

# **INVESTIGATING COGNITIVE CONTROL IN LANGUAGE SWITCHING**

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## **ABSTRACT**

How do bi/multilinguals switch between languages so effectively that there is no obvious intrusion from the alternatives? One can examine this by comparing language selection with task selection, or language switching with task switching. This is the approach adopted in the first of two strands of research presented in this thesis.

In task switching, providing advance warning of the task typically leads to a reduction in the performance ‘switch cost’, suggesting top-down biasing of task selection. It is not clear whether the language switch cost also reduces with preparation, partly because there have been very few attempts to examine preparation for a language switch, and partly because these attempts suffered from non-trivial methodological drawbacks. In Experiments 1-3 I used an optimised picture naming paradigm in which language changed unpredictably and was specified by a language cue presented at different intervals before the picture.

Experiment 1, conducted on ‘unbalanced’ bilinguals, revealed some evidence of reduction in the language switch cost for naming times with preparation, but only when cue duration was short. In an attempt to further optimise the paradigm, in Experiment 2 the cue-stimulus interval (which was varied from trial to trial in Experiment 1), was varied over blocks instead. Visual cues were replaced with auditory cues – the latter also enabled a comparison between semantically transparent word cues (the spoken names of the languages) and less transparent cues (fragments of national anthems).

Experiment 2 revealed a reduction in switch cost with preparation for naming latencies, but only in the second language; the first language showed the reverse. To examine whether the increase in switch cost with preparation in the first language could be due to unbalanced bilinguals biasing processing towards L2, balanced bilinguals were tested in Experiment 3. This revealed a robust reduction in switch cost in naming latencies for both languages, which was driven primarily by the trials with the anthem cues. However, in the error rates the switch cost increased

with preparation interval, thus complicating the interpretation of the reduction observed for response times.

Experiment 4 investigated whether preparation for a language switch elicits the electrophysiological patterns commonly found during preparation for a task switch – a switch-induced positive polarity Event-Related Potential (ERP) with a posterior scalp distribution. Contrary to a recent report of the absence of the posterior positivity in language switching, it was clearly present in the present EEG data. As in task switching, the amplitude of the posterior positivity predicted performance.

The electrophysiological data suggest that preparation for a language switch and preparation for a task switch rely on highly overlapping control mechanisms. The behavioural data suggest that advance control can be effective in language switching, but perhaps not as effective as in task switching. Experiments 1-3 also examined the effect of stimulus associative history – whether the language used on the previous encounter with a given stimulus influenced performance on the current trial). Having previously named a given picture in the same language benefited overall performance, but did not do so more for switches than repeats. Thus, stimulus associative history does not seem to contribute to the language switch cost.

The second strand of my research asked whether bilinguals can set themselves independently for speech vs. comprehension. Previous research has examined the cost of switching the language in output tasks and in input tasks. But, it is not clear whether one can apply separate control settings for input and output selection. To investigate this, I used a paradigm that combined switching languages for speech production and comprehension. My reasoning was that, if there is cross-talk between the control settings for input vs. output, performance in one pathway should benefit if the language selected for the other pathway is the same relative to when it is different: a ‘language match effect’. Conversely, if there is no cross-talk, there should not be a language match effect.

In Experiment 5 bilinguals alternated predictably between naming numbers in their first and second language (in runs of 3 trials), whilst also having to semantically categorise spoken words

which occasionally (and unpredictably) replaced the numbers. The language of the categorisation ‘probes’ varied over blocks of ~17 naming runs, but was constant within a block. The results showed a clear match effect in the input task (categorisation), but not the output task (naming). To examine the potential role of proficiency, Experiment 6 used the same paradigm to test unbalanced and balanced bilinguals. The pattern of results was qualitatively similar in both groups to that observed in Experiment 5: a language match effect confined to the input task. These results suggest ‘leakage’ from the output control settings into the input control settings.



## Acknowledgments

I wrote the following few words on a scrap of paper and kept it on my desk for those difficult days when I needed inspiration;

“Nothing is impossible; the word itself says I’m possible.”

The only way that this PhD has been ‘possible’ is through the help and support of many people. Thanks must first go to my two supervisors Dr. Aureliu Lavric and Prof. Stephen Monsell, I will always be indebted to you for your help, your support and your guidance. During the course of my PhD I had the pleasure of collaborating with Antonia East and Dr. Heike Elchlepp. I really enjoyed working with you and made two good friends in the process. Thank you to the ESRC who provided me with the financial means to be able to undertake this research.

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## **Declaration**

The research reported in this thesis was carried out at the University of Exeter between October 2006 and February 2013 (inclusive of two study breaks for maternity leave) and was supervised by Dr. Aureliu Lavric and Prof. Stephen Monsell.

I have not submitted this dissertation in whole or in part, for any other degree, diploma or qualification at any university. Experiment 4 of Chapter 2 and Chapter 3 are articles that will be submitted to scientific journals. Experiment 4 of Chapter 2 will be submitted by Clapp, A., Lavric, A., East, A., Elchlepp, H. and Monsell, S. Chapter 2 will be submitted by Clapp, A., Lavric, A. and Monsell, S. Experiments 3 and 4 were run in conjunction with a Masters Student, Antonia East, using the behavioural paradigm that I had developed in experiments 1 and 2 of this thesis. The data from experiments 3 and 4 were submitted as part of Antonia's Masters Dissertation in 2011. Antonia is a fluent English - German bilingual and marked the accuracy of participants responses in the two experiments, Heike Elchlepp helped to analyse the ERPs from experiment 4 and helped to prepare figure 2.12.

All of the experiments were designed by me under the supervision of Dr. Aureliu Lavric I carried out all analyses, wrote the first draft and prepared the figures and tables. Dr. Lavric has edited the manuscript.

Amanda Clapp

Exeter, February 2013.



# CHAPTER ONE

## INTRODUCTION

This thesis set out to investigate two key areas of how bilingual speakers process language. There are more bilinguals in the world than there are monolinguals yet the mechanisms underlying the cognitive control of language switching in bilingual speakers, are not well understood. There seems to be a larger and more elaborate literature on task switching than language switching and I feel it is important to draw parallels between these two areas of research. The second strand of the PhD concentrates on the role of ‘top-down’ control in bilingual speech production and comprehension processes. There has been much debate in the psycholinguistic literature as to whether there is a single pathway that is used for speech production and comprehension in monolinguals, or whether there are separate pathways for these two tasks. One can examine this issue in bilingual speakers from a new perspective. The following introductory chapter is split into two sections to reflect these two distinct but related strands of my research.

### **Drawing parallels between task switching and language switching**

The first part of this introduction will expand on the topics mentioned so far, discussing the similarities among studies of language switching and task switching with respect to behavioural and imaging phenomena. This introduction will also explore three key theories of bilingual lexical access; Greens’ (1998) inhibitory control model, Pouslisse and Bongaerts (2000) spreading activation account and Costa and Santesteban’s (2004) language-specific selection threshold hypothesis, discussing how the available data fits these theoretical arguments.

### ***Task switching***

A PhD student sits at her desk and looks at a freshly printed draft of her manuscript, she could meticulously proof read it and mark any errors and omissions, or she could take a page and make it into a paper aeroplane! In order to effectively perform either of these tasks she must engage an

appropriate set of processes that are relevant to the activity; collectively known as a ‘procedural schema’ (Norman & Shallice, 1986) or a ‘task set’ (Monsell, 1996). Depending on the situation there may be a number of task sets competing for selection; reading and origami in this example. Retrieving and implementing the relevant task set from memory is likely to involve a combination of ‘top-down’ (endogenous) control such as the deliberate intention to perform the appropriate task, together with bottom-up (possibly exogenous) factors such as the conflict (or interference) from the alternative tasks that are afforded by the stimulus (Monsell, 2003).

