Costs and advantages in bimodal bilingual language production:

Language-switching and dual-task paradigms

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Zusammenfassung

Frühere Studien zum Sprachwechsel, die sich mit unimodalem (gesprochen–gesprochen) Sprachwechsel beschäftigen, haben längere Reaktionszeiten und höhere Fehlerraten in Wechseldurchgängen als in Wiederholungsdurchgängen gefunden (Sprachwechselkosten), besonders bei bilingualen Personen, die eine Sprache besser beherrschen als die andere. Studien zu gebärdensprachkompetenten Hörenden (bimodalen bilingualen Personen), die eine gesprochene und eine Gebärdensprache beherrschen, haben gezeigt, dass diese oft „code-blends“ produzieren anstatt sequenziell zwischen den Sprachen zu wechseln. Dabei sind „code-blends“, also die simultane Produktion von zwei Wörtern in zwei verschiedenen Sprachen, bei unimodaler bilingualer Sprachproduktion nicht möglich. Die vorliegende Studie beschäftigt sich mit sequenziellem Sprachwechsel und simultaner Sprachproduktion (dual-task) in bimodalen bilingualen Personen. Das Methodenexperiment hat das Sprachwechselparadigma, das früher ausschließlich für unimodale Daten benutzt wurde, für bimodale bilinguale Daten angepasst. Die Anpassung des Sprachwechselparadigmas setzte eine erhebliche methodologische Entwicklung voraus.

Das Methodenexperiment und Experiment 1 untersuchen Modalitätseffekte im Sprachwechsel mit zwei Modalitäten: unimodal (Deutsch–Englisch) und bimodal (Deutsch–DGS). Reaktionszeiten waren kürzer, Fehlerraten niedriger und Wechselkosten kleiner bei bimodalem Sprachwechsel

verglichen mit unimodalem Sprachwechsel, was einen bimodalen Vorteil andeutet. Experiment 2 untersucht simultane bimodale Sprachproduktion und vergleicht dabei dual-task und single-task Durchgänge, um mögliche dual-task Vorteile festzustellen. Frühere Studien stellten dual-task Kosten fest oder, in begrenzten Fällen, keine dual-task Kosten und keinen Vorteil für Antworten in zwei Modalitäten für nicht-sprachliche Aufgaben. Die Ergebnisse von Experiment 2 zeigen, dass ein dual-task Vorteil möglich ist im Kontext des bimodalen bilingualen Sprachwechsels, insbesondere wenn der Proband zu einem dual-task Durchgang (code-blend) wechselt. Es liegt nahe, dass Sprache anders ist als andere Aufgabenkomponenten in Aufgabenwechsel- und dual-task Experimenten, und dass ein code-blend eine Einheit bildet, die größer ist als die Summe ihrer Teile.

Abstract

Previous studies of unimodal (spoken–spoken) language switching have often found longer reaction times and higher error rates in switch trials than in repeat trials, particularly for unbalanced bilinguals. Studies of hearing signers (bimodal bilinguals) have found that they often produce ‘code-blends’ rather than sequential code-switches; such simultaneous production is generally not possible in unimodal utterances. The present study explored sequential language switching and simultaneous language production (dual-task) in bimodal bilinguals. The Methodological Experiment adapted the language-switching paradigm, used previously to test unimodal language switching, to bimodal data and required significant methodological development.

The Methodological Experiment and Experiment 1 examined modality effects in language switching with two Modalities: unimodal (German–English) and bimodal (German–DGS). Reaction times were shorter, error rates lower and switch costs smaller in bimodal switching blocks than in unimodal blocks, indicating a bimodal language switching advantage. Experiment 2 examined simultaneous bimodal language production, comparing dual-task and single-task trials in order to determine whether there are dual-task advantages. Previous studies found dual-task costs, or in some cases, no dual-task cost and no advantage, for responses across modalities in non-language tasks. However, our results show that in a bimodal bilingual switching condition, there can be a dual-task advantage, especially when switching into a dual-task trial (code-blend).

We suggest that language is different from other task components in task-switching and dual-task studies and that a code-blend forms a unit which is greater than the sum of its parts.

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1. General Introduction

Bilinguals are able to communicate in two different languages, and they can switch from one of their languages to the other, which they commonly do. Whereas most bilinguals indeed *speak* two languages, for example German and English, bimodal bilinguals are competent in a spoken language and a signed language. Sign languages are as complex as spoken languages, and they are distinct from the spoken language(s) used in the same country or region in terms of lexicon, phonology, syntax, etc. It follows that a switch from spoken German to German Sign Language (DGS), for example, is as much of a language switch as a switch between any two languages, be they spoken or signed.

However, unimodal (spoken–spoken) language mixing is different from bimodal (signed–spoken) language mixing in one key respect: in unimodal mixing, the two languages are of the same modality (i.e. the vocal-auditory modality) and as such, they share a single primary output channel: the vocal tract. As a consequence, unimodal bilinguals can switch between their languages in the course of a conversation, a behavior that is often referred to as code-switching (cf. Milroy & Muysken, 1995), but they cannot produce two words from the two different languages at exactly the same time.

In contrast, the languages involved in bimodal mixing are of two different modalities and as such, they do not share a primary output channel, which in sign languages (of the visual-spatial modality) is composed of the hands. For this reason, simultaneous natural language production, or code-blending (e.g. Bishop & Hicks, 2005), is possible in bimodal language mixing, while this simultaneous form of mixing is not possible in unimodal language production (e.g., Emmorey, Borinstein, Thompson, & Gollan, 2008). At the same time, the possibility of simultaneous bimodal language production does not preclude sequential bimodal language mixing in the form of language switching, and while rare, it does occur in offline data (ibid.).

The language-switching paradigm has been used widely in the psychological study of bilingual language production, which has focused on unimodal (spoken-spoken) production. In these experiments, participants are instructed to produce words in the correct language for each trial, with the correct response language indicated by a cue and the response word indicated by a stimulus such as a digit or a picture. The trial sequence is designed so that the correct language is either the same as the previous trial (a repeat trial) or different (a switch trial; see Figure 1.1). Previous studies testing unimodal language switching found longer reaction times and higher error rates in switch trials than repeat trials, and these ‘switch costs’ have been replicated often, particularly for unbalanced bilinguals (for reviews, see e.g. Bobb & Wodniecka, 2013; Kiesel et al., 2010; Kroll, Bobb, Misra, & Guo, 2008).

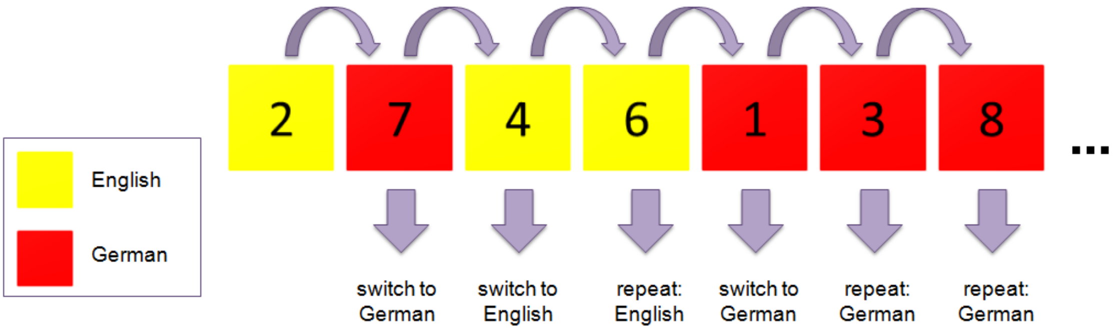

Figure 1.1. Trial sequence in language switching experiments

The study of bilingual speech production is divided into two primary theoretical approaches: (1) language-specific selection models and (2) inhibition models (see Figure 1.2). Selection models assume that language selection is closely tied to lexical selection: lexemes from the incorrect language cannot be selected and therefore do not compete with lexemes from the correct language in later stages of production (e.g., Costa & Caramazza, 1999; Finkbeiner & Caramazza, 2006). Inhibition models, in contrast, assume that bilingual parallel lexical activation occurs first and is followed by the inhibition of one lexeme or language in order to allow selection of the correct lexeme in the correct language (e.g., Green, 1986, 1998; Meuter & Allport, 1999).

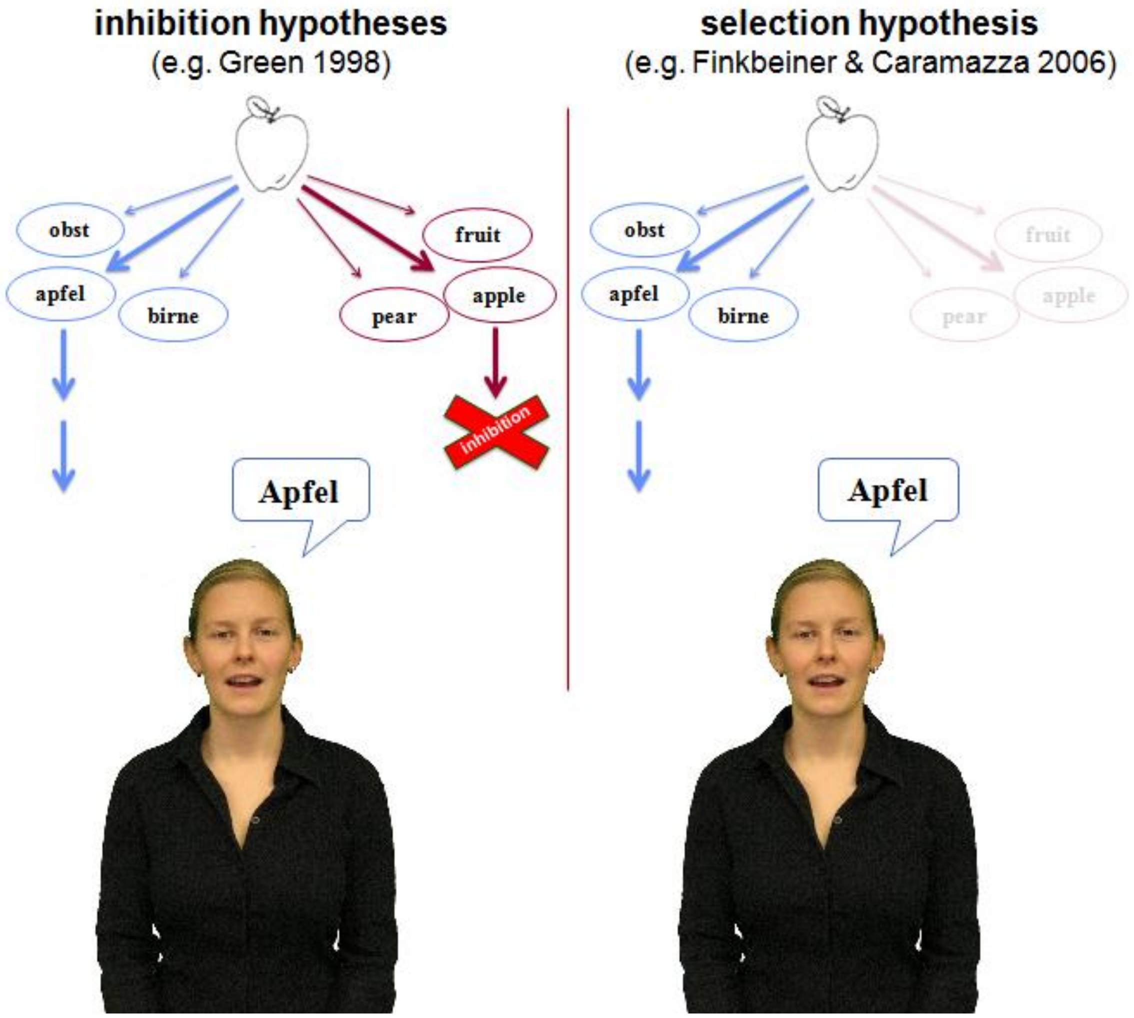

Figure 1.2. Models of bilingual lexical selection

These models were developed on the basis of studies of unimodal language production, in which language selection is forced due to the physiological restrictions associated with sharing a primary output channel. However, in bimodal language production, a spoken word and a sign from the sign language can be and often are produced simultaneously; this observation is consistent with inhibition models because parallel production indicates that the lexemes from both languages can be selected and produced in parallel (Emmorey et al., 2008; see Figure 1.3).

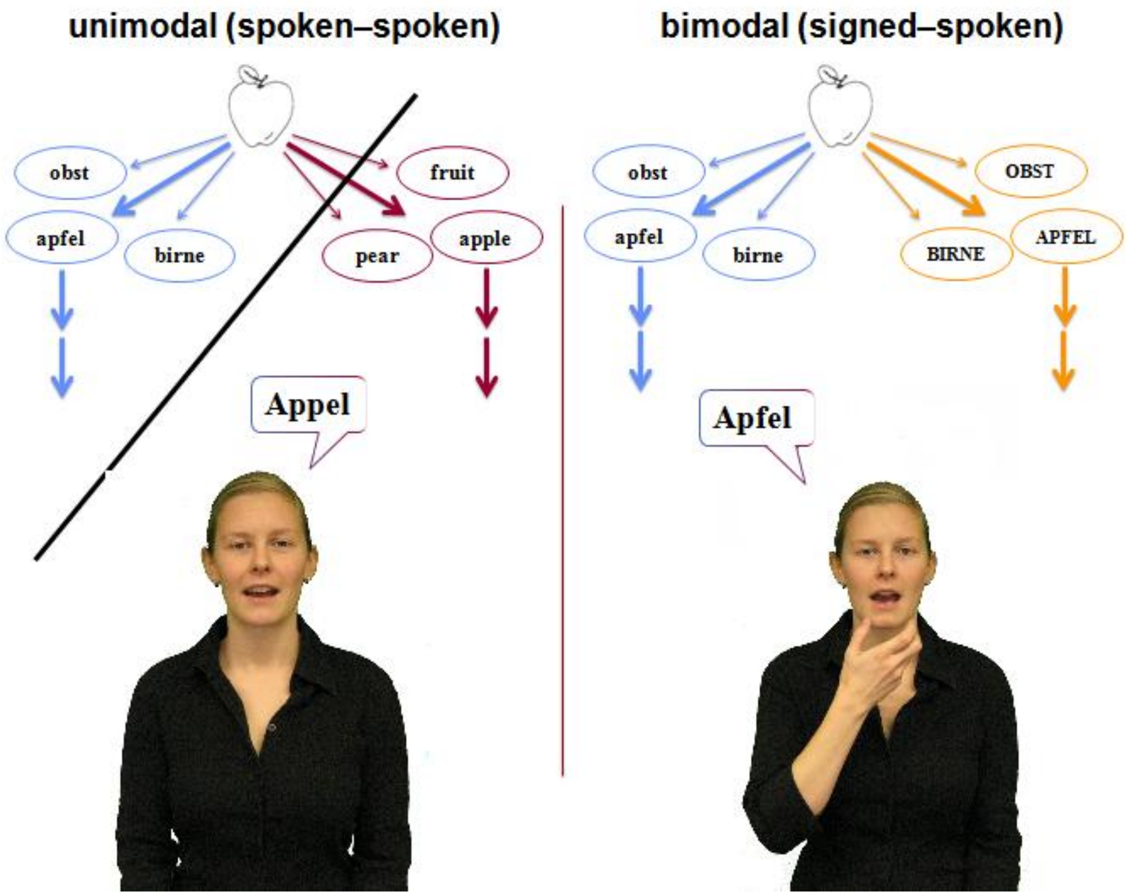

Figure 1.3. Simultaneous bilingual production

Inhibition models assume that language switch costs are a result of the inhibition of one language. In a repeat trial, the correct language of the current trial (*n*) is the same as that of the previous trial (*n*-1): the active language remains active and the inhibited language remains inhibited. For example, in a German–German repeat, the correct language of the previous trial (*n*-1) was German, and German remains active in the current trial (*n*). In a switch trial (*n*), the correct language is different from the correct language of the previous trial (*n*-1): the active language from the previous trial must be inhibited, and the inhibited language must be activated, in order for the current trial to be produced correctly. For example, in a switch from DGS to German, the correct language for the previous trial (*n*-1) was DGS, so DGS was active and German was inhibited in the previous trial; this inhibition of German persists into the current trial and must be overcome in order to produce the current trial's correct language.

