found. Further, the present study also demonstrates longer overall RTs in auditory blocks than in visual blocks, which might also reflect the longer lexical-semantic processing. A longer overall RT, however, increases the inter-stimulus interval and gives rise to potential decay effects. The decay of language activation from the previous trial could then in turn contribute to the reduced switch costs (cf. Meiran, 1996).

However, there is an alternative explanation for the results presented here. In Declerck et al. (2013), it was suggested that vocal production could lead to enhanced switch costs, since hearing one's own auditory utterance in the previous trial (i.e., comprehension) could further facilitate production in that language in the following trial (repetition trials) or cause additional interference (switch trials). This is in line with the findings of Peeters et al. (2014), who have found that comprehension can have an impact on production during language switching. Thus, through auditory comprehension of one's own vocal production, production-based switch costs could be increased. This effect, however, could be decreased with auditory stimuli, since the language-unspecific auditory stimuli could, to some degree, overwrite the memory of the previous vocal response (i.e., the auditory perception of one's own vocal utterance is not the last thing that is heard). With visual stimuli, on the other hand, this would not be the case. Consequently, switch costs could be larger with visual stimuli than with auditory stimuli due to this modality-specific influence on response-related positive and negative priming.

Another alternative interpretation involves the effect of sensory-motor modality compatibility on switch costs (e.g., Stephan & Koch, 2010, 2011). When switching between auditory and visual stimuli and between vocal and manual responses, it has been found that RTs are shorter and switch costs are smaller when vocal responses are combined with auditory stimuli and manual responses with visual stimuli (modality compatible) than when vocal responses are combined with visual stimuli and manual responses with auditory stimuli (modality incompatible; e.g., Stephan & Koch, 2010, 2011). Consequently, the smaller switch costs for auditory than for visual stimulus in the present study might have been caused by compatible (auditory-vocal) vs. incompatible (visual-vocal) stimulus-response mappings. However, it is important to note that the effects of modality compatibility are typically found when switching between modalities within a block (cf. Stephan & Koch, 2010, 2011). When pure modality blocks are implemented, as is the case in the current study, an opposite pattern is frequently found with faster RTs in the modality incompatible condition than in the modality compatible condition (e.g., Stephan & Koch, 2010, 2011). Therefore, it seems rather unlikely that the influence of modality compatibility on switch costs would be in the same direction in pure modality blocks as in mixed modality blocks. Thus, while we cannot completely rule out that the switch costs were affected by modality compatibility, prior results do not seem persuasive to explain the data pattern obtained in the current study.

It could also be, as mentioned in the introduction, that visual and auditory stimuli elicit different control processes (Costa et al., 2012), with visual stimuli resulting in endogenous, goal-driven processes, and auditory stimuli resulting in an alerting effect. This was based on the finding of a preparation benefit for switch costs with visual stimuli, but not with auditory stimuli. Since participants also had time to prepare in the current study due to the predictable language sequence, we should have observed smaller switch costs with visual stimuli than with auditory stimuli according to this study. Yet, since we found another pattern than Costa et al. (2012), we do not assume that our results can be explained by differently elicited control processes by the two stimulus modalities.

In summary, the current study provides evidence that language switch costs occur with both visual and auditory stimuli. Yet, whereas switch costs were observed with language-unspecific auditory and visual stimuli, they were relatively larger with visual than with auditory stimuli. Several factors may play a role in explaining this modality-specific difference in switch costs, which will have to be explored further in future research, so that the most important contribution of the present study refers to the methodological promise that the new auditory sound-naming paradigm may hold for research on bilingual language control.

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Notes

[1] Self-rated scores of second language proficiency have been proven to be a good indication of L2 proficiency (e.g., Leblanc & Painchaud, 1985).

[2] The slower and more erroneous German responses than English responses are somewhat surprising, since L1 performance is typically better than L2 performance. Yet, several studies have found such an effect in mixed language blocks, which has been attributed to global L1 inhibition or independent changes of selection criteria of both languages (e.g., Costa & Santesteban, 2004).

[3] While typically a reversed pattern is observed in switch costs across languages, numerically larger L2 than L1 switch costs have been observed in other language switching studies (e.g., Declerck et al., 2012). Interesting to note is that, similar to those studies, we also observed overall worse L1 than L2 performance. Consequently, it might be that this reversal in overall language activation, demonstrated by the overall worse L1 than L2 performance, might have also reversed the switch cost pattern across languages in our study (cf. Green, 1998).

Table 1

Overall reaction time (RT) in ms and percentage of errors (PE) (SD in parenthesis) as a function of stimulus modality (auditory vs. visual stimulation), language (German vs. English), and language transition (switch vs. repetition).

		German		English	
Stimulus modality		Switch	Repetition	Switch	Repetition
RT	Auditory	1599 (284)	1521 (252)	1504 (219)	1389 (192)
	Visual	1160 (268)	1057 (234)	1070 (198)	921 (181)
PE	Auditory	1.6 (0.1)	1.0 (0.2)	1.2 (0.1)	0.8 (0.1)
	Visual	1.1 (0.1)	1.1 (0.2)	1.0 (0.2)	0.4 (0.1)

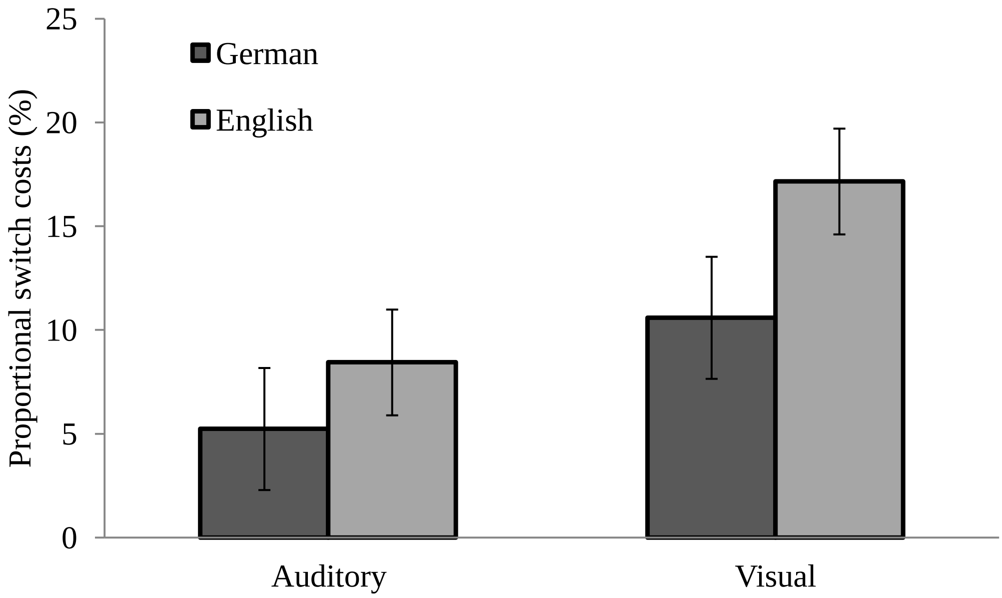

Figure 1. Proportional switch costs with 95% within-subject confidence intervals as a function of stimulus modality (auditory vs. visual stimulation), and language (German vs. English).

Appendix

Table A1

Overview of the concepts represented by sounds and visual depictions in German and English.

German	English
Glocke	bell
Hund	dog
Klavier	piano
Kuh	cow
Regen	rain
Schere	scissors
Trommel	drum
Vogel	bird
Waffe	gun
Zug	train