The ability to switch between two tasks afforded by a single stimulus is a well researched cognitive function (see Kiesel, Steinhauser, Wendt, Falkenstein, Jost, Philipp, & Koch, 2010; Vandierendonck, Liefoghe, & Verbruggen, 2010). While sitting in front of a computer screen in a task switching experiment one might be presented with digits and asked to classify each one as either odd/even or high/low according to some pre-specified instructions (e.g. Rogers & Monsell, 1995). Task switching paradigms fall into two broad categories; voluntary switching and instructed switching. Voluntary switching paradigms are a relatively recent development whereby the participant is allowed to decide when they wish to switch tasks (e.g. Arrington & Logan, 2004, 2005; Arrington, Logan & Schneider, 2007). Instructed switching paradigms can be sub-divided into predictable and unpredictable switching. Predictable switching utilises the ‘alternating runs’ paradigm and unpredictable switching uses either ‘task-cueing’ or ‘intermittent instruction’. The common contrast among all these paradigms is the comparison between trials on which the task changes and those on which it is the same as on the previous trials – this contrast almost invariably reveals an overhead in performance associated with a task change – the ‘switch cost’ (Rogers & Monsell, 1995). In what follows, I will review the ways in which different paradigms have been used to measure the switch cost and explore its modulation by other factors.

Some of the earliest task switching studies involved unpredictable switching and used the task-cueing paradigm (e.g. Biederman, 1972; Meiran, 1996; Shaffer, 1965; Sudevan & Taylor, 1987). Each of the experimental tasks is allocated a particular cue. Each stimulus is preceded or accompanied by a cue indicating the task to be performed on that particular trial. Some researchers have chosen to turn an attribute of the stimulus into the cue, for example, Monsell, Sumner and Waters (2003; experiment 2) presented black digits inside a coloured shape and for some participants the background colour of the shape provided the task cue whilst for other

participants the shape itself (square or diamond) provided the task cue. Another task-cueing paradigm which is less frequently used is the intermittent instruction paradigm (a term coined by Monsell et al., 2003), whereby participants are cued on some trials to either continue with the same task or to switch tasks (e.g. Gopher, 1996; Gopher, Armory & Greenshpan, 2000). On the first trial after a cue there is always a ‘re-start’ cost, even if the instruction indicates to carry on with the previous task (Allport & Wylie, 2000). The increase in reaction time is typically smaller for task repeat cues than for task switch cues and the difference in the magnitude of the re-start costs provides a measure of the switch cost (c.f. Monsell, 2003).

A popular experimental design involving predictable switching is the alternating runs paradigm in which the task switches every *n*th trial. For example, a participant might switch in alternating runs of two trials and would, therefore, perform task AABBA etc. (e.g. Rogers & Monsell, 1995). It can be easy for participants to lose track of where they are within a sequence of trials, especially after making an error and so a (redundant) cue is typically presented on the screen. Some have made use of perceptual cues (e.g. Koch, 2003; Waszak, Hommel, & Allport, 2003) and others have used location cues (e.g. Rogers & Monsell, 1995). Some do not present a redundant cue (e.g., Allport, Styles, & Hsieh, 1994, Experiment 5; Mayr & Keele, 2000), and its absence means that participants must remember the trial sequence in addition to performing the task which may increase their Working Memory load.

In their alternating runs paradigm, Rogers and Monsell (1995) found that the RT switch cost was reduced by about half when the time available for preparation was increased from 150ms to 600ms – the ‘RISC effect’ (reduction in switch cost). However, they reported little improvement in performance when the time available for preparation was further increased from 600ms to 1200ms. Switch costs have been reported in paradigms using RSIs up to 12s (e.g. Kimberg, Aguirre, & D’Esposito, 2000; Sohn, Ursu, Anderson, Stenger, & Carter, 2000). However, even at very long preparation intervals, a residual (asymptotic) cost of switching is still present, regardless of how strong the incentives are to prepare (see Nieuwenhuis & Monsell, 2002). This suggests that there are (at least) two components to the switch cost, one which can be reduced with active preparation, and a residual switch cost which cannot. This being said, there have been some studies in which there was no statistically detectable (or even numerical) switch cost (Astle, Jackson, & Swainson, R., 2008b; Verbruggen, Liefvooghe, Vandierendonck, & Demanet, J., 2007). For example, Verbruggen et al. (2007) reasoned that one factor that may

encourage rapid and effecting preparation for a switch is a short duration of the task cue. Indeed, they found that in the condition where the duration of a visual cue was 64ms-128ms the switch cost was statistically undetectable (though a small numerical switch cost remained).

Some accounts propose that in order to change tasks the current task-set must be replaced or modified by endogenous processes involving (among others) the retrieval of new task rules from memory (Mayr & Kliegl, 2000), the implementation of a new task goal (Rubinstein, Meyer & Evans, 2001), or re-focussing of attention on a different stimulus attribute (Meiran, 2000). Task-set reconfiguration (TSR) must occur in order for the participant to respond and it is thought that part of the switch cost reflects the time takes for TSR to occur (Rogers & Monsell, 1995). Preparation effects provide support for reconfigurational accounts of task switching. If participants are given more time to prepare for a change of task, TSR can be completed (or almost completed) before the stimulus arrives. If TSR is largely complete during the preparation interval there is less to do once the stimulus arrives on the screen and so the response can be selected and executed more quickly than if TSR had to occur after the stimulus, resulting in the RISC effect.

One might assume that switching into a more practiced task would be easier than switching into a less practiced one. Surprisingly, this is typically not the case. A 'paradoxical asymmetry' of switch costs is often found when switching between tasks of unequal strength with a larger switch cost associated with switching to the easier, or more practiced task (e.g. Allport et al., 1994; Allport, & Wylie, 1999; Yeung & Monsell, 2003). Using the Stroop paradigm, Allport et al., (1994) found a larger switch cost associated with switching to the more practised word naming task, than the less practised colour naming task. Allport et al., (1994) described their findings in terms of task priming effects, subsumed under the Task Set Inertia (TSI) account. They proposed that the switch cost is affected by passive decay of activity levels from the previously relevant task set carrying over to the new trial. The longer the interval since a particular task had been used, the greater the amount of passive decay that will have occurred leading to a smaller switch cost on the subsequent trial. They also suggested that the irrelevant task set was inhibited when not in use, and upon switching tasks this inhibition must be overcome, which affects performance. The more dominant task requires greater levels of inhibition and this takes longer/is harder to suppress when switching tasks, leading to a paradoxical asymmetry of switch costs.

The predictable alternating runs paradigm has been a popular choice in task switching. However, it is not possible to dissociate between the active preparation and the passive decay components of the switch cost using this paradigm. One cannot independently manipulate the active preparation element of the switch cost, from the response to stimulus interval (RSI) that contributes toward the passive decay element of the switch cost. Task cueing allows one to unconfound passive decay and active preparation, because it allows the CSI and the RSI to be manipulated independently. In a set of five experiments, Meiran (1996) investigated these two putative components of the switch cost by manipulating the CSI and RSI. He reasoned that a short CSI would be sufficient to allow cue encoding, but probably not long enough to allow the completion of TSR. Meiran (1996) argued that the (larger) switch cost from the short CSI would reflect the additional processing needed to complete TSR after the stimulus appeared on the screen. He asked participants to respond to the location of a stimulus which appeared in one of four quadrants that made up a larger square. The two tasks were up/down and left/right. The same two keys were used for both tasks and thus on some trials the response was classed as 'compatible' and the correct response was associated with the same key for both tasks (e.g. up or left and down or right; the term 'congruent' is often used in the literature for this relationship between stimuli and responses). Other trials were 'incompatible' and the correct response was associated with different keys for the two tasks (e.g. up or right and down or left). Meiran (1996) reported a reduction in the magnitude of the switch cost from the short to the long CSI in his first experiment. However, the RSI varied as a function of CSI with a longer CSI associated with a longer RSI, allowing more time for passive decay of the previous task-set in the long CSI than the short CSI. This confound was resolved in experiment two by varying the CSI whilst keeping the RSI constant, however, Meiran (1996) failed to replicate the RISC effect found in experiment one. There were an almost equal number of compatible and incompatible trials in experiment two which meant that the correct response could be given (on compatible trials) regardless of which task the participants were actually responding to. In experiment three, Meiran (1996) varied the number of compatible and incompatible trials so that half the participants saw 20% compatible and 80% incompatible and half saw 80% compatible and 20% incompatible trials. When the proportion of compatible trials was low, there was a RISC effect as in experiment one.