The longer reaction times and higher error rates for switch trials are interpreted as the result of overcoming this inhibition (e.g., Green, 1986, 1998; Meuter & Allport, 1999; Kroll et al., 2008; Philipp & Koch, 2009; see also Koch, Gade, Schuch, & Philipp, 2010). Such studies also often find a switch-cost asymmetry, with larger switch costs for the dominant language than for the non-dominant language in an unbalanced bilingual (See Figure 1.4). This result does not necessarily hold for balanced bilinguals, who have no dominant language (e.g., Costa & Santesteban, 2004). The switch-cost asymmetry can be accounted for assuming that greater inhibition is required to suppress the dominant language; when switching back to the first language (L1), overcoming this greater inhibition results in slower reaction times and higher error rates as compared to switching back to the less dominant, second language (e.g., Kroll et al., 2008; Meuter & Allport, 1999; Philipp, Gade, & Koch, 2007).

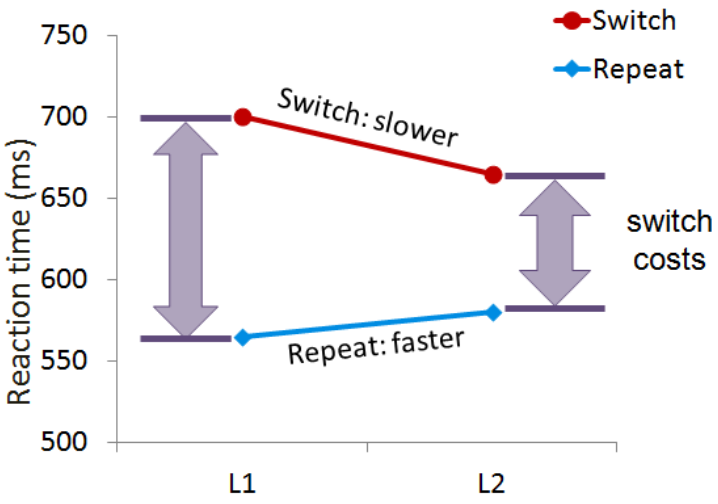

Figure 1.4. Idealized data pattern from a language switching experiment

While language switching experiments have been widely used to study inhibition effects and processing costs in language switching, these studies have dealt with unimodal language production. The Methodological Experiment, presented in Chapter 2, as well as Experiment 1, presented in Chapter 3, compares language switching in unimodal blocks, in which participants switched between two spoken languages, with language switching in bimodal blocks, in which participants named objects in either a spoken or a signed language. Language switch costs were smaller in bimodal blocks than in unimodal blocks, demonstrating a bimodal advantage in language switching. One reason for the smaller switch costs in bimodal blocks could be the fact that the same primary output channel is used in two spoken languages, while bimodal switching involves languages with different primary output channels, so that bimodal language processing represents a very specific case of bilingual language processing.

As mentioned above, the physiological restrictions associated with a shared primary output channel in unimodal production mean that switching between languages is possible for unimodal bilinguals, but words from two spoken languages cannot be uttered simultaneously. However, in bimodal language production, a spoken word and a sign from the sign language can be uttered simultaneously, which opens an interesting possibility for studies using a dual-task design. A widely-used dual-task paradigm is the Psychological Refractory Period (PRP) paradigm (see Pashler, 1994, for an overview) in which two tasks must be performed simultaneously or with a short stimulus-onset asynchrony (SOA). There are two basic results: 1) Performance is worse when two tasks are performed at the same time (dual-task trials) as compared to performing each of the responses in isolation (i.e., in single-task trials; the difference between dual-task trials and single task-trials is termed ‘dual-task costs’). 2) The dual-task cost increases with the increasing temporal overlap of the tasks (i.e., the shorter the SOA, the larger the dual-task costs).

With respect to bimodal bilinguals, producing a sign in a sign language and speaking a word can each be considered as single-tasks, whereas a code-blend represents a dual-task. A recent study (Emmorey, Petrich, & Gollan, 2012) examined bimodal bilinguals using a dual-task paradigm. In this picture-naming study, single-task pure blocks, in which responses always had to be produced in one language only, were compared to dual-task pure blocks, in which only code-blends were produced. The data pattern showed a lack of dual-task costs across pure blocks for manual American Sign Language (ASL) production for RTs and error rates, and there was even a dual-task advantage in error rates for low-frequency signs, meaning that for manual responses involving low-frequency signs, error rates were lower in dual-task than in single-task trials. For English vocal responses, they found a dual-task cost; however, the authors conclude that this cost is a result of timing spoken words to sign production, that is, a coordination cost, rather than a reflection of processing costs.

Many studies have found dual-task costs for contexts other than bimodal bilingual designs (for a review, see Pashler, 1994; Welford, 1952). The extent of these dual-task costs, i.e. their reduction, depends on the manipulation of stimulus onset asynchrony or the degree of interference due to, for example, response-code conflict (e.g. Huestegge & Koch, 2009; Logan & Schulkind, 2000; Navon & Miller, 1987). Dual-task costs have also been reduced or eliminated by setting task priorities or through extensive practice (e.g. Hazeltine, Teague, & Ivry, 2002; Schumacher et al., 2001; Strobach, Liepelt, Pashler, Frensch, & Schubert, 2013). Dual-task advantages were found under very limited circumstances; for example, when a distractor task prevents unnecessary use of cognitive resources (Kristjánsson, Chen, & Nakayama, 2001) or when a second stimulus to which the participant need not respond functions as prime (e.g. Evens & Ludwig, 2010). However, overall, dual-task advantages are rare so that the effect observed with bimodal bilinguals (Emmorey et al., 2012) indicates processing specificities in bimodal language production.

So far, there has been little work on language switching and simultaneous language production involving bimodal bilinguals. The experiments described in the present paper were designed to examine the mechanisms underlying costs in both sequential and simultaneous bimodal language mixing using single-task (the Methodological Experiment; Experiments 1 and 2) and dual-task (Experiment 2) switching designs as well as pure Response blocks (Experiment 2). By doing so, we aim at systematically exploring bimodal language mixing in terms of both switching between languages and producing two languages at the same time (i.e., dual-tasks or Blends). This way, we can both integrate and extend the results of previous studies to provide general insight into the mechanisms of bimodal language processing.

By combining language switching and a dual-task design, we can also address the nature of a Blend. We suggest that a Blend is a unit which is more than the sum of its parts: a dual-task Blend is not simply an additive collection of two single-tasks which each have their own functions; rather, a Blend operates as a unit. We suggest that in this way, language is different from other types of task components. For this reason, we anticipate that Blends will be associated with advantages in some cases and disadvantages in others.

Our hypotheses are as follows: For the Methodological Experiment and Experiment 1, we anticipate that reaction times will be shorter, error rates lower and switch costs smaller in bimodal switching blocks than in unimodal switching blocks. For Experiment 2, we anticipate switch costs and mixing costs. Within the mixed condition, for manual RTs, we anticipate smaller switch costs for dual-task trials than single-task trials. For errors, we anticipate the lowest error rates and smallest switch costs for Blend trials.

2. Methodological Experiment

2.1 Introduction

In any program of research, there are methodological considerations that must be addressed. This paper describes a program of research that required a great deal of methodological development, which will be reported on in this chapter. The experiments reported on in this paper are based on paradigms that have been widely used, but for different tasks and types of tasks than those addressed in the present paper. This chapter reports on the Methodological Experiment, which was the first in the series of three. The Methodological Experiment uses the language-switching paradigm and adapts it to bimodal (signed–spoken) data. Experiment 1 also uses the language-switching paradigm, and it was designed on the basis of the developments made in the Methodological Experiment. These developments were also key in designing Experiment 2. Experiment 2 uses the dual-task paradigm, which has been used extensively for non-language tasks and dual-tasks in which only one of the two tasks is natural vocal language production, and adapts it to bimodal data.

In designing the Methodological Experiment and adapting the language-switching paradigm to bimodal data for the first time, methodological adaptations were required. Additionally, during the course of running the Methodological Experiment and analyzing the data, further unanticipated methodological issues arose. These methodological considerations and adaptations are described together below. These adaptations were used in designing Experiments 1 and 2, the results of which are reported on in Chapter 3. In running Experiments 1 and 2, further issues arose, and these issues and their implications for future studies are discussed in the present chapter.

Previous experiments using the language-switching paradigm have tested sequential unimodal (spoken–spoken) language switching (e.g., Costa & Santesteban, 2004; Meuter & Allport, 1999; Philipp et al., 2007; see Bobb & Wodniecka, 2013, for a review). In language-switching experiments, participants are instructed to produce words in the correct language for each trial. These studies have found longer reaction times and higher error rates in switch trials than repeat trials, and these ‘switch costs’ have been replicated many times for unimodal data from various spoken languages (for reviews, see, e.g., Kiesel et al., 2010, and Kroll et al., 2008).

Until now, there have been no language-switching studies that assess bimodal (signed–spoken) language switching. However, there is no theoretical reason that this paradigm should not be applied to bimodal language production. Indeed, bimodal bilinguals mix their languages naturally conversation (e.g. Bishop & Hicks, 2005). However, the patterns of mixed language production are different for unimodal and bimodal bilinguals, with unimodal bilinguals producing sequential language switches and bimodal bilinguals producing simultaneous code-blends (e.g., Bishop & Hicks, 2005; Emmorey et al., 2008).

This simultaneity is possible in bimodal production because the two languages are of different language modalities and as such, they do not share a primary output channel.

The Methodological Experiment was designed to apply the language-switching paradigm to bimodal bilingual data and to examine the mechanisms underlying switch costs in bimodal language switching. Based on the findings from previous unimodal studies, as well as on the distinct primary output channels of signed and spoken languages, we hypothesize that reaction times will be shorter, error rates will be lower and switch costs will be smaller in bimodal switching blocks than in unimodal switching blocks.

2.2 Methodological considerations and developments

In adapting these existing experimental paradigms to new conditions for this series of experiments, various aspects were taken into consideration. These adaptations will be described by topic below.

2.2.1 Software/hardware

In terms of software, there are many computer programs designed to implement psychological experiments by recording reaction times. The first consideration when selecting a computer program is whether it supports the responses required by the experiments. For the Methodological Experiment, the required responses were vocal responses and manual responses, so the software had to be capable of recording reaction times with a voicekey and a homekey in addition to supporting the appropriate registration functionality at the millisecond level. The Methodological Experiment was programmed in Presentation (Neurobehavioral Systems), which allows both voicekey and homekey response registration at the millisecond level.

In terms of hardware, the greatest methodological consideration was the microphone. In previous language-switching experiments, table-mounted microphones connected to the computer via cables have generally been used. However, in this set of experiments, it was not possible to use a table-mounted microphone because such a microphone would interfere with the manual responses from the signed language. The Methodological Experiment was conducted using the laptop-internal microphone because the external microphones tested produced false vocal response registration in the reaction time data and led to feedback loops of these false response registrations. However, this solution proved to have its own drawbacks, most noticeably a false vocal response for all manual responses caused by the sound of fingers on the homekey. These false positive responses represented not falsified reaction times, but rather superfluous data points, and they were simply removed from the data in analyzing the results from the Methodological Experiment.

For Experiments 1 and 2, a headset with an integrated microphone was used which caused only limited data loss due to false vocal response registration. These false responses were again removed from the data prior to analysis. As these experiments had to do with production and therefore sound perception was not relevant, there was no need for the headphones to be placed on the ears, where auditory input might be a distraction and where the headphones might lead to physical discomfort, especially for those participants wearing glasses. So the headphones were placed around subjects' necks and the attached microphone placed at a location that would not interfere with signing and where the hand would not come into contact with the microphone and cause a false vocal response registration. Since most people are right-handed, a headset with the microphone on the left side was selected.

2.2.2 Response registration

A great challenge in designing this series of experiments was response registration. In unimodal bilingual experiments, responses for both languages are performed in the same way (vocally) because the languages share a language modality, i.e. the vocal-auditory language modality. For this reason, response registration is the same for both languages. For most experiments, a voice key is used which registers a response when a sound threshold is reached. Registering the sound threshold for vocal responses across spoken languages provides directly comparable response registrations for different spoken languages. Sign languages, on the other hand, are of the visual-spatial modality, so sign language responses cannot be registered using a microphone. It is standard practice to use a button press or homekey release for non-language manual responses, so a homekey may be used for a sign language response as well.

In designing the Methodological Experiment, this approach was taken. However, in the course of running the experiment, analyzing the data and reviewing the videos, it became clear that the homekey, which was assigned as the spacebar on the laptop, was inadequate as a timing point for the sign language responses in the study. The reason is that for many signs, homekey release did not coincide with sign production onset (see Figure 2.1). Rather, there was a lag between homekey release and sign onset. Due to this lag, RTs were skewed faster, with differing amounts of skewedness, for eight of the 12 stimuli. The fact that RTs were skewed faster is problematic in and of itself, but the differing amounts of skewedness compromised the internal validity of the manual responses. For this reason, manual responses could not be analyzed in the results from the Methodological Experiment.

Figure 2.1. Sign onset for the signs SUN (left) and FLOWER (right). For SUN, the place of articulation is near the forehead, so there is a large lag between komekey release and sign onset. For FLOWER, the place of articulation is in the neutral signing space, where the homekey is located.

For Experiments 1 and 2, a methodological workaround for this issue had to be found. In a previous bimodal experiment making use of a homekey to record sign language RTs (Emmorey et al., 2012), this issue was addressed by performing a post-hoc video analysis and post-hoc calculations to compensate for the lag between homekey release and sign onset. In Experiments 1 and 2, this issue was addressed at the design stage, i.e. in stimulus selection. In this series of experiments, participants are seated at a table in front of a laptop, with the homekey assigned to a key on the laptop keyboard. In this setup, the homekey is in the neutral signing space in front of the participant. So, only signs that are produced in the neutral signing space were selected as stimuli (see Figure 2.2). In this way, the lag between homekey release and sign onset is minimized, and, most importantly, any remaining lag is homogenized among the stimuli. This method of stimulus selection preserves the internal validity of the manual responses and allows for statistical analyses to be performed which compare the manual responses to each other.

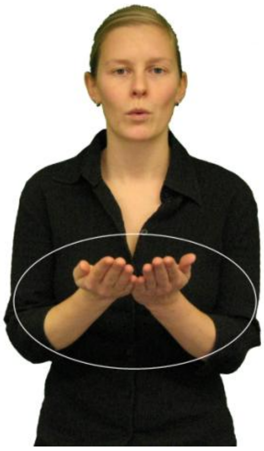

Figure 2.2. Neutral signing space

2.2.3 Stimuli selection

For all experiments in this series, the language assigned the highest priority in terms of stimulus selection was DGS. Particularly for the Methodological Experiment, which tested subjects with a limited knowledge of DGS, the first priority was selecting easy-to-learn signs that signing subjects would likely be familiar with and which non-signers could easily learn. Such signs will have a high level of iconic transparency in their form-to-meaning mapping (e.g., Bellugi & Klima, 1976). Highly transparent signs have been shown to be retained very well by non-signers over short periods of time (Lieberth & Gamble, 1991). This quality of being easily retained is important for the Methodological Experiment because some participants first performed in the German-English switching blocks before producing the newly-learned signs in bimodal switching blocks.

Figure 2.3. The DGS sign FLOWER

An example of a transparent sign in the Methodological Experiment is FLOWER (Figure 2.3). The sign FLOWER is produced by opening the hand, palm facing up, as if the fingers were the petals and the arm were the stem. For this sign, there is a transparent iconic mapping between the object represented by the sign and the visual phonological components of the sign itself, i.e. the handshape, movement, orientation and place of articulation of the sign. Due to the sign's iconic transparency, it is assumed that this sign will be relatively easy to learn and retain. An additional consideration which ties in closely with iconicity is the ability of the item to be represented as a line drawing for the stimulus, which is required for all stimuli used in this series of experiments.

The next consideration for stimuli selection, which was an inflexible criterion, was the number of hands used in a sign. In sign languages, individual signs can be one-handed or two-handed in their citation form (see Figure 2.4).

For a two-handed sign, both hands would have to press a homekey. If both hands pressed the same homekey, this might lead to confounds if, for example, one hand started producing the sign while the other continued to keep the homekey pressed. If each hand had a separate homekey, it is almost certain that there would be at least small differences in response time for the two hands, which might also lead to a confound, or at least to an unnecessarily complex data pattern. In order to preclude possible confounds resulting from two-handed signs, only one-handed signs were used, and there was only one homekey. Participants used only their dominant hand in these experiments to release the homekey and to produce signs, and the non-dominant hand was not used.

Figure 2.4. The two-handed DGS sign BOOK

Finally, as mentioned above, response registration for many of the stimuli in the Methodological Experiment was problematic due to a lag between homekey release and sign onset, which resulted in the manual data being excluded from the analysis for that experiment. In order to avoid this problem, in Experiments 1 and 2, only signs were chosen which are produced in the neutral signing space and, as such, which lead to equivalent minimal lag between homekey release and sign onset across stimulus items.

Although characteristics of the DGS signs were the first priority in stimulus selection, there were important considerations on the level of the spoken languages as well. For vocal responses, the functionality of the experimental software and hardware was an issue. In tests using both the laptop-internal microphone and the external microphone, it was found that spoken words longer than two syllables triggered the microphone for a second vocal response within one trial and often led to a vocal response feedback loop that caused a series of trials with false vocal response registrations. For this reason, stimuli were limited to spoken words that were one or two syllables in both German and English. A final consideration in stimuli selection, necessarily of low priority due to the demands of manual responses, had to do with whether the words in German and English were cognates. In this case, an attempt was made to use a balance between spoken word pairs that are cognates and those that are not.

2.2.4 Theoretical considerations

Experimental paradigms are tied with theoretical assumptions; in adapting a paradigm to new conditions, these theoretical assumptions must also be addressed. In psycholinguistic research, there have been many studies addressing word frequency (e.g. Allen, McNeal, & Kvak, 1992; Forster & Chambers, 1973; Oldfield & Wingfield, 1965; for bimodal language production and frequency effects, see Emmorey et al., 2012; Emmorey, Petrich & Gollan, 2013). However, assessing frequency effects is beyond the scope of the current series of experiments, and the priorities of these experiments lay elsewhere.

For all experiments in this series, the stimuli base was limited to commonly-occurring and iconically transparent signs due to participants’ status as L2 learners; while there is currently no extensive work on sign frequency in German Sign Language, for the purposes of this series of experiments it can be assumed that none of the signs selected as stimuli are of very low frequency. For all experiments in this series, the requirement of one-handedness restricts the pool of possible stimuli; and for Experiments 1 and 2, the limitation of the place of articulation to the neutral signing space even more severely limited the pool. For these reasons, no analyses of frequency effects could be conducted.

An additional effect which has been studied extensively but which could not be addressed in this series of experiments is the cognate effect. Cognate facilitation effects are found in some contexts, while cognate interference effects are found in others (e.g. Costa, Santesteban, & Caño, 2005; Dijkstra, Miwa, Brummelhuis, Sappelli, & Baayen, 2010). For the present series of experiments, again the priority lay elsewhere, and there were too few stimuli to consider analyses of cognate effects. The simple approach, and the approach taken, was to try not to have too many or too few cognate pairs in German and English. Importantly, there are no real cognates between German Sign Language and either of the two spoken languages studied in the present paper, or between any signed language and any spoken language, due to the fact that languages of different modalities make use of radically different phonological resources. Thus, this factor must remain a low priority in studies taking a bimodal approach.

Related to the issue of spoken language cognates in L2 learners is pronunciation. During Experiments 1 and 2, which used the same set of stimuli, it became obvious that there was a problem with phonological interference with one stimulus: worm. The vocal responses in native German and accented English were not different enough from each other to be easily distinguished in judging whether a participant had made an error. In this case, it was difficult and often impossible to judge whether the item was produced in the ‘correct’ language or not. If it was impossible to judge and the participant did not appear to have noticed an error, the trial was labeled as ‘correct’. For future experiments using both German and English responses, the stimulus *worm* (German ‘wurm’) should be excluded.

Such phonological interference is possible not only between languages, but also within a language. In tests, it was found that for vocal responses, interference was caused when too many words in the stimuli set contained the same consonant, especially if the words started with the same phoneme. For example, in a pilot study, the stimuli spider (‘spinne’), chair (‘stuhl’), scissors (‘schere’), and fish (‘fisch’) were used; in German, all four items contain the phoneme /ʃ/, and the first three begin with that sound. The interference became apparent when subjects produced hesitations or non-target words of the correct language on trials with the affected stimuli, and pilot study participants also reported having difficulty due to this interference.

Furthermore, phonological interference between stimuli may cause problems not only within a spoken language, but also within a signed language. Especially in Experiments 1 and 2, in which the stimuli all have the same place of articulation in neutral signing space (see Figure 2.2), it is possible for signs with a similar phonological structure to cause interference in production. For example, in Experiments 1 and 2, some participants produced hesitations when signing DOLPHIN and DOOR. These two signs have a similar phonological structure: both are produced in the neutral signing space, both are oriented with the palm facing backwards, and both have a flat B handshape (see Figure 2.5).

The difference in phonological structure between these two signs is found only in the parameter Movement, with DOPLHIN having an arced path movement and an internal movement in which the pinky finger moves closer to the wrist, while DOOR has no path movement, but does have an internal movement in wrist flexion and extension, with the fingertips moving repeatedly towards and away from the body. Although these two signs form a (near) minimal pair, it seems that their phonological structure is similar enough to cause interference.

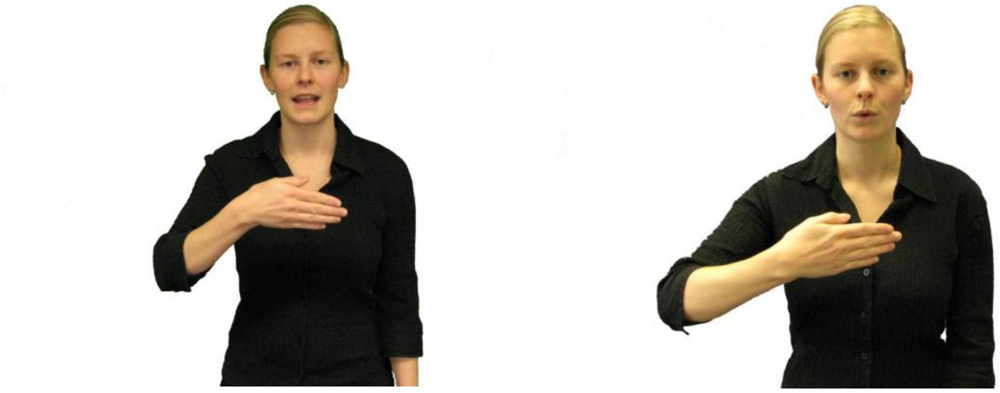

Figure 2.5. The DGS signs DOLPHIN (left) and DOOR (right)

Additionally, in Experiment 1, there was a great deal of interference between KEY and MONEY (Figure 2.6). These two signs most likely form a minimal pair. Both signs are produced in the neutral signing space, with the palm facing inward/upward, with an A handshape. Both signs have no path movement, and the only difference in phonological structure is in the internal movement, with wrist rotation for KEY and finger rubbing for MONEY. At the same time, there was no apparent interference between either of these two signs and FLOWER, which also has a similar phonological structure, differing slightly in the parameter Orientation (upward rather than inward/upward, a difference that is unlikely to produce a minimal pair) and in the internal movement, which for FLOWER involves finger extension (see Figure 2.3).

Figure 2.6. The DGS signs KEY (left) and MONEY (right)

These instances of interference indicate that phonological structure should be taken into account in stimulus selection. Interference stemming from similarities in the phonological structure of signs can be avoided firstly by avoiding minimal pairs, i.e. pairs of signs in which three of the four parameters (handshape, place of articulation, orientation, and path movement) are the same. However, this may not be feasible due to the limited pool of possible stimuli and, especially, the requirement of the place of articulation in the neutral signing space for all signs. It must be left to future research on the phonological structure of signs to determine the status of the three types of internal movement (handshape change, wrist movement and finger wiggling) as well as path movement in mental representations of signs.

An additional source of interference can be semantic. Care should be taken that semantic co-activation between stimuli is minimal. An example of semantic interference in Experiment 1 occurred between the stimuli *sun* and *glasses*, leading to the non-target word *sunglasses*. In the Methodological

Experiment, there was some hesitation observed during the production of *door* and *key*, while in Experiments 1 and 2, there was interference between *door* and *chair*, after *key* was removed for Experiments 1 and 2 due to this interference.

Additional interference was possible not between, but rather within certain stimulus items. One instance was the production of the German word *regenwurm* (‘earthworm’) instead of *wurm* (‘worm’). In this case, it seems that the longer word may simply have been more activated in participants’ mental lexicons than the shorter word, though there is no clear explanation as to why this may be, since shorter words are generally more frequent and therefore are assumed to have a higher resting activation level. Alternatively, the stimulus image may have had characteristics that are more strongly associated with the word *regenwurm* for that participant. In any case, this stimulus item should not be included in future experiments due to this issue and the pronunciation issue outlined above.

Similarly, several participants in Experiments 1 and 2 experienced interference with the stimulus item *garbage*. Although the stimuli were taken from a validated set (Szekely et al., 2004), many participants occasionally produced the non-target synonym *trash*, and some occasionally produced the non-target synonym *rubbish*. This stimulus item caused by far the most interference, and should be left out of future studies. However, trials in which it was clear that non-relevant interference had occurred, e.g. with the response ‘trash’, were still quite rare; these trials were eliminated from all analyses.

Finally, there are also foundational theoretical questions involved in the issue of whether vocal and manual language responses are temporally compatible and therefore whether they can be directly compared in an RT analysis, or whether doing so would compromise the internal validity of the reaction times. This question remains even if one can be entirely sure that in a particular experiment there is no lag between homekey release and sign onset, which is not at all the case in Experiment 1 and which, despite the measures taken, is also not the case for Experiments 1 and 2. There are great differences in language production across language modalities, with the production of individual signs slower across the board than the production of individual words (Bellugi & Fischer, 1979; see also Brentari, 2002).

This disparity has to do with physical difference in the primary articulators, with the vocal tract moving at a much faster rate than the hands, and it is tied to the greater degree of simultaneity in signed languages as compared to the sequentiality of spoken languages (Bellugi & Fischer, 1979). More importantly here, the preparatory stage, in which the articulators are brought into position for word or sign production, is much longer for sign language than spoken language: it takes the hands much longer to reach onset position than the vocal articulators (Myers et al., 2005). So even if both sign and word onset coincide with the respective RT measures, it is not clear that sign onset is temporally comparable to word onset in vocal language production (ibid.). It is also clear that the vocal response registration of a volume threshold makes vocal RTs compatible with each other, but it should be noted that the sound threshold usually does not coincide with word onset. For this reason, all RT analyses in this study were performed separately for vocal and manual responses.

2.3 Method

2.3.1 Participants

Twenty-four participants took part in the Methodological Experiment. In order to test whether there were differences between signers and non-signers, we tested two groups. In the first group, signers, there were 12 participants, all hearing native speakers of German (age 21–28, 7 women and 5 men) who learned English in school; eight of them had completed two semesters of German Sign Language (DGS) courses at RWTH Aachen University and were currently in the third semester, and four had completed three or more semesters. In the second group (non-signers), there were 12 participants, all hearing native speakers of German (age 21–28, 8 women and 4 men) who learned English in school and had no prior DGS competence. Participants either received 6 € or fulfilled partial course requirements by participating in the experiment.

2.3.2 Task and procedure

The experiment was programmed in Presentation on a 15.4” Lenovo laptop with a screen resolution of 1280 × 800. Language cues were squares in one of three solid colors (red, blue, yellow), measuring 400 × 400 pixels, for the three languages. The mapping of cue color to language was counterbalanced across participants. The stimuli were 12 line drawings of common objects: apple, beard, cat, door, flower, glasses, heart, island, key, money, nose, and sun, taken from the International Picture-Naming Project database (Szekely et al., 2004). The stimuli measured 300 × 300 pixels.

The task was picture naming in German, English or DGS. Participants performed in three different conditions: two bimodal, German/DGS and English/DGS; and one unimodal, German/English. For reaction times, response registration was as follows. For the vocal languages, the onset of the word was recorded using a voicekey (voice onset). For DGS, the onset of the sign was recorded using a homekey (motion onset). Participants were instructed to use their dominant hand to keep the homekey pressed during all bimodal blocks (i.e. in the blocks with the language pairs German/DGS and English/DGS) and to release the homekey only to produce a DGS sign. Errors were recorded by the experimenter.

The procedure was as follows: The experiment lasted approximately 45 minutes, with 5–10 minutes of preparation before the experiment and 5–10 minutes for filling out a questionnaire and debriefing afterwards. In the training part, participants were given an instruction sheet to read, and they were given the opportunity to ask clarifying questions regarding the procedure of the experiment. Then, for Group 1 (signers), they were walked through the list of stimuli to make sure that they were familiar with the DGS signs and English words.

For Group 2 (non-signers), they were told the German translation equivalent of each sign and then taught the sign. They were shown the sign and asked to repeat it, once for each sign. Then they were quizzed on the 12 signs and, if necessary, corrected and shown the sign again and asked to repeat it. They had no trouble learning the 12 signs, which were highly iconic or emblematic (see Section 2.2.3 Stimuli selection). Then they were walked through the list of stimuli to make sure that they were familiar with the English words.

Finally, all participants completed a short training phase in which they were familiarized with the stimuli and the pace of the experiment as well as the procedure involved for both vocal and manual responses (i.e., key releases/presses and vocal word production). In this training phase, participants were presented with three short single-language blocks, with one block for each language. In each of these blocks, they were presented with all 12 stimuli once each (in a randomized order) with the same timing as in the real experiment.

Following the practice phase, there were six blocks of 96 trials per participant (with two consecutive blocks for each of the three conditions: German/DGS, English/DGS and German/English), with the sequence of language pairs counterbalanced across participants. Each trial was as follows: the language cue (a colored square) was presented for 500 ms. The stimulus then appeared within the colored square, and both the cue color as a frame and the stimulus were shown for 1500 ms, followed by 1000 ms of black screen. The participant was supposed to respond after the appearance of the stimulus but before the end of the trial. If the participant did not respond quickly enough, or, on vocal trials, if they responded but the microphone did not register their response because their voice was not loud enough, they were shown the message "schneller/lauter!!" ('faster/louder!!' in German) for 500 ms, followed by a black screen for 1000 ms before the beginning of the next trial.

2.3.3 Design

In the first analysis, focusing on the unimodal blocks only, the within-subject independent variables were Language (German vs. English) and Shift (repeat vs. switch). The between-subjects independent variable was Group (signers vs. non-signers). In the second analysis, focusing on German responses across Modalities, the within-subject independent variables were Modality (unimodal vs. bimodal) and Shift (repeat vs. switch). The between-subjects independent variable was Group (signers vs. non-signers). The dependent variables were reaction time and error rate.

2.4 Results

The first two trials of each block were excluded from both the error analysis and the reaction time analysis. Also, for the RT analysis, reaction times below 250 ms and above 2000 ms were excluded, along with trials in which the participant made an error and the following trial. Additionally, a trial was excluded from the RT analysis if there was any sort of technical problem (< 1.8 % of trials). The mean reaction times and error rates across Modalities and groups, by language, are presented in Table 2.1.