Given the constant RSI of experiment three, Meiran (1996) suggested that carry over effects cannot be the sole source of the switch cost, thus suggesting a role for active TSR.

Waszak, Homel & Allport (2003) proposed the stimulus may evoke either the response from the task in which the stimulus has previously appeared, or the task itself because of associations formed on previous encounters. The importance of stimulus-task associative history was highlighted by Allport et al., (1994) who manipulated two tasks in order to create non-overlapping response-sets. First, they chose the classic Stroop interference task. Secondly, they chose a numerosity naming task where a group of digits (all the same) were presented on the screen and participants either had to name the digit, or the number of digits that were present on the screen. Participants were divided into two groups and switched between one of the Stroop tasks and one of the numerosity tasks. One group of participants switched between the colour naming part of the stroop task and numerosity naming (i.e. responding '2' to a group of two number 3s), with the other group participants performing the complementary task to the same stimuli. Allport et al., (1994) reported no cost of switching for either group replicating results from other studies that used 'univalent' stimuli that only afforded one task (Jersild, 1927; Spector & Biedermann, 1976). In the second half of Allport et al's. (1994) experiment participants swapped tasks and those who performed colour naming and numerosity judgment now performed word reading and digit naming, and vice versa. Both groups now showed large task switch costs, initially the cost of switching was ~300 ms, after the first few lists the switch cost decreased but a reliable, residual cost of switching still remained even after more than 150 trials. Although the stimuli in the second half of the experiment were also univalent, they resulted in a large switch cost, indicating that it arose because the stimuli have recently been used in different tasks than the one currently performed. This switch cost may have been caused by conflict from stimulus-task associations which formed during the first half of the experiment. Allport and Wylie (1999, 2000) and Wylie and Allport, (2000) have further elaborated this account proposing that facilitatory and/or inhibitory effects between competing tasks are retrieved from memory upon presentation of a stimulus.

Waszak et al., (2003) proposed that task related information is linked to each stimulus creating numerous 'bindings' between the stimulus and its response (S-R bindings), its action goal and other task-specific events. Once formed, these stimulus-task-action links (S-R-event bindings) may be retrieved from memory when the stimulus is next encountered. In a series of

experiments, Waszak et al., (2003; 2004; 2005) used simple line drawings with an object name superimposed, the object name corresponded to the picture on the majority of stimuli. Using a variant of the instructed switch paradigm (Monsell, Yeung & Azuma, 2000) Waszak et al., (2003) presented stimuli in cued sequences of two or three trials. For example, a cue (letter “P” to indicate picture naming) was replaced after 2.5s with two or three stimuli, then a cue (letter “W” to indicate word naming) was replaced after 2.5s with two or three stimuli etc. Some of the stimuli had been previously encountered in the same task, whilst others had been encountered in both tasks. Stimuli that had been presented in both tasks were responded to more slowly than those only presented in the same task. For the word stimuli, interference effects were only present for trials following the cue, and not for subsequent trials within the run. For picture stimuli, interference effects were found on all trials.

A single prior presentation was sufficient to cause an interference effect, and four prior presentations caused interference effects which persisted after a lag of 100-200 trials. Waszak et al. (2003) manipulated congruency to see if the interference was a result of having the stimuli associated with a different response rather than a different task. The majority of trials were congruent and thus elicited the same response in both tasks. Waszak et al. (2003) reported interference when these stimuli had previously been encountered in both tasks, suggesting interference from the stimulus associative history rather than stimulus-response bindings. Waszak et al.’s use of an instructed switch paradigm created marked difference between their task switch and task repeat conditions; there was a 2.5s delay during the presentation of the cue on task switch trials. It is possible that effects of stimulus associative history may have been exaggerated by the restart cost which is typically found in such paradigms.

Until recently, it was typical to use one cue per task, and this means that the cue only changed on task change trials and not on task repeat trials. This is thought to increase the magnitude of the switch cost due to priming of the cue on those trials where the cue is repeated (e.g. Logan & Bundesen, 2003; Mayr & Kliegl, 2003). A simple way to dissociate task change effects from cue change effects is to have two cues per task. This means that the cue can change on every trial even if the task remains the same. Logan and Bundesen (2003) investigated the relative contributions to the switch cost that originates from a change of cue and a change of task. In a digit classification task, Logan and Bundesen (2003, experiment 3 and 5) asked participants to make an odd/even judgment using the word cues “odd-even” and “parity”, or to

make a high/low judgment using the word cues “high-low” or “magnitude”. There were 3 trial type conditions; on some trials the cue changed but the task did not (cue change only), on some trials the cue changed and the task changed (cue and task change), on some trials the cue is repeated and thus the task is also repeated (cue and task repeat). The authors found little difference in the magnitude of the switch costs between the ‘cue change task change’ condition and the ‘cue change task repeat’ condition. They suggested this indicated that the change of task contributed very little to the magnitude of the switch cost. To support this, they investigated the effects of cue change on the overall switch cost and found a reliable cost of switching when they compared the ‘cue change task repeat’ condition and the ‘cue repeat task repeat’ condition. This led them to suggest that the entire switch cost originates from the change of cue, rather than the change of task. They proposed that a participant retrieves a cue-stimulus compound from memory which enables the response on each trial. Response times on repeat trials are faster than switch trials due to the perceptual priming of the cue from the previous trial. Switch trials are slower because a new cue-stimulus compound must be retrieved from memory.

Since this idea was proposed, a number of studies have found reliable and robust task switch costs over and above the cue change switch cost (Altmann, 2006; Arrington, Logan, & Schneider, 2007; Jost, Mayr, & Rösler, 2008; Mayr & Kliegl, 2003; Monsell & Mizon, 2006). Mayr and Kliegl (2003) presented participants with coloured shapes (blue, green or red, triangles, circles or squares) and asked them to discriminate either the shape or its colour using two single-letter cues per task. They used the same three cue change / task change conditions as Logan and Bundesen (2003). In experiments one and two, Mayr and Kliegl (2003) found that a substantial part of the switch cost was due to cue change effects, with a robust switch cost on trials where the cue changed but the task repeated. They also found that the cue-switch cost was sensitive to manipulations of practice (exp. 1), with successive blocks yielding ever smaller cue-switch costs. Mayr and Kliegl (2002) also reported the cue-switch cost to be sensitive to manipulations of preparation (exp.2), with a greatly reduced switch cost for long preparation intervals relative to short preparation intervals. They proposed that each cue was associated with a set of stimulus-response (S-R) mappings. On switch trials a new set of S-R mappings had to be retrieved from long term memory and this delayed responses; cue repetition trials benefited from priming of the recently used S-R mapping and this leads to a reaction time benefit. Contrary to Logan and Bundesen (2003), Mayr and Kliegl (2003; experiments 1 and 2) reported that a task

change also contributed quite substantially toward the overall switch cost. Although Mayr and Kliegl (2003) found a substantial task-switch cost, they did not find a RISC effect; the task-switch cost was sensitive to manipulations of response repetition with faster reaction times when the response was different to the previous trial, than when it was the same (experiments one and two).