Table 2.1. Mean reaction times and error rates across Modalities and Groups, by Language

		Reaction times (ms)				Error rates (%)			
		Signers		Non-signers		Signers		Non-signers	
		Rep.	Sw.	Rep.	Sw.	Rep.	Sw.	Rep.	Sw.
Ger./ Engl.	Ger.	798	861	785	870	3.68	8.30	2.38	6.46
	Engl.	785	837	778	829	1.31	5.27	0.74	3.61
Ger./ DGS	Ger.	741	783	740	796	0.36	4.19	0.92	1.15
	DGS	606	625	663	683	0.19	0.55	0.19	0.72
Engl./ DGS	Engl.	746	789	735	813	1.90	4.57	1.71	2.00
	DGS	609	596	708	671	1.57	1.50	1.04	1.30

In order to determine whether we replicated the results of previous language switching experiments, we tested the German/English (unimodal) switching blocks in isolation. The unimodal data are presented in Figure 2.7. For RTs, we conducted a Group × Language × Shift mixed-design analysis of variance (ANOVA). There was a significant main effect of Language, $F(1, 22) = 7.404$; $p < .05$ and Shift, $F(1, 22) = 54.606$; $p < .001$, and importantly, the interaction between Language and Shift was also significant, $F(1, 22) = 5.547$; $p < .05$. Switch costs were larger for participants' first language (German: 74 ms) than for their second language (English: 52 ms). There was no significant overall effect of Group, $F < 1$, and no significant interaction including group, $F < 1.5$.

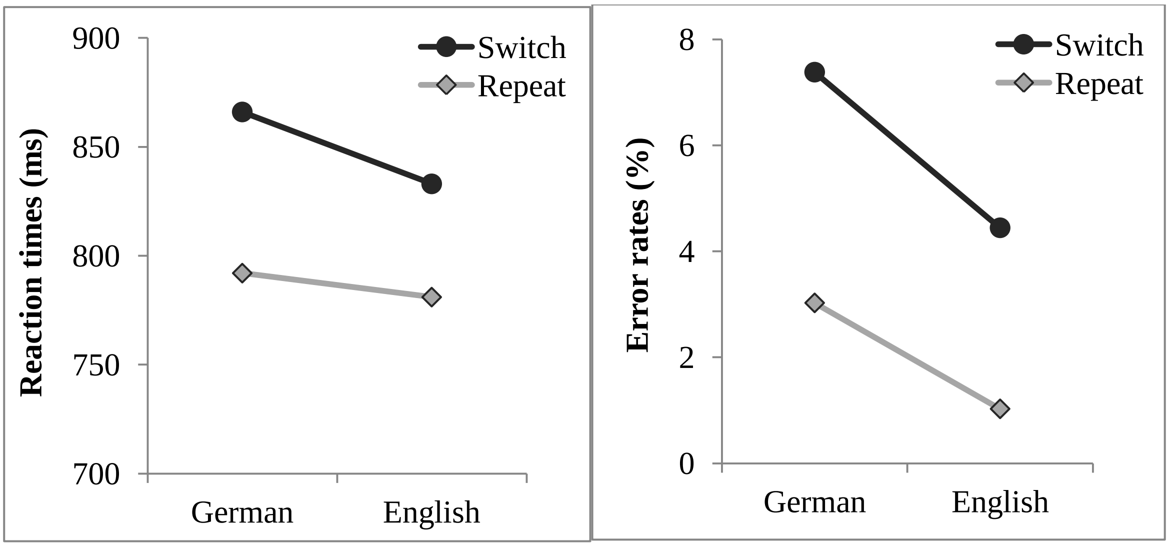

Figure 2.7. RTs, error rates as a function of Language (German vs. English) in unimodal switching blocks

For error rates, we conducted a Group × Language × Shift mixed-design ANOVA. There was a significant main effect of Language, *F*(1, 22) = 12.448; *p* < .01, and Shift, *F*(1, 22) = 60.816; *p* < .001. Switch costs were slightly larger for participants' first language (German: 4.4%) than for their second language (English: 3.4%), although the interaction between Language and Shift was not significant, *F* < 1. Once again, there was no significant overall effect of Group, *F*(1, 22) = 1.681; *p* > .05, and no significant interaction including group, *F* < 1. So, for the unimodal blocks, we found longer RTs, higher error rates and larger switch costs for L1 as compared to L2, indicating that we found the expected data pattern in the unimodal blocks.

In order to compare unimodal and bimodal language switching, we compared performances from the two Modalities. These data are presented in Figure 2.8. For reaction times, we restricted our analysis to German vocal responses only as a function of whether the German response was performed in the context of a unimodal language switching block (German/English) or in the context of a bimodal switching block (German/DGS). The reason for this decision is that manual response registration for reaction times is not directly comparable to vocal response registration in this experiment, and arguably in general, so in order to make sure we were comparing apples to apples, so to speak, we compared German responses in one Modality to German responses in the other Modality (see Section 2.2.4 Theoretical considerations). We also excluded the English/DGS switching blocks from our analysis: all DGS responses were excluded, and English responses from the English/DGS blocks were left out of the analysis due to issues of language dominance, as discussed below.

For RTs, we conducted a Group × Modality × Shift mixed-design ANOVA on German responses only. There was a significant main effect of Modality, *F*(1, 22) = 21.523; *p* < .001, and Shift, *F*(1, 22) = 54.417; *p* < .001, and the interaction between Modality and Shift was also significant, *F*(1, 22) = 4.497; *p* < .05. The results indicate that vocal responses are slower in unimodal switching blocks than in bimodal switching blocks, and switch costs were larger for unimodal blocks (74 ms) than for bimodal blocks (50 ms). There was no significant main effect of Group, *F* < 1, and no significant interaction including group, *F* < 1.2, meaning that there was no observable difference between signers and non-signers.

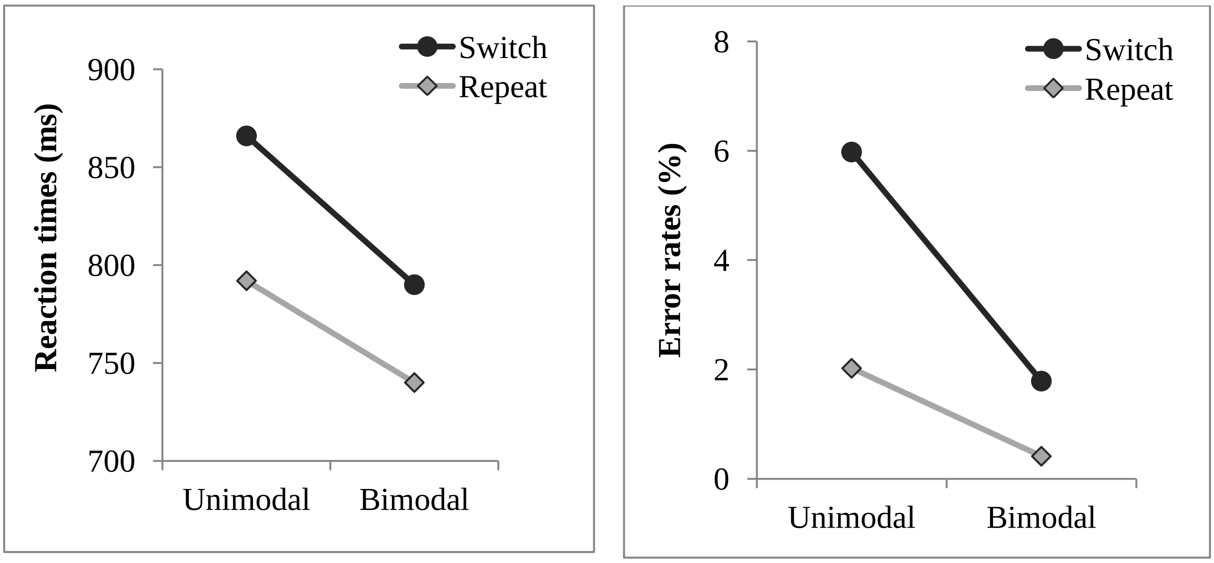

Figure 2.8. RTs (German responses only), error rates (all responses) as a function of Modality

For error rates, we conducted a Group × Modality × Shift mixed-design ANOVA. Because there was no difference in error registration between vocal and manual responses, this analysis includes all responses. There was a significant main effect of Modality, F (1, 22) = 32.267; $p < .001$, and Shift, F (1, 22) = 67.088; $p < .001$, and the interaction between Modality and Shift was also significant, F (1, 22) = 10.983; $p < .01$. Switch costs were larger for unimodal blocks (4%) than for bimodal blocks (1.4%). (The same analysis performed on German responses only, as in the reaction time analysis above, shows the same pattern as this analysis, the only noteworthy difference being that the interaction between Modality and Shift failed to reach significance: $F = 3.058$; $p > .05$.) There was no significant main effect of Group, $F < 2.1$, and no significant interaction including group, $F < 3.4$. So, we found shorter reaction times, lower error rates and smaller switch costs for bimodal switching blocks as compared to unimodal switching blocks, and no difference between signers and non-signers.

2.5 Discussion

The Methodological Experiment was designed to examine the mechanisms underlying switch costs in unimodal and bimodal language switching. Looking at the unimodal blocks in isolation, our results replicated those of previous studies (e.g., Meuter & Allport, 1999; Philipp et al., 2007), which found asymmetric switch costs, with larger switch costs for L1 than for

L2 in unbalanced bilinguals. This is important since it shows that our experimental conditions are comparable to those in previous studies.

In order to directly compare unimodal switching to bimodal switching, we analyzed vocal responses across Modalities. We found shorter RTs, lower error rates and smaller switch costs in bimodal language switching, suggesting an advantage for bimodal language switching or, conversely, a relative cost for unimodal language switching. Thus, the results of the Methodological Experiment demonstrate a bimodal advantage in language switching.

As mentioned, in analyzing our RT data for modality effects, only vocal responses were taken into consideration. There are two reasons for this: First, response registration for vocal and manual responses may not be directly comparable due to physiological differences in the vocal and manual motor systems. Second, the manual response times in this experiment also reflect a measurement inaccuracy. The homekey registers the onset of the preparation phase rather than that of the stroke phase of the DGS sign (using Kendon's, 1980, gesture phase analysis of preparation–stroke–retraction), and the registration of preparation onset for a sign is not comparable to the response registration as recorded using a voice key. Additionally, many of the signs used in this experiment have different-sized preparation phases, with some produced in neutral signing space near the homekey (minimal preparation phase), some produced above the head (long preparation phase), and some at positions in between those two extremes, which means that the manual response times for the various stimuli are also not comparable to each other (see Section 2.2.2 Response registration).

In the Methodological Experiment, we observed an advantage for language switching across language modalities (one spoken and one signed language), as compared to language switching within one language modality (only spoken languages). In contrast, in previous task switching experiments *not testing language*, the addition of a modality switch (all else remaining equal) often led to longer reaction times and larger switch costs (e.g., Philipp & Koch, 2010; Sohn & Anderson, 2003; Yeung & Monsell, 2003). Our results for an additional modality switch in a language-switching experiment show a pattern opposite to these previous results, which is an indication that language modality may be different from other task components in task-switching experiments.

So what is the source of the shorter RTs, lower error rates and smaller switch costs in bimodal switching? In the Methodological Experiment, participants are required to switch, that is to produce only one lexeme in one language. Unimodal bilinguals produce code-switches but not code-blends in natural language production, which indicates that in the unimodal production mode, only one lexeme remains active through production, and the other must be inhibited (e.g., Kroll et al., 2008; Philipp et al., 2007; Philipp & Koch, 2009). In contrast, bimodal bilinguals can and do produce code-blends in natural language production, which indicates that in the bimodal production mode, the two lexemes can remain active and so uninhibited through production (Emmorey et al., 2008).

We interpret our data based on the assumption of dual parallel lexical activation in bimodal language production, an assumption we make based on the fact that parallel bimodal word production (i.e. code-blending) is possible and indeed common, and we assume that inhibition plays a crucial role in language switching in this context (cf. Green, 1986; 1998). However, it is clear that for nearly all bimodal bilinguals, during bimodal production of utterances longer than a word or two, the two languages cannot be produced in their full complexity. Rather, one language functions as a base, while elements of the other are inserted into that base.

For unimodal language switching, we assume that lexical inhibition takes place (e.g., Kroll et al., 2008; Philipp et al., 2007; Philipp & Koch, 2009). In contrast, for bimodal language switching, we assume that both lexemes can remain uninhibited until a very late stage and that the non-target lexeme is inhibited only just before the target lexeme is uttered, which we attribute to ‘output channel inhibition’. The difference in the size of switch costs might thus indicate that ‘early’ lexical inhibition is costlier than ‘late’ output channel inhibition. In a different context, Pyers and Emmorey (2008) found that bimodal bilinguals produce non-manual and occasionally manual elements of ASL while speaking English to non-signers, and they posit that this is due to a lack of what they term articulatory inhibition for ASL, meaning that ASL is activated and elements of ASL are produced with the facial and occasionally the manual articulators.

In the case of language switching experiments, there is no clear distinction between the inhibition of an output channel (the vocal or manual production channels) and the inhibition of an articulator (the larynx or the arm). However, the distinction can be made in a context which is broader than language switching experiments. Just as speech is generally accompanied by co-speech gesture, manual signing is generally accompanied by mouth movements. Many sign languages, including DGS, incorporate mouthings to a great degree. Mouthings are mouth movements which are paired with a manual sign and which represent words from the spoken language, but they themselves are not words (e.g., Boyes-Braem, 2001). In hearing L2 signers at least, mouthings can be interpreted as the result of a type of articulatory (though not output channel) inhibition. In this case, the vocal output channel is not entirely inhibited; rather, only the vocal articulator (the larynx) is inhibited, while the mouth is uninhibited. This analysis supports the position which sees mouthings as a type of code-blending (see, e.g., Boyes-Braem, 2001; Sutton-Spence, 2007).

In the Methodological Experiment (and in Experiments 1 and 2), no instruction was given as to whether the participants should produce mouthings.

Indeed, not all participants produced mouthings, and most of those who did, did so inconsistently. Interestingly, several participants, including one non-signer, produced English mouthings paired with DGS signs in some manual trials of the English/DGS blocks. Thus, it seems that in a bilingual, in the case of dual activation in an atypical signed–spoken language pair (in this case English and DGS), a non-standard mouthing can appear. An example from the Methodological Experiment would be the DGS sign BLUME paired with the English mouthing of *flower*.

In terms of the underlying control mechanism which may cause this pairing in signing accompanied by mouthings, it seems that the English lexeme, which is selected in parallel with the DGS lexeme, remains activated through production. Articulatory (laryngeal) inhibition is applied, and a sign and its mouthing are produced. In terms of the Methodological Experiment, a participant who produced mouthings with the DGS signs for some trials might have used articulatory inhibition in these trials whereas for DGS signs produced without mouthings, one may speculate that output channel inhibition was involved. Consequently, we suggest that in the Methodological Experiment, both articulatory inhibition and output channel inhibition took place and that both forms of such a relatively late, response-related inhibition are less costly than lexical inhibition.

Our analyses found no statistically significant difference between the two Groups (signers and non-signers) on our measures in any analyses. For this reason, the variable Group was not included in Experiments 1 and 2. The fact that we did not find a statistically significant performance difference between these groups on these tasks of course does not mean that there is no difference between signers and non-signers generally, especially considering that the small number of subjects limits the statistical power of our tests. We assume there is a stark difference in the representation of the 12 DGS signs for signers and non-signers in this study: for signers, they are just signs of the sign language, but for non-signers, we assume that the DGS signs we taught them are learned as emblematic gestures, i.e. conventionalized, culture-specific gestures with a lexicalized meaning which can be understood without co-occurring speech (e.g. McNeill, 1992).

An example of an emblematic gesture would be ‘thumbs-up’, in which the hand forms a fist and the thumb sticks upward at a right angle from the hand, and which in many Western cultures means *good* (but which in other cultures may mean something else entirely). In fact, two of the signs used in this study may be seen as pre-existing emblematic gestures: MONEY, in which the rubbing together of coins is mimed; and HEART, in which the upper chest is tapped. Since we found no statistically significant difference between signers and non-signers for vocal responses in the Methodological Experiment, it follows that bimodality is advantageous whether the bimodality is an aspect of a single spoken language system (speech and co-speech gesture) or whether the bimodality extends across language boundaries with two languages of different modalities (signed and spoken).