Although Mayr and Kliegl (2003) and Logan and Bundesen (2003) both reported an effect of cue change on the overall switch cost, only Mayr and Kliegl (2003) found any effects of task change. They proposed different interpretations of the cue change portion of the switch cost. Mayr and Kliegl (2003) suggested that priming of control processes arising from the retrieval of S-R mappings from memory (c.f. Arrington et al., 2007) was responsible, whilst Logan and Bundesen (2003) theorised that it was perceptual priming of the cue from the previous trial. In light of these differences, and of Mayr and Kliegl's (2003) failure to find a RISC effect, Monsell and Mizon (2006) set out to investigate differences between paradigm design using the same cue change / task change conditions as Logan and Bundesen (2003) and Mayr and Kliegl, (2003). Monsell and Mizon (2006) were able to replicate the results from Logan and Bundesen's (2003) study and found that the task switch cost and effects of preparation could be attributed to a change of cue, not a change of task. Changes to paradigm design in Monsell and Mizon's (2006) experiment two included an equal probability that any one of the three trial types could be presented. In contrast to their first experiment, this paradigm revealed switch cost and preparation effects that were attributable to task change, rather than cue change. In experiment three, Monsell and Mizon (2006) reported a paradigm in which the task switch cost could be attributable to both task and cue change effects, thus replicating the work of Mayr and Kliegl (2003), with the important difference that task change effects (the switch cost) reduced with preparation.

It was clear from the first three of Monsell and Mizon's (2006) experiments that variation in paradigm design could lead to quite dramatic differences in the relative contributions of cue change and task change on the switch cost. Next, Monsell and Mizon (2006) varied the probability of a task switch in a between subjects comparison varying the probability of a change of task at either 25%, 50% or 75%. When the probability of a task change was low, Monsell and Mizon (2006) found a large switch cost and RISC effect, the magnitude of these effects reduced when the chance of a change of task increased. They reasoned that if the probability of a change

of task is high, participants may prepare for a change of task before the cue is presented leading to faster responses on switch trials than one might have expected. However, actively preparing to switch trials on a task repeat trial would slow responses since participants would have to stop TSR processes and switch back to the previously relevant task-set. The two effects together would reduce the magnitude of the switch cost. By keeping the probability of a change of task relatively low, participants are not discouraged from preparing for a change of task in advance of the cue.

Another important issue in the task-cueing paradigm is the interpretability of the cue. If the cue is difficult to interpret it can place additional cognitive load onto participants and cue interpretation may even become a task in itself. A number of studies have noted the importance of self-instruction on participant performance (e.g., Goschke, 2000; Miyake, Emerson, Padilla, & Ahn, 2004), arguing that verbal cues are an effective aid to TSR because participants are provided with a description of the task and do not need to generate it themselves. Accordingly, a linguistic cue was thought to be highly transparent, because of the pre-existing semantic relationship between the cue word and the task (e.g. Arbuthnott & Woodward, 2002; Logan & Schneider, 2006a). Arbuthnott and Woodward (2002) investigated how such prior cue-task associations affected the switch cost. Participants were asked to make a categorisation judgment on one of three types of stimuli; digits (odd vs. even), letters (vowel vs. consonant) or symbols (math vs. text). One of each stimulus was displayed on every trial (three characters per trial) with a cue to indicate the relevant character. Verbal cues consisted of a task description (odd or even, vowel or consonant, math or text) and they were assumed to have a prior association with the task. The spatial cue indicated the appropriate task by displaying a row of asterisks alongside the relevant attribute. The shape cue consisted of pre-defined symbols associated with each task (e.g. \* for the digit task, O for the letter task and ¥ for the symbol task). Arbuthnott and Woodward (2002) predicted that the verbal cue would result in the smallest switch cost due to biasing competition toward the appropriate response. They found that cue transparency indeed influenced the size of the switch cost: the verbal cue was associated with the smallest switch cost, while there was little difference in switch cost between the spatial cue and shape cue conditions.

### ***Language switching***

There has been a surge of interest in language switching over the last decade and similarities are emerging in the behavioural phenomena documented in task and language switching. Parallels can also be drawn between the theoretical accounts of task and language switching, with overlap between some models of lexical access in bilinguals and theories of task-set control. Inhibition accounts of lexical access and the Task Set Inertia account both propose passive carryover effects from one trial to the next.

The effectiveness with which bilinguals can select words from the target language has led to a number of theories of bilingual lexical access. There is some contention as to whether or not lexical nodes from the non-target language compete for selection. One type of theory proposes that the bilingual brain contains a mechanism which only considers for selection those lexical nodes in the target language (Costa, 2004; Costa & Santesteban, 2004; Costa & Caramazza, 1999; Costa, Miozzo & Caramazza, 1999; Roelofs, 1998; Verhoef, Roelofs & Chwilla, 2009a; 2009b). Alternative theories assume that lexical selection occurs through greater activation of lexical nodes within the target language (Bloem, van den Boogaard & La Heij, 2004; Poulisse & Bongaerts, 1994) or via reactive inhibition of lexical nodes within the non-target language (Green, 1986; 1998; Hermans et al., 1998).

### ***Can models of bilingual lexical access explain basic switching phenomena?***

In the most typical language switching experiment, a bilingual speaker is presented with simple stimuli such as digits or line drawings and asked to name them in either their native language (L1) or their second language (L2). Responses are typically slower and more error prone when the language changes (switch trial), than when it remains the same (repeat trial) – the language switch cost (e.g. Costa & Santesteban, 2004; Jackson, Swainson, Cunnington, & Jackson, 2001; Meuter & Allport, 1999). Several theories of bilingual lexical access are able to explain the source of the language switch cost and the most influential accounts is Green's (1998) Inhibitory Control (IC) model<sup>1</sup>. The IC model is based on language task schemas which are created and/or

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<sup>1</sup> Green's Supervisory Attentional System (SAS) is based on Norman and Shallice (1986). Norman and Shallice proposed two separate control systems; contention scheduling and SAS, with three levels of functioning: a fully

modified by the Supervisory Attentional System (SAS). A language task schema is a dynamic mental device which contains information needed to complete a goal, much like (part of) a task-set. There is a language task schema for each task that a bilingual might perform and these compete to control output of the bilingual lexico-semantic system by activating or inhibiting language tags that are assigned to each lemma. Importantly, each schema is language-specific. During L1 speech production for example, the relevant language task schema is selected which triggers the reactive inhibition of L2 lemmas. In order to switch languages and speak in L2, the language task schema for L2 production must be selected and the inhibition of the previously irrelevant L2 lemmas must be suppressed. This takes time and leads to longer response latencies and typically more errors, on language switch trials than language repeat trials – the switch cost.

The amount of inhibition applied to lemmas in the non-target language is proportional to the strength of the language, with more proficient languages requiring greater levels of inhibition than less proficient languages. For a balanced bilingual, proficiency of L2 is approaching (or equal to) that of L1 and similar levels of inhibition and thus overcoming inhibition are required for L1 and L2, leading to switch costs of a comparable magnitude. A symmetrical switch cost is typically reported when bilingual speakers switch between their two dominant languages (e.g. Costa & Santesteban, 2004). Unbalanced bilinguals are more proficient in L1 than in L2 and would need to apply greater levels of inhibition to L1 when speaking in L2 than vice versa. On switching languages, it is harder to overcome the inhibition applied to L1, than to L2, and thus the IC model predicts a larger switch cost for the dominant language. Such a paradoxical asymmetry of switch costs has been found in the language switching literature for digit naming (e.g. Jackson et al., 2001; Meuter & Allport, 1999) and picture naming (e.g. Costa & Santesteban, 2004; Verhoef et al., 2009a) studies.

However, strong inhibition of L1 in unbalanced bilinguals should also lead to a benefit in repeating L2 (cf. Yeung & Monsell, 2003) and because this benefit of repeating L2 may be as large as the cost of switch to L1, there is no logical reason for an asymmetric switch cost. Is it possible that instead of disproportionately slow reaction time on L1 switch trials, the asymmetry is caused by disproportionately faster reaction time on L1 repeat trials? A small number of language switching studies have reported an asymmetry of switch costs driven primarily by

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automatic processing system governed by schemas, a partially automatic processing system which is not subject to conscious control, and a part of SAS that is subject to deliberate control.

differences on repeat trials, with faster naming for L1 repeat than L2 repeat (e.g. Jackson et al., 2001; 2004; Verhoef et al., 2009a). It was this finding that drove Verhoef et al., (2009a; 2009b) to propose their L1-repeat benefit hypothesis (see also Jackson et al., 2001). According to this account, for unbalanced bilinguals L1 competes for selection on L2 switch and L2 repeat trials but L2 only competes for selection on L1 switch trials. If an unbalanced bilingual speaker is well-prepared to speak in their native language, as they are on L1 repeat trials, the response latencies should be disproportionately fast because the L2 task-set is not active and is not competing for selection. Switch trials are slower (or more error prone) than repeat trials but the magnitude of this difference is larger for L1 than it is for L2 due to the benefit of repeating being confined to L1, leading to a paradoxical asymmetry of switch costs. Verhoef et al. (2009a; 2009b) proposed that as the proficiency of L2 increases to the level of L1, L2 would compete for selection on all trials, including L1 repeat trials. This would lead to switch costs of comparable magnitude for both languages, since there is no longer a reaction time benefit to repeating L1.

In contrast to Green's IC model, the Spreading Activation Account proposed by Poulisse and Bongaerts (1994) assumes that all lemmas are active during lexical selection. A pre-verbal language component causes lemmas in the target language to receive more activity than their translation equivalent which leads to lexical selection in the correct language. The control processes within the spreading activation account are not well specified, but one may use their basic theoretical principles to surmise how the model might account for some behavioural phenomena. On switching languages, the pre-verbal message needs to be altered so that more activity is directed to lemmas in the bilingual's other language. Presumably, this takes time and accounts for longer responses on language switch trials than language repeat trials. Poulisse and Bongaerts (1994) stated that more frequently used lemmas will have a higher baseline activity level than less frequently used lemmas, therefore, L1 lemmas will typically have a higher baseline activity level than L2 lemmas, especially for unbalanced bilinguals. The higher the baseline, the less activity is needed for the lemma to reach the threshold for lexical selection. The Spreading Activation Account predicts an asymmetric switch cost due to the differing baseline activity levels of L1 and L2 in unbalanced bilinguals, but switching into the dominant language should incur the smaller switch cost; the opposite from the paradoxical asymmetry typically found in the literature. As L2 proficiency increases, the baseline activity levels of L2 lemmas will also increase which means that the resting baseline activity level of L2 lemmas in highly

proficient bilingual speakers may be approaching, or equal to those of L1. As a result, similar amounts of activity are needed in order for the lemmas of L1 and L2 to reach the lexical selection threshold which may account for the symmetrical switch costs observed in balanced bilinguals.

Costa and Santesteban (2004) proposed that highly proficient (very balanced) bilinguals deal with lexical selection differently to unbalanced bilinguals. In a series of picture naming experiments, they replicated the paradoxical asymmetry of switch costs with a group of unbalanced bilinguals. They also reported a symmetrical switch cost when a group of balanced bilinguals switched between L1 and L2. Costa and Santesteban asked a different group of balanced bilinguals, highly proficient in L1 and L2, to switch between L1 and a much weaker L3. Given the asymmetry of proficiency, one might predict results comparable to the unbalanced bilinguals. However, the switch cost was symmetrical. To account for this finding, Costa and Santesteban (2004) proposed that unbalanced bilinguals reactively inhibit lexical entries in the non-target language and that as proficiency of L2 increases, there is a shift in the type of mechanism used for lexical selection. They suggested that in highly proficient bilinguals the lexical selection mechanism is sensitive only to the target language and so reactive inhibition of the non-target language is no longer required. Once this mechanism has been developed, it can be applied to any language, regardless of proficiency. Thus, if a highly proficient bilingual could use a language specific selection mechanism to name in L2, without reactively inhibiting L1, they could also use this mechanism in access the much weaker L3 without L1 inhibition.

In a subsequent study, Costa, Santesteban and Ivanova (2006) found a paradoxical asymmetry of switch costs when balanced bilinguals, highly proficient in L1 and L2 switched between a weak L3 and a very weak L4. This is clearly at odds with Costa and Santesteban's (2004) earlier lexical selection account, which postulated that balanced bilinguals should show a symmetrical switch cost, regardless of which languages they switch between. Costa et al. (2006) suggested that their lexical selection mechanism might only be effective when one of the languages being used is L1. Although they stood by their original theory, Costa et al. (2006) argued that in some circumstances a balanced bilingual may need to resort to inhibitory control to perform lexical selection.

To sum up, models of bilingual lexical access fall into 3 distinct categories; a language specific selection mechanism developed by balanced bilinguals (e.g. Costa & Santesteban, 2004;

Costa et al., 2006), accounts of spreading activation (e.g. Poulisse & Bongaerts, 2004; Verhoef et al., 2009a; 2009b) and accounts of reactive inhibition (e.g. Green, 1998). Each type of model offers an explanation for some of the behavioural phenomenon of language switching, but no single model can explain all of the findings. Green's (1998) IC model competently explains the behavioural switch cost, both the symmetrical switch cost typically found in balanced bilinguals and the paradoxical asymmetry of switch costs typically found in unbalanced bilinguals. The IC model struggles to explain the symmetrical switch cost displayed by balanced bilinguals who switched between L1 and a weak L3 in Costa and Santesteban's (2004) study- though this is one-off finding which has not been replicated by a different author so far. There are also other experimental findings such as cross-language priming (Grainger & Frenke-Mestre, 1998) which may pose a problem for the IC model, because translation equivalents are reactively inhibited during the lexical selection process. Spreading activation accounts are able to explain cross language priming since activity is spread to the translation equivalent of the target word. They are also able to explain the symmetrical switch cost but not the paradoxical asymmetry of switch costs displayed by unbalanced bilinguals.

### ***Electrophysiological studies of task-switching***

A range of brain imaging techniques have been employed in the task switching literature to investigate pre- and post-stimulus effects. Neural signalling occurs via the generation of action potentials caused by the flow of charged particles across the neuronal membrane. The electrical activity of synchronously active neurons can be recorded at the scalp using the electroencephalogram (EEG). It is believed that much of the observed activity arises from cortical pyramidal cells which are aligned perpendicularly to the surface of the scalp (Dale & Sereno, 1993). Event-related potentials are epochs of EEG that are time locked to an event. They are regarded as manifestations of brain activity occurring in preparation for, or in response to, a discrete activity (Fabiani, Gratton & Coles., 2000). They have a superior temporal resolution but due to conduction of electrical activity through the brain, finding the neural source of the ERP is notoriously difficult. The energy demand of the electrochemical signals which underlie ERPs is met by an increased level of oxygenated blood to the area of active tissue. BOLD fMRI (Blood Oxygen Level Dependent Functional Magnetic Resonance Imaging) measures these changes in

the flow and volume of oxygenated blood in the brain. This hemodynamic response begins around one to two seconds after the eliciting electrical activity is detected by the EEG and it is also temporally extended over ~12-20 seconds. Since the haemodynamic response is slow and lags behind the eliciting electrical activity, fMRI's temporal resolution is relatively poor, but its spatial resolution is unrivalled among non-invasive brain-mapping techniques.