Previous studies of co-speech gesture have shown that gesture aids the speech production process (see, e.g., Alibali, Kita, & Young, 2000; Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001; Kita, 2000). The results from the Methodological Experiment, which found smaller switch costs for bimodal switching, fit in well with these studies and extend previous knowledge by showing that this advantage is not restricted to the simultaneous use of both the hands and the mouth in monolingual production, but also extends to sequential language switching across language modalities. So, in language production in general, it seems that a bimodal utterance may be less costly than a unimodal utterance.

However, language competence remains an important aspect in language switching experiments. Previous studies comparing highly-proficient unimodal bilinguals with L2 learners have found differences between those groups: asymmetric switch costs were not found in the response latencies of highly-proficient bilinguals (e.g., Costa & Santesteban, 2004). For the participants in the Methodological Experiment, the spoken language modality was clearly dominant, with German as their dominant first language and English as an L2. For the signers, DGS was clearly an M2 (second-modality) language and their first sign language, as well as being their L3 (or L4 or higher, depending on their elective choices in school and what they were studying at university, with all other languages being spoken languages).

In the unimodal blocks, these participants showed the typical switch cost asymmetry for unbalanced bilinguals. Comparing the bimodal and unimodal blocks, we found a switching advantage for L1 in the bimodal blocks as compared to the unimodal blocks. Our data clearly indicate the strong effect of language modality on language switching for both non-signers and intermediate signers, which suggests that the effect has more to do with modality than with language competence level. Future experiments with highly-proficient bimodal bilinguals, namely advanced M2 signers, Codas, and/or interpreters, would show whether the modality effect holds across all language skill levels and whether the modality effect is modulated by higher levels of proficiency.

Another aspect of language competence relevant to this study involves the English/DGS switching blocks, which were excluded from the analyses presented above. Overall, looking at all blocks, RTs are shorter and switch costs are smaller in the bimodal blocks. However, looking at the languages in isolation (see Table 2.1) reveals that the differences between blocks stem largely from the German responses, while for English, there is little difference between the blocks. Also, focusing on the bimodal blocks for these two languages, particularly RTs, there is basically no difference between English and German vocal responses across the bimodal blocks. There is also very little difference between signers and non-signers.

Looking at the languages here in terms of dominance brings clarity to the issue. As the participants’ L1, German is dominant in both block types in which it appears (i.e. paired with either English or DGS), so we are able to see the modality effect of the bimodal switch cost advantage. DGS is the non-dominant language in both block types in which it appears (i.e. paired with either German or English), and here it does not seem to matter which spoken language is paired with the sign language. In contrast, English, the participants’ L2, is the non-dominant language when paired with German, but it is the dominant language when paired with DGS (see Table 2.2). In looking at asymmetric switch costs, the relevant feature of the language incurring larger switch costs is its dominance. For English in this study, the differing dominance status between the bimodal and unimodal blocks may have been a confounding factor, canceling out any switch cost asymmetry and hiding any bimodal switch cost advantage. For this reason, the results from the English/DGS switching blocks were not included in the analyses above.

Table 2.2. Mean reaction times and error rates for German (L1) and English (L2) across Modalities and Groups, by Language

		Reaction times (ms)				Error rates (%)			
		Signers		Non-signers		Signers		Non-signers	
Language	Block type	Rep.	Sw.	Rep.	Sw.	Rep.	Sw.	Rep.	Sw.
L1 (German)	Unimodal	798	861	785	870	3.68	8.30	2.38	6.46
	Bimodal	741	783	740	796	0.36	4.19	0.92	1.15
L2 (English)	Unimodal	785	837	778	829	1.31	5.27	0.74	3.61
	Bimodal	746	789	735	813	1.90	4.57	1.71	2.00

2.6 Conclusion

In summary, the Methodological Experiment found shorter reaction times, lower error rates and smaller switch costs in bimodal language switching as compared to unimodal language switching, examining only German vocal responses for RTs. This result suggests that there are different inhibitory mechanisms at work in unimodal and bimodal language switching. We suggest that lexical inhibition is involved in unimodal switching, whereas output channel inhibition is involved in bimodal switching. This Methodological Experiment revealed further methodological issues that must be addressed, particularly with regard to RTs for manual responses, and these issues will be addressed in Experiment 1, presented in Chapter 3.

3. Experiments 1 & 2

3.1 Experiment 1

3.1.1 Introduction

Experiment 1, a bimodal language-switching experiment, was designed to compare unimodal and bimodal language switching. We hypothesized that in the bimodal switching blocks, reaction times would be shorter, error rates lower and switch costs smaller than in the unimodal blocks, i.e. that bimodal switching is associated with lower processing costs, particularly switch costs (cf. Chapter 2, which presents the Methodological Experiment).

3.1.2 Method

3.1.2.1 Participants

Eighteen participants took part in Experiment 1, all hearing native speakers of German (age 22–26; 17 women, 1 man) who learned English in school and had completed 7–9 semesters of German Sign Language instruction in the Deaf Education program at the University of Cologne.

3.1.2.2 Task and procedure

Experiment 1 was programmed in Presentation on a 15.4” Lenovo laptop with a screen resolution of 1280 × 800 pixels. An external microphone was used. Language cues were squares in solid primary colors (red, blue, yellow), measuring 400 × 400 pixels, for the three languages. The mapping of cue color to language was counterbalanced across participants. Stimuli were ten line drawings of common objects: chair, dolphin, door, egg, garbage, mountain, pitcher, scissors, suitcase, worm. The stimuli images measured 300 × 300 pixels and were taken from the International Picture-Naming Project database (Szekely et al., 2004).

The task throughout Experiment 1 was picture naming, with three languages (German, English, DGS) performed in two Modalities: unimodal (German-English) switching and bimodal (German-DGS) switching. Reaction times for vocal responses in German and English were registered using a voice key (voice onset), recorded by the software, with response registration triggered by the voice surpassing a sound threshold. Reaction times for manual responses in DGS were registered using a homekey (motion onset). In analyzing our RT data, vocal and manual responses were analyzed separately in order to avoid confounds: Due to timing differences in language production between languages of different modalities, it may not be possible to accurately compare RTs between signed and spoken languages directly. In Experiment 1 (and Experiment 2), for manual responses, we minimized and standardized the lag between homekey release and sign onset by choosing signs that all have the same place of articulation (neutral signing space at the homekey) in order to be able to directly compare all manual responses to each other.

Stimuli were chosen taking into consideration the place of articulation of the DGS sign: all signs in this study are produced in neutral signing space, which is where the homekey was located relative to the seated participant, in order to minimize the lag between home key release and sign onset and ensure that RTs for some signs do not skew shorter or longer than others. Participants were instructed to keep the homekey pressed during bimodal blocks and to release it only in order to produce a DGS sign. Errors were recorded by the experimenter.

Experiment 1 lasted approximately 30 minutes, with 5–10 minutes of instruction and training, 20 minutes for the experiment itself, and 5–10 minutes for a short questionnaire and debriefing afterwards. The instruction consisted of the participant reading an instruction sheet and, if necessary, asking clarifying questions; the experimenter also informed the participant as to the stimuli words/signs in the three languages. The training was a short mock experiment with 4 blocks of 10 trials, two for each Modality, in which participants were familiarized with the cue and stimuli images, the pace of the experiment, and the procedure for both vocal and manual responses.

There were four experimental blocks of 100 trials each, with two consecutive blocks for each Modality. The sequence of Modalities was counterbalanced across participants. In each trial, the language cue was presented for 500 ms. The stimulus then appeared within the cue square, and both the cue as a frame and the stimulus were shown for 1500 ms, followed by 1000 ms of black screen. The participant was supposed to respond after the appearance of the stimulus but before the end of the trial. If the participant did not respond quickly enough, or if the response was too quiet for the microphone to register it, they were shown the message “schneller/lauter!!” (‘faster/louder!!’) for 500 ms, followed by a black screen for 1000 ms before the beginning of the next trial.

3.1.2.3 Design

In a first analysis, the unimodal blocks were examined in isolation. The within-subject independent variables were Language (German vs. English) and Shift (repeat vs. switch). The dependent variables were reaction time and error rate.

In a second set of analyses, unimodal blocks were compared to bimodal blocks. As it is difficult to directly compare vocal and manual RTs, the RT analysis was first restricted to German responses across Modalities. In this analysis, the within-subject independent variables were Modality (unimodal vs. bimodal) and Shift (repeat vs. switch). In order to compare switch costs in RTs across unimodal and bimodal switching while including all three languages and without creating a confound based on timing differences between spoken and signed languages, an additional analysis examined proportional scores; the within-subject independent variable was Modality (unimodal vs. bimodal), and the dependent variable was the proportion of the switch cost (ms) to repeat trial RTs (ms). For error rates, all three languages were included in an analysis in which the within-subject independent variables were Modality (unimodal vs. bimodal) and Shift (repeat vs. switch).

3.1.3 Results and Discussion

The first two trials of each block were excluded from the analysis for both reaction times and error rates. In order to remove outliers from the analyses, approximately 1% of all trials were excluded, half on either end of the data spread, for vocal and manual responses and repeat and switch trials separately. For both vocal and manual RTs, trials in which the participant made an error and the subsequent trial were excluded. Also, a trial was excluded from the RT analysis if a technical problem occurred (e.g. if the voice key did not work properly; 2.7%). Due to a technical problem in converting the Presentation output file, the last trial of each block was excluded from the RT analysis (1%). Mean reaction times and error rates across Modalities, by language, are presented in Table 3.1.

Table 3.1. Mean reaction times and error rates across Modalities (unimodal and bimodal), by Language (German vs. English vs. German Sign Language [DGS])

		Reaction times (ms)		Error rates (%)	
		Repeat	Switch	Repeat	Switch
Unimodal	German	778	836	2.22	5.04
	English	811	835	1.34	2.24
Bimodal	German	713	731	0.82	3.44
	DGS	1565	1580	1.00	0.56

Previous experiments on unimodal language switching found smaller switch costs for L2 than for L1; in order to determine whether we replicated these results, we tested the German-English (unimodal) switching blocks in isolation. The unimodal data are presented in Figure 3.1. For RTs, we conducted a Language × Shift analysis of variance (ANOVA). There was no significant main effect of Language, $F(1, 17) = 2.8$; $p > .05$; $\eta_p^2 = .141$, but there was a significant main effect of Shift, $F(1, 17) = 24.034$; $p < .001$; $\eta_p^2 = .586$. Importantly, the interaction between Language and Shift was significant, $F(1, 17) = 20.607$; $p < .001$; $\eta_p^2 = .548$, meaning that switch costs were significantly larger for participants' L1 (German: 58 ms) than for their L2 (English: 24 ms).

For error rates, we conducted a Language × Shift ANOVA. There was a significant main effect of Language, $F(1, 17) = 10.779$; $p < .01$: $\eta_p^2 = .388$, and Shift, $F(1, 17) = 7.316$; $p < .05$; $\eta_p^2 = .301$. Switch costs were numerically larger for L1 (2.82%) than for L2 (0.89%), but the interaction between Language and Shift did not reach significance, $F(1, 17) = 2.597$; $p > .05$; $\eta_p^2 = .133$.

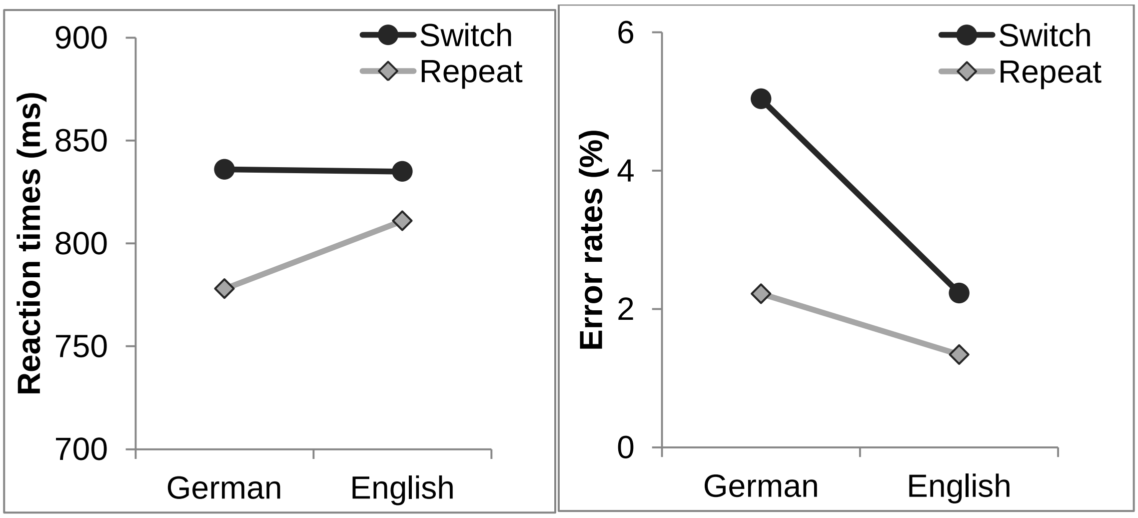

Figure 3.1: RTs, error rates as a function of Language (German vs. English) and Shift (repeat vs. switch) in unimodal switching blocks

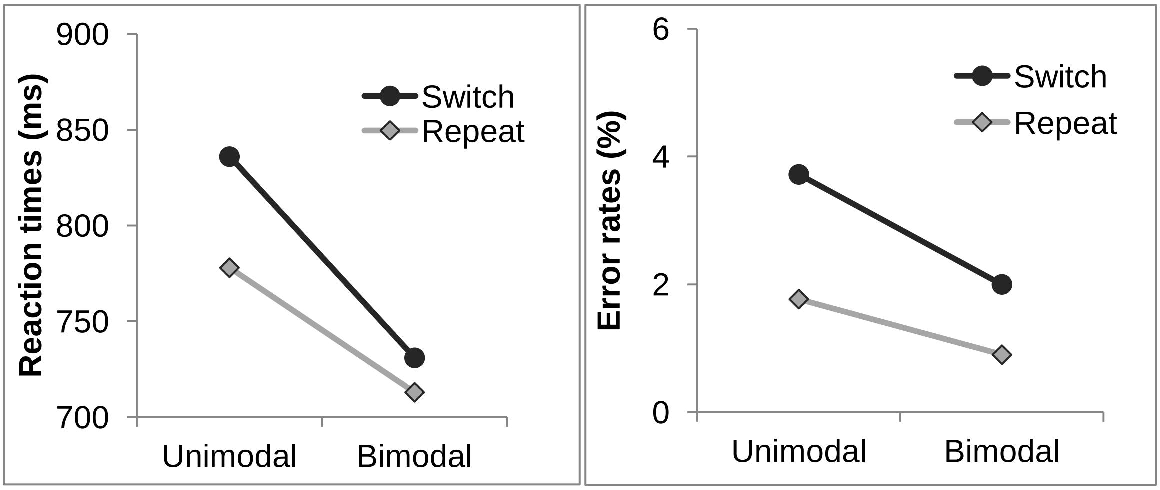

Figure 3.2. RTs (German responses only), error rates (all responses) as a function of Modality (unimodal vs. bimodal) and Shift (repeat vs. switch)

In the next set of analyses, we compared unimodal language switching directly to bimodal language switching. These data are presented in Figure 3.2. Manual response registration is not directly comparable to vocal response registration in our study, and, arguably, manual response production generally is not directly comparable to vocal response production. A previous study dealing with manual and vocal responses in a bimodal design also conducted separate analyses for vocal and manual responses (Emmorey et al., 2012).

So, we restricted a first RT analysis across modality conditions to German vocal responses as a function of whether they were performed in the context of a unimodal language-switching block (German/English) or a bimodal switching block (German/DGS). We conducted a Modality × Shift ANOVA. There were significant main effects of Modality, $F(1, 17) = 68.240$; $p < .001$; $\eta_p^2 = .801$, and Shift, $F(1, 17) = 18.784$; $p < .001$; $\eta_p^2 = .525$, and importantly, the interaction between Modality and Shift was also significant, $F(1, 17) = 7.148$; $p < .05$; $\eta_p^2 = .296$. The results indicate that German vocal responses are faster in bimodal switching blocks than in unimodal blocks, and switch costs were smaller for bimodal blocks (18 ms) than for unimodal blocks (58 ms).