The temporal dynamics of fMRI mean that it is hard to differentiate between pre stimulus activity which reflects the preparation for a change of task, and post stimulus activity which reflects stimulus processing and response selection. In contrast, the very high time-resolution of EEG/ERPs makes this technique particularly well suited. A substantial corpus of task switching studies have measured ERP components which are thought to reflect reconfiguration processes in anticipation of a change of task (see Karayanidis, Jamadar, Ruge, Phillips, Heathcote, & Forstmann, 2010, for a review). Virtually all of these studies investigating pre-stimulus activity have reported a protracted posterior positivity (though see Astle, Jackson, & Swainson, 2008a, for a notable exception in one of the conditions of the experiment in which the tasks were spatially cued) from ~300ms after the response in an alternating runs paradigm or from ~400-500ms following presentation of the cue in task-cueing (e.g. Astle, Jackson & Swainson., 2006, 2008a, b; Hsieh & Chen, 2006; Karayanidis et al., 2003; Kieffaber & Hetrick, 2005; Moulden, Picton, Meiran, Stuss, Riera & Valdes-Sosa, 1998; Nicholson, Karayanidis, Poboka, Heathcote & Michie., 2005; Nicholson, Karayanidis, Bumak, Poboka & Michie, 2006a; Nicholson, Karayanidis, Davies & Michie, 2006b; Rushworth, Passingham & Nobre, 2002b; Rushworth, Passingham & Nobre, 2005; Swainson, Cunnington, Jackson, Rorden, Peters & Morris, 2003; Swainson, Jackson & Jackson, 2006; Tiegues, Snel, Kok, Plat & Ridderinkhof, 2007; Wylie, Javitt & Foxe, 2003). Kieffaber and Hetrick (2005) and Tiegues et al. (2007) have suggested that this positivity is a modulation of the P3b component of the ERP, perhaps reflecting working memory processes associated with updating the relevant task-set. Some of these studies also reported a switch induced anterior frontal negativity (Moulden et al., 1998; Wylie et al., 2003; Astle et al., 2006, 2008a, b; Gladwin, Lindsen & de Jong., 2006) which overlapped temporally with the posterior positivity. Two further switch induced components have been reported in the task switching literature. First, Rushworth et al. (2002b) reported a frontal positivity with an onset latency ~200-300ms after the cue which was believed to reflect a re-mapping of responses upon switching tasks. Second, Tiegues et al. (2006, 2007) reported a broadly distributed negativity with

a fronto-central topography which emerged around 800ms after the cue; Karayanidis et al. (2003) observed a similar negativity in their alternating runs study in the longest RSI condition and Astle et al.'s (2008b) negativity had a similar scalp distribution and duration in some conditions. This latter negativity generally appeared after the onset of the afore mentioned posterior positivity and may therefore reflect the active maintenance of the achieved state of preparation.

Lavric, Mizon & Monsell, (2008) investigated which (if any) of the components above reflected effective preparation for a task switch. Behaviourally, they reported a robust switch cost which reduced by around 50% from their short to long CSI. Switch vs. repeat differences in the ERP data emerged around 150ms into the cue interval in the form of a frontal positivity (cf. Rushworth et al., 2002b). Around 500ms after the cue a positivity emerged in central-posterior regions along with a negativity in the anterior regions. Because a temporal Principal Components Analysis found one principal component to capture both the posterior positivity and the anterior negativity, Lavric et al. referred to them collectively as the posterior positivity-anterior negativity effect (PP-AN). Previous analyses of RT distributions has shown the switch cost to be much smaller for trials with fast responses than trials with slow responses, consistent with effective preparation resulting in a small switch cost (Nieuwenhuis & Monsell, 2002). Lavric et al. (2008) have therefore analysed their ERP data as a function of RT distribution. PP-AN was very robust on the fast trials and nearly undetectable (during the CSI) on the slow trials. Intriguingly, when task preparation was inefficient (slow response trials) or was made difficult by the short CSI there were signs of the switch-induced posterior positivity from around 300ms *after* the stimulus. The amplitude of the PP-AN component was also found to be correlated with the RT RISC effect over subjects (see also Elchlepp, Lavric, Mizon & Monsell, 2012, for a correlational analysis of the experiment reported by Lavric et al., 2008). Lavric et al. (2008) concluded that PP-AN, is an EEG 'signature' of TSR – it is robust during the preparation interval when TSR is initiated effectively and is delayed and has a more variable onset when TSR is late (ineffective).

Although many ERP studies have had a strong focus on preparation for a switch (e.g. Astle et al., 2008a, b; Karayanidis et al., 2003; Elchlepp et al., 2012; Lavric et al., 2008; Tiegies et al., 2006; 2007), most/all of them have also reported the switch vs. repeat differences following stimulus onset. What tends to be found nearly universally is that the amplitudes for switch trials are more negative-going than those for repeat trials from ~200-300ms following

stimulus onset. Lavric and colleagues (Elchlepp et al., 2012; Lavric et al., 2008), who have performed detailed temporal PCA analyses of the post-stimulus switch negativity found it to be separable into three components – an earlier negativity with fronto-central distribution and two later posterior negativities, of which one may be what tends to be referred in the EEG/ERP literature as the P3b component. One of the difficulties of investigating the post-stimulus effects of switch is that they, particularly the earlier negativity, are contaminated by switch-repeat differences that start (or are caused by processing) in the preparation interval. One interpretation of the posterior negativity (the largest of the switch-induced post-stimulus effects) is that it may reflect conflict, or competition, from the previously but no longer relevant task set. Karayanidis et al. (2003) and Elchlepp et al. (2012) have tested this hypothesis using alternating runs and task-cueing, respectively. Both studies compared ‘bivalent’ stimuli (which afford responses both task) with ‘univalent’ stimuli (which afford responses in only one of the two tasks), on the premise that for univalent stimuli there should be no/little conflict from the irrelevant task. In both studies the posterior post-stimulus switch negativity was substantially attenuated in response to univalent stimuli relative to bivalent stimuli, but in neither study was it completely eliminated. Indirect support that the switch negativity may (at least in part) be reflect task set conflict also comes from a study by Elchlepp, Rumball & Lavric (2013), in which the authors examined the behavioural and ERP correlates of single task performance (odd/even digit classification) for stimuli that contained an irrelevant character that was previously (in other blocks and on the previous day) associated with another task. The presence of the character previously associated with another task resulted in a performance decrement and a posterior negativity with a similar time-course and scalp distribution to the posterior switch-induced negativity in task switching (note, however that there was no trial-to-trial switching in Elchlepp et al., 2013, and the negativity is not a switch vs. repeat effect, but a stimulus valence effect).

### ***Electrophysiological studies of language switching***

There is a much less substantial ERP literature on language switching. Most of these studies have investigated inhibitory mechanisms operating during lexical access in speech production. In a digit naming paradigm, Jackson, Swainson, Cunnington and Jackson (2001) asked bilinguals to name digits, while delaying the response until after the stimulus was removed from the screen. Their short stimulus duration trials (250ms) were used for the RT analysis and long stimulus

duration trials (1000ms) to analyse ERP data, so that the waveform was not contaminated by muscle artefact from the vocal response. They found a switch-induced frontal negativity emerging around 280ms after stimulus onset, reliable when switching from L1 into L2 but not vice versa. An independent component analysis suggested this frontal negativity originated from the same neural substrate as N2 which is associated with response inhibition during Go/No-Go paradigms (e.g. Falkenstein, Hoormann, & Hohnsbein, 1999). Jackson et al. (2001) concluded that this N2 modulation supported Green's (1998) IC model, reflecting the high levels of inhibition required to suppress L1 when switching into L2. Jackson et al. (2001) asked participants to withhold their response for 1000ms during the long interval trials used for ERP analysis so one cannot rule out the possibility that the N2 modulation may have reflected withholding the vocal response until it could be executed. There was another, later effect induced by switch: greater positivity at 350-700ms following the stimulus onset. Because this effect was not language specific and given its timing, the authors interpreted as a reflection of remapping of language-specific phonology to articulation.