For proportional scores of RTs, which can be used to compare responses from all languages while avoiding the response timing confound, a paired *t*-test (two-tailed) revealed that the proportion of switch costs to repeat trial RTs was lower for bimodal blocks (German and DGS responses; 1.78%) than for unimodal blocks (English and German responses; 5.28%; $t(17) = 2.998$; $p < .01$). A Wilcoxon signed-rank test revealed a similar result, $p < .01$. These results further support the finding of smaller switch costs in bimodal blocks than in unimodal blocks.

For error rates, we conducted a Modality × Shift ANOVA on all responses; errors can be compared directly for manual and vocal responses. There were significant main effects of Modality, $F(1, 17) = 10.706$; $p < .01$; $\eta_p^2 = .386$, and Shift, $F(1, 17) = 7.579$; $p < .05$; $\eta_p^2 = .308$, with a lower percentage of errors in the bimodal blocks compared to unimodal blocks and in repeat trials compared to switch trials (see Figure 3.2). Switch costs were numerically smaller for bimodal blocks (1.09%) than unimodal blocks (1.95%), but the interaction between Modality and Shift did not reach significance, $F(1, 17) = 1.815$; $p > .05$; $\eta_p^2 = .098$. Excluding English and DGS trials from the error analysis did not change the pattern of results, with bimodal switch costs (2.63%) still numerically, although not significantly, smaller than unimodal switch costs (2.82%).

Experiment 1 was designed to examine the mechanisms underlying switch costs in bimodal language switching. Looking at the unimodal blocks in isolation, our results replicated those of previous studies (e.g. Meuter & Allport, 1999; for a review, see Bobb & Wodniecka, 2013), which found asymmetric switch costs, with larger switch costs for L1 than for L2. This finding indicates that our experimental conditions are comparable to those in previous studies.

The most important findings of Experiment 1 were shorter overall RTs, lower error rates, and smaller switch costs in bimodal blocks than in unimodal blocks, which suggest an advantage for bimodal language switching. In analyzing our RT data for modality effects, only vocal responses were taken into consideration in a first analysis. As mentioned above, RTs for the spoken and signed languages were not directly compared in this study due to production differences between the language modalities. So, in order to avoid confounds in our results, we conducted the RT modality analysis using vocal responses only.

Since a direct comparison with DGS is not possible, the English data were correspondingly left out of the first analysis. In order to compare all responses across Modalities while avoiding the confound that would be created by comparing vocal and manual RTs directly, we also assessed proportional scores, i.e. the proportion of switch costs to repeat trial RTs in each Modality, with the proportion for each language calculated separately. This analysis patterned with the results from the German-only bimodal analysis, finding significantly lower switch costs for bimodal blocks than unimodal blocks.

The results of Experiment 1, thus, also extend the results of the Methodological Experiment, which also demonstrated smaller switch costs in bimodal switching blocks than in unimodal switching blocks. However, the comparison in the Methodological Experiment was restricted to German vocal responses: a proportional analysis was not possible because manual RTs for DGS reflected wide variation due to the fact that the various signs had different places of articulation which were various distances from the homekey. This was carefully controlled in Experiment 1 so that RTs for DGS could be used to calculate proportional scores. This approach also makes possible an analysis of switch costs within DGS; in this analysis, a paired t-test (two-tailed) revealed a marginally significant result: Repeat trials were faster than switch trials for DGS, $t(17) = 2.095$, $p \leq .05$, and a Wilcoxon signed-rank test also found a marginally significant result, $p = .053$, demonstrating language-switch costs of 1.0 %. Thus, Experiment 1 also provides initial evidence for language-switch costs in a sign language.

Additionally, the participants' competence level in the sign language is considerably higher in Experiment 1 than in the Methodological Experiment, so Experiment 1 also extends the result of the Methodological Experiment in this respect. However, participants in both studies are L2 learners; future studies could include hearing native signers or interpreters in order to assess whether the results hold for very high language competence levels.

In summary, Experiment 1 provides evidence for a bimodal advantage in sequential language switching. In natural speech production, however, bimodal bilinguals generally produce simultaneous code-blends rather than sequential code-switches. Therefore, in Experiment 2, the simultaneous production of a sign and a spoken word was explored using a dual-task design in order to determine whether the bimodal advantage extends to simultaneous production.

3.2 Experiment 2

3.2.1 Introduction

In Experiment 2, a dual-task paradigm was combined with a language-switching paradigm. We consider a response in either German or DGS as a single-task trial, whereas a Blend response (i.e., a simultaneous response in German and DGS) is considered a dual-task trial. Additionally, participants performed in both pure blocks, in which only one type of response (German, DGS, or Blend) was required, and mixed blocks, in which they switched among all three Response-types.

For Experiment 2, we anticipated that for vocal responses, there would be a dual-task cost, that is, RTs would be longer in pure dual-task (Blend) blocks than in pure single-task (German or DGS) blocks; for manual responses, we anticipated no dual-task costs (cf. Emmorey et al., 2012). Also, we anticipated mixing costs for both languages, i.e. we anticipated that reaction times would be shorter in pure blocks than in mixed blocks. Examining the mixed blocks in isolation, for vocal responses, we anticipated longer reaction times for dual-task (Blend) trials than for single-task (German) trials (i.e., dual-task costs) and language-switch costs. For manual responses, we hypothesized that reaction times would be shorter and switch costs smaller for dual-task (Blend) trials than for single-task (DGS) trials, which represents a dual-task processing advantage. As for error rates, we hypothesized that they would be lower and their concomitant switch costs smaller for Blend trials than for German or DGS trials.

3.2.2 Method

3.2.2.1 Participants

Twelve participants took part in Experiment 2, all hearing native speakers of German (age 22–26; 11 women, 1 man) who learned English in school and had completed 7–9 semesters of German Sign Language instruction in the Deaf Education program at the University of Cologne.

3.2.2.2 Task and procedure

The set-up of Experiment 2 was comparable to that of Experiment 1. Task cues for single-task trials were squares in solid primary colors (red, blue, yellow) measuring 400 × 400 pixels. Although there were only two languages in Experiment 2, three colors were used in order to conform to Experiment 1. Two of the three colors were selected for each participant, and the selection of colors and the mapping of cue color to language were counterbalanced across participants. Task cues for dual-task trials were a 2 × 2 checkerboard of the two relevant language cue colors, measuring 400 × 400 pixels in total. Stimuli were also the same as in Experiment 1, selected in order to ensure manual RT compatibility among items.

The task throughout Experiment 2 was picture naming. There were three Response-types: German, DGS and Blend. German and DGS responses were single-task, while Blend trials were dual-task and included both the German word and the DGS sign. Analyses were performed based on Task-type (single-task, dual-task) for vocal and manual RT analyses and on the basis of Response-type (German, DGS, Blend) for error analyses and analyses of individual effects. These different kinds of analyses are necessary due to the fact that vocal and manual responses cannot be directly compared in RT analyses, but they can in error analyses.

In total, there were four conditions in Experiment 2; three were pure conditions in which only one task was performed, one for each Response-type: German, DGS, and Blend. The final condition was a mixed condition, with switching between the three Response-types. Reaction times for vocal responses in German and Blends were registered using a voicekey (voice onset), recorded by the software, with response registration triggered by the voice surpassing a sound threshold. Reaction times for manual responses for DGS and Blends were registered using a homekey (motion onset). Participants were instructed to keep the homekey pressed during DGS, Blend and mixed blocks and to release it only in order to produce a DGS sign. Errors were recorded by the experimenter.

Experiment 2 lasted approximately 45–50 minutes, with 5–10 minutes of instruction and training, 30–35 minutes for the experiment itself, and 5–10 minutes for a brief questionnaire and debriefing afterwards. The training was a short mock experiment with 4 blocks of 10 trials, one for each condition, in which participants were familiarized with the cue and stimuli images, the pace of the experiment, and response procedure for vocal, manual and dual-task vocal-manual responses. There were a total of 8 experimental blocks in Experiment 2. For pure conditions, there was one block of 70 trials for each condition. For the mixed condition, there were five consecutive blocks of 90 trials. The sequence of conditions was partially counterbalanced across participants so that each condition appeared equally often at each sequence position (Table 3.2).

Table 3.2: Sequences of conditions in partial counterbalancing in Experiment 2

	Sequences of conditions (24 total; sequences 1–12 used in Experiment 2)											
	1	2	3	4	5	6	7	8	9	10	11	12
1	DGS	Ger.	Bl.	Mix	DGS	Ger.	Mix	Bl.	DGS	Bl.	Ger.	Mix
2	Ger.	Bl.	Mix	DGS	Ger.	Mix	Bl.	DGS	Bl.	Ger.	Mix	DGS
3	Bl.	Mix	DGS	Ger.	Mix	Bl.	DGS	Ger.	Ger.	Mix	DGS	Bl.
4	Mix	DGS	Ger.	Bl.	Bl.	DGS	Ger.	Mix	Mix	DGS	Bl.	Ger.
	13	14	15	16	17	18	19	20	21	22	23	24
1	DGS	Bl.	Mix	Ger.	DGS	Mix	Ger.	Bl.	DGS	Mix	Bl.	Ger.
2	Bl.	Mix	Ger.	DGS	Mix	Ger.	Bl.	DGS	Mix	Bl.	Ger.	DGS
3	Mix	Ger.	DGS	Bl.	Ger.	Bl.	DGS	Mix	Bl.	Ger.	DGS	Mix
4	Ger	DGS	Bl.	Mix	Bl.	DGS	Mix	Ger.	Ger.	DGS	Mix	Bl.

3.2.2.3 Design

As in the previous study of bimodal language production (Emmorey et al., 2012), and as in the Methodological Experiment and Experiment 1, in all RTs analyses, vocal (German, Blend) responses and manual (DGS, Blend) responses were analyzed separately in order to avoid confounding the results. In the error analysis, vocal and manual responses were analyzed together.

In a first analysis, the pure blocks were examined in isolation. The within-subject independent variable was Task-type (single-task vs. dual-task), and the dependent variables were vocal RT and manual RT. There was no error analysis for pure blocks because the task was the same throughout each block and consequently hardly any errors occurred. (Such errors were excluded from all analyses.)

In a second analysis, we assessed mixing costs; we again analyzed only RTs. The within-subject independent variables were Task-type (single-task vs. dual-task) and Condition (pure blocks vs. mixed blocks), and the dependent variables were vocal RT and manual RT.

A third analysis examined the mixed blocks in isolation. For the vocal and manual RT analyses, the within-subject independent variables were Task-type (single-task vs. dual-task) and Shift (repeat vs. switch). However, in this analysis, “switch” is actually a pooling of two transitions; for example, the label “DGS switch” pools DGS trials in which the previous trial was German with those in which the previous trial was a Blend. In order to examine individual effects between these Transitions (from-German, from-DGS, from-Blend), we performed additional analyses.

Finally, we also analyzed error rates in the mixed blocks. For the error analysis, vocal and manual responses can be compared directly and both components of a Blend can be assessed together. The within-subject independent variables were therefore Response-type (German vs. DGS vs. Blend) and Shift (repeat vs. switch). Following the interaction analysis, further analyses were again carried out in order to examine individual effects between Transitions for each Response-type.

3.2.3 Results and Discussion

The first two trials of each block were excluded from the analysis for both reaction times and error rates. In order to remove outliers from the analyses, approximately 1% of all trials were excluded, half on either end of the data spread, separately for vocal and manual responses, pure and mixed blocks, single-task and dual-task trials, and within the mixed blocks, repeat and switch trials. For the RT analysis, trials in which the participant made an error and the subsequent trial were excluded. Also, trials in which a technical problem occurred were excluded. Examples of technical problems are the voice key not working properly, the participant saying “um” before the target word, or the homekey registering two responses, presumably due to hesitation on a manual response. Technical errors made up 1.3% of all trials, with 0.3% in DGS trials, 0.8% in German trials, and 0.2% in Blend trials. Mean reaction times are presented in Table 3.3.

Table 3.3. Mean vocal and manual RTs across Conditions (pure vs. mixed), by Task-type (single-task vs. dual task). For vocal RTs, single-task means German responses and dual-task means vocal responses in Blends. For manual RTs, single-task means DGS responses and dual-task means manual responses in Blends

Condition		Task-type			
		Single-task		Dual-task Blend	
Pure	vocal RTs	687		810	
	manual RTs	516		507	
		Single-task		Dual-task Blend	
		Repeat	Switch	Repeat	Switch
Mixed	vocal RTs	707	742	840	876
	manual RTs	536	592	555	588

Dual-task costs in pure blocks. In a first analysis, in order to determine whether our data patterned with the results of the previous bimodal dual-task study (Emmorey et al., 2012), which found a dual-task cost across pure blocks for vocal responses and no dual-task cost across pure blocks for manual responses, we tested the pure blocks in isolation. RTs for vocal and manual responses were analyzed as function of whether the response was made in the context of a dual-task or single-task pure block.

For vocal responses, anticipating longer RTs for dual-task than single-task responses, we conducted a one-tailed paired *t*-test and a one-tailed related-samples Wilcoxon signed rank test. As anticipated, the *t*-test revealed significantly longer RTs for dual-task blocks than single-task blocks, *t*(11) =

7.908; $p < .001$, and the Wilcoxon test found a similar result, $p < .01$. For manual responses, anticipating no difference between single-task and dual-task RTs, we conducted a two-tailed paired *t*-test and a two-tailed related-samples Wilcoxon signed rank test. RTs in dual-task blocks were numerically shorter than in single-task blocks, but, as anticipated, the difference was not statistically significant, $t(11) = 1.228$; $p > .05$; Wilcoxon: $p > .05$. So, for pure blocks in isolation, we found a dual-task cost for vocal responses and none for manual responses; our results patterns with those of the previous bimodal study (Emmorey et al., 2012).

Mixing costs. In a second analysis, in order to assess mixing costs, we compared RTs across Conditions, comparing responses from the pure conditions to repeat trials from the mixed condition. The data are presented in Figure 3.3.

For vocal responses, we conducted a Task-type (single-task vs. dual-task) × Condition (pure vs. mixed) ANOVA. There was a significant main effect of Task-type, $F(1, 11) = 97.554$; $p < .001$; $\eta_p^2 = .899$, indicating dual-task costs. The main effect of Condition was marginally significant, $F(1, 11) = 4.112$; $p = .067$; $\eta_p^2 = .272$. RTs in pure blocks were numerically shorter than RTs in mixed blocks. The interaction between Task-type and Condition was not significant, $F(1, 11) = 0.445$; $p > .05$; $\eta_p^2 = .039$, though mixing costs were numerically smaller for single-task trials (20 ms) than for dual-task trials (30 ms).

For manual responses, we also conducted a Task-type (single-task vs. dual-task) × Condition (pure vs. mixed) ANOVA. There was no significant main effect of Task-type, *F*(1, 11) =.363; $p > .05$; $\eta_p^2 = .032$, but there was a significant main effect of Condition, *F*(1, 11) = 8.941; $p < .05$; $\eta_p^2 = .448$, with RTs in the pure conditions shorter than those in the mixed condition (i.e., mixing costs). Interestingly, the interaction between Task-type and Condition was also significant, *F*(1, 11) = 5.496; p < .05; $\eta_p^2 =.333$, with smaller mixing costs for single-task trials (20 ms) than for dual-task trials (48 ms) for manual RTs.