In a receptive language switching study, Jackson, Swainson, Mullin, Cunnington and Jackson (2004) asked bilinguals to make an odd vs. even judgment to a small corpus of visually presented number words (one to four and seven to nine). Stimuli were presented in alternating runs of two trials per language; language was not cued except by the word itself; the RSI varied between 1.5 and 2.5 s. Jackson et al., reported a cost of switching for L1 but not for L2 in the RT analysis. The switch cost was greater for L1, but the authors noted that it was driven by a reaction time benefit for L1 repeat trials on which responses were substantially faster than on all the other types of trial. The electrophysiological analysis revealed an early switch induced positivity emerging over the fronto-central scalp ~250-350 ms, but this was not language specific. The authors interpreted as reflecting early semantic processing. There was a switch-induced posterior negativity between ~180ms and ~430ms which is reminiscent of post-stimulus negativities elicited by a task switch, though in Jackson et al. this effect was more right-lateralised. Finally, there was a switch-induced positivity over the right frontal regions around 416-660ms after stimulus onset. Noting the lack of an N2 modulation by switching, which they found in their earlier study that examined switching of language for output (Jackson et al., 2001, see above), the authors concluded that inhibition of the non-target language may not be exerted

in switching receptive language and that switch costs during receptive language tasks result from competition between the control mechanisms that map the bilingual lexicon onto responses.

Verhoef et al. (2009a) tested their L1-repeat benefit hypothesis in unbalanced bilinguals using a cued picture naming paradigm with two CSIs (750ms and 1500ms). Their theory postulated that the switch cost tends to be larger (in unbalanced bilinguals) in L1, not because of difficulties of overcoming inhibition on L1 switch trials but because L2 repeat trials are nearly as hard as L2 switch trials (due to competition from L1) – hence a disproportionately small switch cost in L2. Verhoef et al. (2009a) found that in their longer CSI, the switch cost was symmetrical. Given sufficient time to prepare, they suggested, participants applied a top down bias favouring lexical selection in the target language, leading to a symmetrical switch cost at the longer CSI. There was insufficient time to apply this bias before stimulus onset during the shorter CSI which led to a paradoxical asymmetry of switch costs, with participants taking longer to switch into L1 than into L2. If an endogenous, top down bias can manifest itself behaviourally, then it should also be apparent in the ERP data. They used N2 as a marker of reactive inhibition of the non-target language ('reactive' refers here to the fact that inhibition is exerted to reduce the interference from the non-target language). N2 had larger amplitude for long CSIs than short CSIs, in all conditions apart from L1 repeat where the amplitude was the same. Verhoef et al. (2009a) took this as evidence to support their L1-repeat benefit hypothesis, and suggested that the non-target language competes for selection on all trials except those on which L1 is repeated. If, as Verhoef et al. (2009a) suggested, participants apply a lexical bias during long CSIs one might assume that this would manifest during the ERP during preparation interval. It seems curious then that Verhoef et al. (2009a) chose not to analyse their ERPs in either of the CSIs. It is, of course, possible that participants begin to reactively inhibit the non-target language once the stimulus appears on the screen, and such inhibition may be reflected in the post-stimulus N2. If this is the case, it should be mainly the strength of the language rather than CSI (short vs. long) that modulates the magnitude of N2.

In a subsequent study, Verhoef et al. (2009b) investigated preparation for a language switch. Because this study is of direct relevance to one of the experiments in the current thesis (Experiment 4 in Chapter 2), it will be discussed at length in Chapter 2. Here I will only briefly outline the main design features and key findings of the study. Verhoef et al. (2009b) used virtually the same design as their other ERP study discussed above (Verhoef et al., 2009a),

except that there were two cues per language rather than one and only one CSI (750ms). The central finding of the ERP analysis, which was confined to the CSI, was that there did not seem to be a posterior positivity elicited by preparation for a language switch (of the kind observed in task switching), though preparation was not assessed behaviourally, because there was only one CSI. There was however a fronto-central negativity induced by switching in the late part of the CSI in Verhoef et al.'s ERPs – which was reminiscent of the negativities reported by task switching studies that used long CSIs (>1s) – along with an earlier posterior negativity that has not been reported in task switching. To my knowledge, there have not been other studies examining preparation for a language switch.

### *Aims of the current research*

The above review of the behavioural and electrophysiological studies of task switching as well as the theoretical accounts put forward in the two domains reveals a key difference in emphasis between the task switching and the language switching literatures. The task switching literature has been very much concerned with establishing the relative weight of endogenous (top-down) control and passive (associative and other) inertia, as sources of the switch cost. Consequently, the empirical study has been focused on isolation of effects of endogenous control, task-set inertia and associative history. Preparation effects provide arguably the ‘cleanest’ measure of endogenous control of task-set, because one would not expect changes in passive TSI elicited by the cue and the stimulus is not yet present. Consequently, there has been a very strong emphasis in task switching on preparatory processes.

The language switching literature has been concerned mostly with the competition between languages and how such competition is resolved, mainly as a function of proficiency/language dominance, hence the strong focus on the asymmetry of switch cost over languages. In stark contrast to the task switching literature, there has been precious little research in the language switching domain on isolating the contribution of endogenous control generally, and more specifically on preparation for a language switch. It is not clear whether either the behavioural (RISC effect) or the electrophysiological (switch-induced posterior positivity) correlates of preparation for a switch are at all present in language switching. Of the two language switching studies that have reported analyses of the RISC effect, one reported a

reduction in switch cost with increasing the CSI (Costa & Santesteban, 2004) and the other an increase in switch cost with increasing the CSI (Philipp, Gade, & Koch, 2007); both studies are discussed at length in Chapter 2. The only ERP study to date that investigated preparation for a language switch found no switch-related positivity in the preparation interval. With regard to ‘bottom-up’ factors that may influence competition in language selection, one that has been largely (or completely) neglected is the stimulus associative history. In task switching stimulus associative history has been reported to influence both the overall performance and the switch cost (see above).

In the research presented in the first part of this thesis I aimed to address this gap in the literature and document the empirical correlates of preparing for a language switch whilst being sensitive to key methodological developments in task switching over the last decade or so. I also intend to document the effects of stimulus associative history in language switching, which, to my knowledge, has not been done thus far.

## **Controlling speech production vs. comprehension: is there cross-talk of selection settings?**

The question of whether speech production and speech comprehension are tasks performed by a single pathway or by separate pathways is a complex issue that has been debated for some years within the monolingual literature. Much of the current evidence comes from patient data and empirical studies using neurologically normal monolinguals. Language selection in bilinguals has been largely overlooked in this area, yet it could prove valuable. One might consider two extremes of a continuum whereby access to the lexicon is via a single pathway which is shared by speech comprehension and speech production, or via two completely separate pathways.

So far in this introduction I have described expressive (output) language switching studies where participants are asked to overtly name digits (e.g. Jackson et al., 2001, 2004; Meuter & Allport, 1999) or pictures (e.g. Costa & Santesteban, 2004; Verhoef et al., 2009a,b), all of which have reported substantial switch costs. There have been several studies in which participants have been asked to switch their receptive (input) language (Caramazza & Brones, 1980; Dufour & Kroll, 1995; Eckhardt & Feldman, 1984; Jackson, et al. 2004; Thomas &

Allport, 2000; Von Studnitz & Green, 2002) and these have generally reported very small or no switch costs.

Von Studnitz and Green (2002) asked bilingual speakers to make an animate / inanimate judgment (mapped onto two button presses) in response to words presented visually in alternating L1-L2 runs. A list of 128 words were presented in the first half of the experiment and their translation equivalents presented in the second half of the experiment. Von Studnitz and Green (2002) did find a small switch cost, but it was limited to novel items presented in the first half of the experiment. The switch cost was also confined to those trials on which the response was the same as the previous trial. Task switching studies have also found that repeating the response made on the preceding trial improves performance on task repeat trials and hinders performance on task switch trials (e.g., Rogers & Monsell, 1995). Thus, the switch cost in this study seemed to be caused entirely to response repetition effects. The responses were non-linguistic (they were freshly learned category-to-button mappings) which means that language (lexical) selection could not be the source of the switch cost in this study.