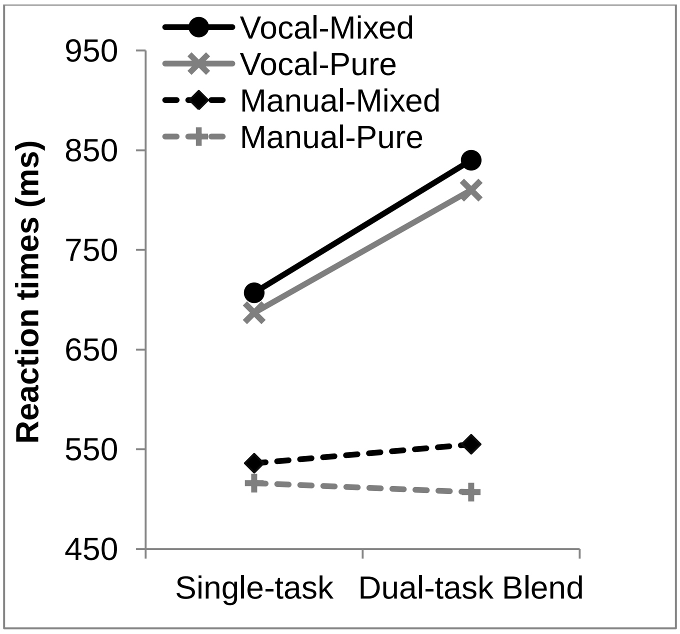

Figure 3.3: RTs (mixed blocks: repeat trials only), with vocal and manual responses separate, as a function of Task-type (single-task vs. dual-task) and Condition (pure vs. mixed)

Overall, vocal RTs in single-task trials were shorter than in dual-task trials, while there was no difference for manual RTs; this result mirrors that of the first analysis. That is, we found dual-task costs for vocal responses but not for manual responses. As regards mixing costs, RTs in the pure blocks were overall shorter than RTs in the mixed blocks for both vocal and manual responses, which is the expected pattern of mixing costs. Mixing costs are generally a robust finding (cf. Los, 1996; for a review, see Kiesel et al., 2010), and the results from Experiment 2 show that in a bimodal design, as expected, mixing costs were found.

However, assessing the interactions provides more information about the sources of mixing costs. For vocal responses, mixing costs were numerically, though not significantly, larger for dual-task trials than for single-task trials; it is possible that there is a significant difference and that Experiment 2 lacks the power to uncover it. For manual responses, mixing costs were significantly larger for dual-task trials (Blends) than for single-task trials (DGS), which represents a significant dual-task processing disadvantage in mixing cost.

The vocal RTs show a comparable data pattern with numerically larger mixing costs for dual-task trials (Blends) than for single-task trials (German). Yet, the interaction was not significant for vocal RTs, which might be due to the fact that Experiment 2 lacks the power to uncover it. So at least for manual responses, we found a significant dual-task disadvantage in mixing costs.

Mixing costs can be interpreted as reflecting a relatively global consequence of between-task interference (cf. Los, 1996; Philipp, Kalinich, Koch, & Schubotz, 2008; Rubin & Meiran, 2005). The larger mixing costs for dual-task trials than for single-task trials (statistically significant for manual responses, numerically for vocal responses) thus might indicate an even larger between-task interference for Blends than for single-task responses.

Language switching with dual-task trials. In a third set of analyses, we examined the mixed blocks in isolation. The RT data are presented in Figure 3.4. For vocal responses, we conducted a Task-type (single-task vs. dual-task) × Shift (repeat vs. switch) ANOVA. There were significant main effects of Task-type, $F(1, 11) = 122.32$; $p < .001$; $\eta_p^2 = .917$, indicating dual-task costs, and Shift, $F(1, 11) = 10.275$; $p < .01$; $\eta_p^2 = .483$, indicating switch costs. However, there was basically no difference in switch costs (single-task: 35 ms; dual-task: 36 ms), and the interaction between Task-type and Shift was not significant, $F(1, 11) = .011$; $p > .05$; $\eta_p^2 = .001$.

For manual responses, we conducted the same Task-type (single-task vs. dual-task) × Shift (repeat vs. switch) ANOVA. There was no significant main effect of Task-type, $F(1, 11) = .476$; $p > .05$; $\eta_p^2 = .041$, but there was a significant main effect of Shift, $F(1, 11) = 14.8$; $p < .01$; $\eta_p^2 = .574$, demonstrating switch costs. Importantly, the interaction between Task-type and

Shift was also significant, $F(1, 11) = 5.883$; $p < .05$; $\eta_p^2 = .348$; switch costs were larger for single-task trials (56 ms) than for dual-task trials (33 ms).

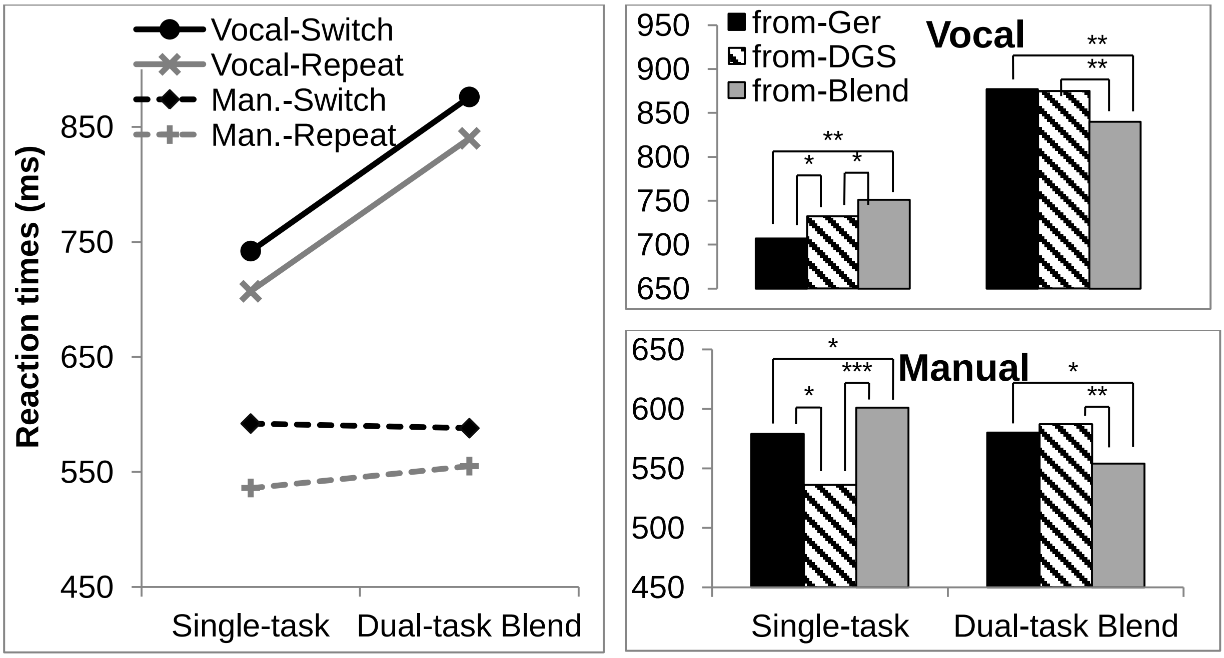

Figure 3.4. Left: RTs, with vocal and manual responses separate, as a function of Task-type (single-task vs. dual-task) and Shift (repeat vs. switch) in the mixed condition only. Top right: All Transitions (from-German, from-DGS, from-Blend) for vocal responses, separated into single-task and dual-task trials. Bottom right: All Transitions for manual responses, separated into single-task and dual-task trials.

So, within the mixed blocks, for vocal responses, we found longer RTs for dual-task trials than single-task trials; this pattern fits in with the previous analyses of the pure blocks and mixing costs. RTs for repeat trials were shorter than RTs for switch trials, which means that switch costs were also found here. However, there was no difference in switch costs between single-task and dual-task trials, meaning that switch costs were the same for German responses alone and German responses in a Blend, i.e. there was no dual-task advantage and no disadvantage. For manual responses, we found no overall difference in RTs between single-task and dual-task trials; this pattern also fits in with the previous analyses. RTs for repeat trials were shorter than RTs for switch trials, i.e. switch costs were found. Switch costs for manual responses in dual-task Blend trials were significantly smaller than in single-task DGS trials. In this case, the smaller switch cost for dual-task trials represents a dual-task advantage.

In order to examine individual effects of each transition in RTs, taking single-task and dual-task responses separately, we compared the three Transitions (from-German, from-DGS, from-Blend) for both vocal and manual responses separately; see Figure 3.4. For single-task responses, we conducted 3 one-tailed paired *t*-tests as well as 3 one-tailed related-samples Wilcoxon signed rank tests each for vocal and manual responses. We anticipated the shortest RTs for repeat trials (i.e., German from-German, DGS from-DGS), followed by single-task to single-task switch trials (i.e. German from-DGS; DGS from-German), and the longest RTs for trials in which the previous trial was a dual-task Blend. From-Blend trials are expected to incur the longest RTs because the entire unit of the Blend must be inhibited before one of its task components is reactivated and produced in isolation. In this instance, we expect the Blend to be associated with a disadvantage.

For single-task responses, on separate measures of both vocal and manual RTs, the test results support our hypotheses. All differences between all measures were statistically significant, $t > 1.8$; $p < .05$, though the Wilcoxon test for German from-DGS vs. German from Blend was only marginally significant, $p < .07$. Repeat trials incurred shorter RTs than all other trial types. Single-task to single-task switch trials (DGS from-German, German from-DGS) showed longer RTs than repeat trials and shorter RTs than from-Blend trials. Most importantly, from-Blend trials incurred the longest RTs. Taken together, the data support the assumption that repeat trials are easiest, while switching from a Blend to a single-task is most difficult. It seems that inhibiting a Blend in the previous trial in order to produce one of its component tasks as a single-task is more costly than inhibiting one single-task in order to produce a different single-task.

For dual-task responses, we anticipated the shortest RTs for repeat trials (i.e., Blend from-Blend) and longer RTs for Blend from-DGS and Blend from-German, but no difference between these trials since we see no theoretical basis for a difference between Blend from-DGS trials and Blend from-German trials. We conducted 2 one-tailed paired *t*-tests and 2 one-tailed related-samples Wilcoxon signed rank tests (Blend from-Blend vs. Blend from-German; Blend from-Blend vs. Blend from-DGS) as well as 1 two-tailed *t*-test and 1 two-tailed Wilcoxon test (Blend from-German vs. Blend from-DGS) for vocal and manual responses separately.

For dual-task responses, the test results support our hypotheses for both vocal and manual RTs. Repeat trials incurred shorter RTs than all other trials, $t(11) > 2$; $p < .05$, though the Wilcoxon test for Blend from-Blend vs. Blend from-German was only marginally significant, $p < .08$. Also, we found no difference between Blend from-German and Blend from-DGS for dual-task trials for either vocal or manual responses, $t \leq 1.3$; $p > .2$. So, for dual-task trials, it matters only *whether or not* the previous trial is also dual-task, and not, in the case of switch trials, *which* single-task was performed in the previous trial.

Table 3.4: Mean error rates by Response-type (German, DGS, Blend) and Shift (repeat vs. switch)

Response-type	Repeat	Switch
German	0.53	5.43
DGS	0.70	3.00
Blend	0.16	0.63

Finally, we examined error rates from the mixed blocks. Error rates are presented in Table 3.4. The error rate analysis is advantageous in that it avoids confounds due to issues of timing and differences in language production processes across language modalities as exist for RT analyses. Since the three Response-types can be compared to each other directly on the measure of error rates, we conducted a Response-type (German vs. DGS vs. Blend) × Shift (repeat vs. switch) ANOVA. As Response-type is a variable with three levels, we report ε - values when different from 1.0 and use the Huynh-Feldt test to report *p* values based on corrected degrees of freedom. However, we still report non-corrected degrees of freedom. The data are presented in Figure 3.5.

There was a significant main effect of Response-type, $F(2, 22) = 14.266$; $p < .01$; $\eta_p^2 = .698$, and Shift, $F(2, 22) = 41.620$; $p < .001$; $\eta_p^2 = .791$, and importantly, the interaction between Response-type and Shift was also significant, $F(2, 22) = 8.279$; $p < .05$; $\varepsilon = .737$; $\eta_p^2 = .580$. Switch costs in Blend trials (0.5%) were significantly smaller than in German trials (4.9%; $F(1, 11) = 11.528$; $p < .01$; $\eta_p^2 = .512$, as measured for the interaction of Response-type and Shift in a post-hoc analysis comparing Blend and German trials only). The difference in switch costs between Blend trials and DGS trials (2.3%) was also significant ($F(1, 11) = 8.901$; $p < .05$; $\eta_p^2 = .447$ for the corresponding interaction). The difference in switch costs between German and DGS trials was only marginally significant ($F(1, 11) = 4.471$; $p = .058$; $\eta_p^2 = .289$ for the corresponding interaction). This result demonstrates a clear advantage for dual-task blends for error rates in the mixed condition. In the results of all three ANOVAs, there were significant main effects of both Task-type and Shift as well ($F > 4.9$; $p < .05$), indicating that error rates were significantly smaller in Blend trials as compared to single-task trials.

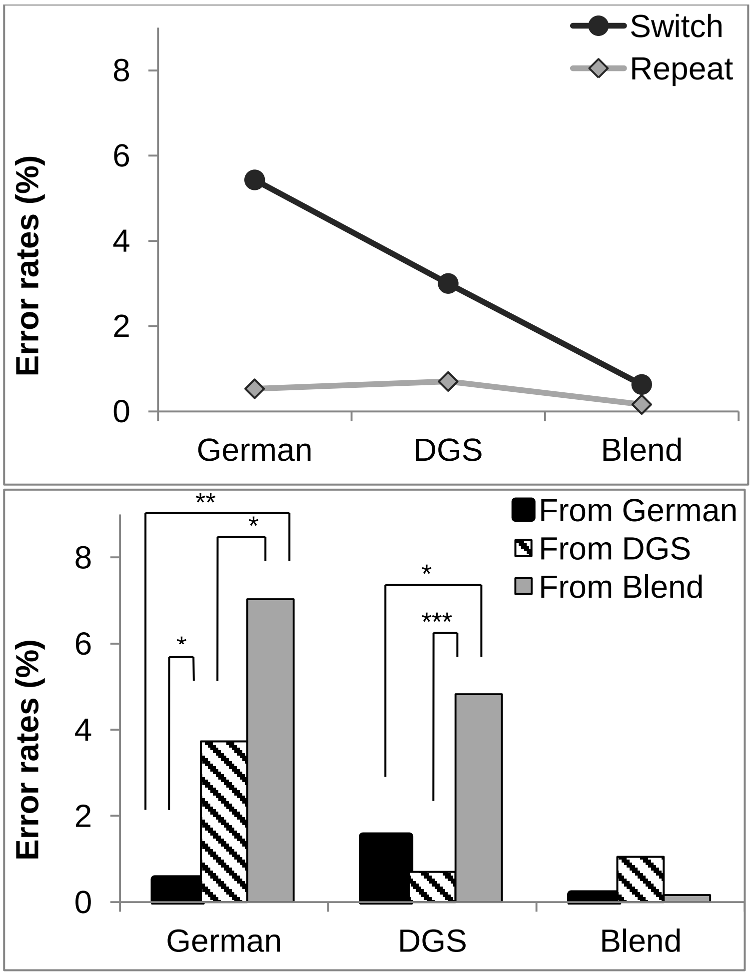

Figure 3.5. Top: Error rates in mixed blocks by Response-type (German vs. DGS vs. Blend) as a function of Shift (repeat vs. switch). Bottom: Error rates in mixed blocks split by Response-type in the current trial (German vs. DGS vs. Blend) as a function of the previous trial (Transition: from-German vs. from-DGS vs. from-Blend)

In order to examine individual effects of each Transition, we compared the three Transitions within each Response-type (see Figure 3.5). For German and DGS Response-types, anticipating the lowest error rates for repeat trials and the highest error rates for trials in which the previous trial was a dual-task Blend, we conducted 3 one-tailed paired *t*-tests as well as 3 one-tailed related-samples Wilcoxon signed rank tests for German and DGS. For Blend responses, since there were again no significant differences hypothesized between Blend from-German and Blend from-DGS, we conducted 3 two-tailed paired *t*-tests as well as 3 two-tailed related-samples Wilcoxon signed rank tests.

For the Response-type German, the Transition with the numerically highest error rate was German from-Blend (7.0%), followed by German from-DGS (3.7%), and the lowest error rate was for the repeat German from-German (0.5%). All three tests between the three Transitions revealed a significant difference in error rate, $t(11) > 2.6$; $p < .05$; Wilcoxon: $p < .05$.

For the Response-type DGS, the numerical data pattern was the same, with the highest error rate in the Transition DGS from-Blend (4.8%), followed by DGS from-German (1.5%) and DGS from-DGS (0.7%). There was a significant difference between DGS from-Blend and DGS from-DGS, $t(11) = 5.742$; $p < .001$; Wilcoxon: $p < .01$, as well as between DGS from-Blend and DGS from-German, $t(11) = 2.980$; $p < .01$; Wilcoxon: $p < .01$. However, there was no significant difference between DGS from-German and DGS from-DGS, $t(11) = 1.131$; $p > .05$; Wilcoxon: $p > .05$.

Taken together, in both single-task Response-types German and DGS, the data pattern demonstrates a significantly higher error rate when switching from a Blend to a single-task trial than when switching from one single-task trial to another or when repeating the same Response-type. This clearly shows a specific effect due to performing both a German vocal response and a DGS manual response simultaneously in trial *n*-1.

For the Response-type Blend, all error rates were low. There were no significant differences between any of the transitions (two-tailed: $t < 1.6$; $p > .1$; Wilcoxon: $p > .1$).

So, in terms of errors, for all Response-types taken together, we found significantly lower error rates and significantly smaller switch costs for dual-task trials, indicating a clear dual-task advantage for errors in this bimodal design. The finding of the smallest switch costs for the Response-type Blend indicates that this particular dual-task response is more than just a collection of two individual single-task responses because it produces error rates that are lower, and switch costs that are smaller, than those of either single-task response alone. If a Blend is more than the sum of its parts, then language seems to be different from other task components in dual-task studies. The finding that the error rate is always higher when participants switch away from a Blend trial supports the assumption that a Blend has a very specific nature. Thus, switching away from and into a Blend trial seems to incur specific costs which reflect mechanisms specific to bimodal language production.

4. General Discussion

The Methodological Experiment and Experiments 1 & 2 were designed to examine the mechanisms underlying switch costs and dual-task costs in bimodal language switching. In the Methodological Experiment and Experiment 1, unimodal (spoken–spoken) language switching was compared to bimodal (signed–spoken) language switching. In Experiment 2, the simultaneous production of both a vocal German and a manual DGS response (i.e., a Blend) was examined in a combined dual-task and task-switching design.

The most important results are as follows:

1) Language switch costs were found for both spoken (vocal) and signed (manual) languages (Methodological Experiment, Experiments 1 & 2)
2) Language-switch costs were substantially smaller when switching between a signed and a spoken language than when switching between two spoken languages (bimodal advantage for switch costs, Methodological Experiment & Experiment 1).
3) For manual (but not for vocal) RTs, language-switch costs were smaller for dual-task Blend trials than for single-task trials (bimodal advantage for switch costs, Experiment 2).
4) Language-switch costs in terms of RT and error rate were larger when switching from a dual-task Blend trial to any single-task trial (German or

DGS) as compared to switching from one single-task trial to the other (Experiment 2).

5) Dual-task costs were observed for vocal but not manual responses in pure and mixed blocks (Experiment 2).
6) Mixing costs were found for vocal and manual responses and were (numerically for vocal responses and significantly for manual responses) larger for dual-task Blend trials than for single-task trials (bimodal disadvantage for mixing costs, Experiment 2).

These findings will be discussed in turn. First, we focus on language-switch costs in unimodal vs. bimodal language switching. Second, we discuss language-switch costs and mixing costs in a situation in which dual-task Blends are sometimes produced, followed by a discussion of dual-task costs.

4.1 Unimodal and bimodal language switching

The Methodological Experiment and Experiment 1 demonstrated the occurrence of language-switch costs – that is longer RTs and a higher error rate in language switch trials than in language repetitions trials. These language-switch costs were found for both spoken languages (German and English, with larger switch costs for the dominant vocal language; cf. Meuter & Allport, 1999; Philipp et al., 2007) and for DGS, a signed language. Importantly for the bimodal context, Experiment 1 found shorter reaction times, lower error rates and smaller switch costs in bimodal language switching as compared to unimodal language switching, indicating a bimodal advantage in language switching.

In previous studies using the task-switching paradigm, the addition of a non-language modality switch (all else remaining equal) often led to increased RTs and larger switch costs (e.g. Philipp & Koch, 2010; Sohn & Anderson, 2003; Yeung & Monsell, 2003). The results for an additional language-modality switch in the Methodological Experiment and Experiment 1 showed a pattern opposite to previous results for non-language modality switching. The implication is that language modality may be different from other task components and even other response modalities in task-switching experiments. Previous studies of co-speech gesture have shown that gesture aids the speech production process, indicating that bimodal (vocal language plus gestures) is better than unimodal (see e.g. Goldin-Meadow et al., 2001; Kita, 2000). The results from the Methodological Experiment and Experiment 1, which found smaller switch costs for bimodal language switching, fit in well with these studies and extend previous knowledge by showing that the bimodal advantage not only occurs within a language in speech and gesture, but also extends to language modality itself.

To account for the bimodal advantage in the Methodological Experiment and Experiment 1, it is important to look at the characteristics of language production in these experiments. In these experiments, participants were instructed to switch languages, producing one lexeme from one language per trial, rather than blending. Unimodal bilinguals produce code-switches in natural language production, which indicates that in the unimodal production mode, only one lexeme remains active, and the other must be inhibited (e.g., Kroll et al., 2008; Philipp et al., 2007; Philipp & Koch, 2009). In contrast, bimodal bilinguals can and do produce code-blends in natural language production, which indicates that in the bimodal production mode, the two lexemes can remain active and so uninhibited through production (Emmorey et al., 2008). In line with these observations, our interpretation of the results from Experiment 1 is based on the assumption of dual parallel lexical selection in bimodal language production.

We further assume that inhibition plays a crucial role in language switching (cf. Green, 1986, 1998). For unimodal language switching, we assume that lexical inhibition takes place (e.g., Kroll et al., 2008; Philipp et al., 2007; Philipp & Koch, 2009). In contrast, for bimodal language switching, both lexemes can remain uninhibited, and the output channel must be inhibited at a later stage of production in order to prevent the non-target lexeme from being uttered. The difference in the size of switch costs might thus indicate that lexical inhibition is costlier than output channel inhibition. In a different context, Pyers and Emmorey (2008) found that bimodal bilinguals produce non-manual and occasionally manual elements of ASL while speaking English to non-signers, and they posit that this is due to a lack of what they term articulatory inhibition for ASL, meaning that ASL is activated and elements of ASL are produced with the facial and occasionally the manual articulators. So there may be different inhibitory mechanisms, or at least different degrees of inhibition, at work in unimodal and bimodal language switching. The difference in the size of switch costs may indicate that lexical inhibition in unimodal switching is costlier than output channel inhibition in bimodal switching.

4.2 Switch costs and mixing costs including dual-task Blends

Although bimodal bilinguals can perform sequential language switching as in the Methodological Experiment and Experiment 1, the simultaneous execution of both a spoken word and a sign (i.e., a Blend) is much more common in natural production (Bishop & Hicks, 2005; Emmorey et al., 2008). Thus, in Experiment 2 of the present study, such Blends were included in the language-switching paradigm in order to examine dual-task costs, mixing costs and switch-costs in one experiment. The results of Experiment 2 show a complex pattern of results that includes both bimodal advantages and bimodal disadvantages.

As a first result, Experiment 2 also found language-switch costs for both vocal and manual responses, with shorter RTs and lower error rates incurred by repeat trials than by switch trials. Thus, we assume that inhibition plays a central role in bimodal single-task and dual-task switching as well. Inhibition theories assume that a response in the current trial that was activated in the previous trial will be associated with shorter RTs and lower error rates than a response which was not activated in the previous trial—this is the basis for the general assumption that repeat trials will have shorter RTs than switch trials.

This assumption also means that, in any kind of switch trial, the currently relevant response was inhibited in the previous trial and must be reactivated. With respect to the specific effects of Blend trials, it is most interesting to compare the different kinds of switch trials: A switch to a single-task from a single-task (i.e., German from-DGS or DGS from-German), a switch to a single-task from a dual-task (i.e., German from-Blend or DGS from Blend), and a switch to a dual-task from a single-task (i.e., Blend from-German or Blend from-DGS).

For single-task from single-task switch trials, we assume that the inhibitory processes are the same as for the language-switching design in the Methodological Experiment and Experiment 1, i.e. that in order to perform one single-task, the other single-task in the other language modality must be inhibited using output channel inhibition. This assumption is supported by the longer RTs and error rates incurred by single-task from single-task switch trials as compared to repeat trials. The error rates show the same effect, though the difference between DGS from-German switch trials and DGS from-DGS repeat trials was not significant. However, this may reflect a ceiling effect due to the relatively low error rates in manual responses, and it is possible that a future study with more power or a shorter inter-trial interval would find a statistically significant difference here.

Whereas we can assume output-channel inhibition in single-task from single-task switch trials, this is not possible for switches from a Blend or into a Blend. When switching to a single-task from a dual-task Blend, one of the languages modalities remains relevant in the current trial while the other becomes irrelevant. When switching to a dual-task Blend from a single-task, the modality (i.e. vocal vs. manual) that was executed in the previous trial remains relevant as part of the Blend. Consequently, pure output-channel inhibition could be disadvantageous in such trials.

Therefore, we hypothesized that switching to a single-task from a dual-task would be more difficult than switching to one single-task from the other single-task. And indeed, single-task from dual-task switch trials incurred longer RTs and higher error rates than single-task from single-task switch trials. Put differently, switching from a Blend trial to a German (or DGS) trial results in higher RTs and error rates than switching from DGS to German (or from German to DGS). Thus, it seems that inhibiting one single-task from the previous trial in order to produce a different single-task is relatively easy, while inhibiting a Blend in order to produce one of its component tasks as a single-task is more difficult.

This pattern of results also indicates that there is no persisting activation of the relevant language modality (e.g., the vocal response in a Blend and the German response), which might be taken as evidence that a Blend should be seen as a unit which is more complex than just two single-tasks. If the Blend were simply a collection of two single-tasks, it would be easy to switch from a Blend to either single-task because the single-task would simply remain activated. The results rather indicate that switching from a Blend leads to the inhibition of both language modalities (i.e., vocal and manual) so that the reactivation of the relevant language modality of the single-task trial is necessary. Furthermore, the even longer RTs and higher error rate in those switch trials as compared to single-task from single-task switch trials could be explained by an additional inhibition of the Task-type (single-task vs. dual-task). The execution of two simultaneous responses must be suppressed as only a single response is relevant.

Such a switch in Trial-type also takes place when switching to a dual-task from a single-task (i.e., Blend from-German and Blend from-DGS trials). Yet, for this specific switch it is again important to consider the very specific nature of a Blend. A Blend consists of the simultaneous execution of a vocal and a manual response. Thus, both language modalities must be taken into account.

For manual RTs, switch costs were smaller but mixing costs were larger in dual-task trials than in single-task trials, and for all responses taken together, error rates were lowest and switch costs smallest for Blends. The finding of smaller switch costs in dual-task trials than in single-task trials represents another context in which we observed a bimodal advantage in task switching. (The other context discussed above is the smaller switch cost in bimodal compared to unimodal switching in the Methodological Experiment and Experiment 1).

In a dual-task from single-task switch trial, the activated task from the previous trial can remain activated and an additional task is added. In this instance, persisting activation of the language modality from a previous single-task trial does not seem to interfere (much) with the formation of the Blend, whereas the persisting activation of a Blend from a previous trial *does* interfere with the production of one of its components as a single-task. In other words, it seems that you do not have to inhibit the relevant language modality from the previous trial in order to produce a Blend on the current trial. Rather, only the language modality which was not activated in the previous trial must be reactivated. In a bimodal context, it seems that the Blend is advantageous in additive contexts (in which the dual-task Blend response is formed by the addition of one language modality) and disadvantageous in subtractive contexts (in which the single-task response is formed by the subtraction of one language modality from the Blend).

Studies using a dual-task design that have found a true dual-task advantage, in which the same response performed in a dual-task trial was associated with a lower cost than in a single-task trial, are few and far between. The most relevant in the context of the current study is the previous bimodal dual-task study (Emmorey et al., 2012), which, without manipulations designed to eliminate dual-task costs, found a dual-task advantage across pure blocks in the limited context of manual error rates for low-frequency signs. Experiment 2 found a dual-task advantage for switch costs for error rates and manual RTs within mixed blocks as well as evidence that the Blend forms a unit which is greater than the sum of its parts. These results indicate that language modality may be different from other task components in dual-task designs.

However, in addition to the advantage in switch-costs in dual-task manual RTs, we also observed larger mixing costs for manual RTs in dual-task trials than in single-task trials. Thus, there was a dual-task processing *disadvantage* in mixing costs but a dual-task processing *advantage* in switch costs. Such a data pattern of differential effects in mixing costs and switch costs does occur in other contexts as well, for example in asymmetric effects due to language dominance (cf. Christoffels, Firk, & Schiller, 2007; Declerck, Philipp, & Koch, 2013).

Switch costs and mixing costs are different markers of cognitive control: Whereas the trial-by-trial modulation due to inhibition and activation largely influences switch costs, mixing costs are a more global measure of interference (cf., Philipp et al., 2008; Rubin & Meiran, 2005). Therefore, since the dual-task processing advantage in switch costs relates to inhibitory effects that occur on a trial-to-trial basis, it is not surprising that we observed a differential pattern for mixing costs. Rather, this finding supports the notion that inhibitory effects play a crucial role in the dual-task processing advantage in switch costs.

4.3 Dual-task costs

In both pure blocks and mixed blocks, the results showed dual-task costs for vocal but not for manual responses. In other words, a German vocal response was performed more slowly in a Blend than as a single-task German response. However, the source of the observed dual-task cost is not clear, i.e. it is not a clear case of a processing cost resulting from, for example, cognitive interference or inadequate short-term memory. As in the previous bimodal dual-task study (Emmorey et al., 2012), participants in Experiment 2 timed their vocal responses to their manual responses on dual-task trials, making the vocal responses slower overall, which reflects a coordination cost for vocal responses (cf. response grouping, Lien & Ruthruff, 2004). That the dual-task cost for manual RTs represents such a coordination cost or response grouping is supported by the finding that the manual response preceded the vocal response in 99.6% of Blend trials; excluding trials in which the vocal response preceded the manual response from the analysis did not change the pattern of results.

If the vocal RTs in dual-task Blend trials are mainly influenced by their coordination with manual responses, it is difficult to interpret their pattern of results. This would also explain why the pattern of mixing costs was numerically the same for vocal and manual responses but significant only for manual responses, and it is possible that this coordinating cost may be obscuring differences in switch costs between single-task and dual-task trials. The coordination cost incurred by vocal responses in Blend trials certainly influenced the dual-task cost and may have obscured other processing costs and/or advantages that may result from Blend production.

4.4 General conclusion

In summary, the Methodological Experiment and Experiment 1 found shorter reaction times, lower error rates and smaller switch costs in bimodal language switching as compared to unimodal language switching, indicating that for language tasks, an additional language modality leads to a reduction in costs rather than an increase, as is the case for non-language tasks in task-switching experiments. The result suggests that there are different inhibitory mechanisms at work in unimodal and bimodal language switching, with lexical inhibition, at work in unimodal switching, being costlier than the output channel inhibition that is involved in bimodal switching.

The results from Experiment 2 show a complex pattern of dual-task processing advantages and disadvantages. In terms of mixing costs, there was a dual-task processing disadvantage, which is the expected pattern. Within the mixed condition, there was a clear dual-task processing advantage found in switch costs for overall error rates and for manual RTs, a pattern opposite to that of previous cross-modal experiments in which the modality element was something other than language modality. These results lead us to suggest that language is different from other task components in task-switching and dual-task studies and that a Blend forms a unit which is greater than the sum of its parts. The unit formed by the Blend leads to a disadvantage in switching to single-task trials, and it leads to an advantage in switching to dual-task trials.

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