In a lexical decision task, Thomas and Allport (2000) asked bilinguals to decide if a letter string was a word or non-word (lexical decision task). In one part of the experiment they were asked to decide if a letter string was a word in L<sub>x</sub> only, and thus class L<sub>y</sub> words as nonwords and the target language switched from L<sub>x</sub> to L<sub>y</sub>. In another part of the experiment participant's classified strings as words irrespective of language. Thomas and Allport (2000) reported a substantially larger switch cost when participants were asked to perform the lexical decision task in a particular language, than if lexical decision was not language-specific. There is no obvious need for a bilingual to bias input language because the stimulus automatically cues the language, which means that the competition that may arise early on in analysing the visual word form is rapidly resolved by the automatic activation of the target language. Hence, there must be some other source of the switch cost that is found in (some) receptive switching studies. Thomas and Allport (2002) proposed that these switch costs are caused by competition between the control structures, the language task schemas in Green's IC model (see first part of this introduction), which map lemmas to responses. Each language has its own task schema and these compete to control the bilingual lexico-semantic system. The switch cost may be a reflection of this competition between task schemas.

Jackson et al.'s (2004) study presented number words visually in either L1 or L2 and asked participants to decide if they were odd or even. The switch cost was larger (and statistically reliable only) for L1. The ERP results (already discussed in the first part of this Introduction) revealed a set of effects of switch that were distinct from those seen in the study by the same group that examined switching language for production (Jackson et al., 2001). According to inhibition models (e.g. Green, 1987), reading a word in one language activates the translation equivalent(s) in the bilinguals other language(s) and the non-target language is reactively inhibited in order to avoid unwanted lexical intrusions from the non-target language. Jackson et al., (2004) expected this reactive inhibition to be reflected as a modulation of N2. However, their receptive language paradigm did not exhibit frontal N2 modulation. The absence of N2 may indicate the existence of a lexical selection mechanism which is not language specific (c.f. Jackson et al., 2004), but one that lies somewhere outside the bilingual lexico-semantic system. Thomas and Allport (2000) had previously found evidence to support the idea of competition between the task-schemas that are language specific and Jackson et al. proposed that this might be the source of the switch cost they observed.

One can see the need for setting one's output language endogenously in order to select the appropriate language for speech, but there is no logical necessity to set the input language because it may be automatically cued by the stimulus' orthography or phonology. In fact one can think of situations in which strong top-down tuning for a particular input language may be disadvantageous – for instance, when one attempts to determine the language of the input. This raises the important, yet thus far unexplored, issue of whether in situations when one can benefit from selecting both the language for speech and tuning for a language for auditory comprehension, one can do so independently. In other words, one can ask whether language selection for input vs. output can be controlled with little/no cross-talk. There is a substantial body of literature on the relation between input and output pathways, especially on the relation between the input and output pathways for speech. In what follows I summarise what I found to be the most relevant and conclusive in this literature. Monsell (1987) evaluated the empirical evidence to examine the separability of pathways to speech production and comprehension and devised six models ranging from completely shared to completely independent pathways with varying degrees of overlap in between. The remainder of the introduction uses these models as a basic framework for evaluating the empirical evidence.

### ***The relation between input and output pathways for speech***

On the basis of the then-available evidence, Monsell (1987) outlined six possible models of relation between speech production and auditory comprehension: 1) separate; 2) separate with sublexical input-output links; 3) separate with sublexical input-output and output-input links; 4) common sublexical but separate lexical representations; 5) separate sublexical but common lexical representations; 6) common sublexical and lexical representations. There have been a small number of cases of *differential aphasia* reported in the literature which are relevant for deciding among these models. This disorder is characterised by different types of aphasia in a bilingual's different languages. For example, a patient may present with Broca's aphasia in the native L1 and Wernicke's aphasia in their second language. The first such case of differential aphasia was reported by Albert and Obler (1978). A young woman of 35 years, underwent surgery to remove a tumour in the posterior part of the left temporal lobe. She was a native speaker of Hungarian and learned French and English as a child, and later learned Hebrew as a young adult. A week and a half after the operation she presented with a differential aphasia. She exhibited a Broca's aphasia in Hebrew, being unable to speak it but able to comprehend it. She exhibited a Wernicke's aphasia in English, being able to speak it fluently but was not able to understand it. She displayed only mild deficits in Hungarian and French. Albert and Obler (1978) believed that this pattern of results was due to separable cerebral organisation of the patients languages.

A case of transitory aphasia was reported by Potzl in 1923 (c.f. Fabbro, 1999). An Austrian businessman spoke only Czech till he was 14 when he started to learn German. He suffered a stroke aged 60 which mainly affected the left supramarginal gyrus. His comprehension in Czech and German were both spared but he could no longer speak his second language; German. These two examples of bilingual aphasia suggest separability of the input and output pathways. Albert and Obler's (1978) patient's ability to speak in a language that she could not comprehend, and to comprehend a language that she does not speak would suggest that the input and output pathways are separate. If they were not, any language impairment present for speech production would be also present for speech comprehension. This evidence rules out models five and six.

There are many patients who do not show impairments which are specifically input related, or specifically output related in the way that classical aphasic patients do. Martin, Lesch

and Bartha (1999) studied a patient, MS, who had anomia following brain injury. Anomia is a condition which is characterised by difficulties naming objects. MS could speak clearly, and typically gave clear and correct descriptions for items that could not be named. This would suggest preserved access to semantic information held in the conceptual functional domain which somehow bypasses lexical selection. This would rule out models 5 and 6 which have a common lexical representations shared by input and output pathways.

The opposite pattern of impairment to MS, can be found in patients who have word meaning deafness. People with this condition present with a comprehension deficit which is confined to the auditory modality with written comprehension and speech production both preserved. Although first reported by Bramwell in 1897 (c.f. Franklin, Turner, Lambon Ralph, Morris & Bailey, 1996) the condition still remains rare. Kohn and Friedman (1986) discussed two patients, HN and LL, who were both unable to comprehend a spoken word but could do so once they themselves, had written it down. LL tended to regularise spellings of irregular words, spelling 'cough' as 'coff' which suggests a reliance on phonology whilst HN was able to correctly spell aurally presented irregular words indicating lexical access. This pattern might be explained by models three or four with lexical and sub-lexical links, though it is likely that the lexical links are damaged for LL.

Using the data from aphasic patients of both monolingual and bilingual backgrounds, one can see that the input and output routes cannot be completely shared. Evidence from anomia and word meaning deafness suggest that the two routes cannot be completely separate either. Further support for separate, but linked input and output pathways can be found in a series of experiments by Monsell and Banich (1982; c.f. Monsell, 1987) using neurologically normal individuals. Monsell and Banich (1982; c.f. Monsell, 1987) investigated the effects of perceptual and phonological priming by presenting sentences which did not have a final word (e.g. Swan lake is a famous - -). Participants were asked to perform one of six tasks, for example, participants might be asked to overtly name what they thought was the missing word or silently mouth the missing word. An auditory lexical decision task followed after 30s to 6 minutes after the initial experiment with the interval filled with other priming or lexical decision probe trials. Monsell and Banich (1982; c.f. Monsell, 1987) found all six sentence completion conditions primed related words in the subsequent lexical decision task. They believed these findings suggest that generating a word's phonology activates nodes in the lexicon. Interestingly, stronger

priming resulted from mouthing the missing word than from other phonology-generation tasks. If speech production without audible sound can prime the auditory lexical decision task, there must be a connection between the input and output lexicons

### *Aims of current research*

The evidence reviewed above suggests that the input and output pathways for speech are unlikely to be completely shared or completely separate. There must be links between certain parts of the model to account for the priming observed in Monsell and Banich's (c.f. Monsell, 1987) study, or for the ability of a brain damaged patients to repeat out loud a word that they cannot comprehend. Furthermore, the evidence also suggests reciprocal input-output links. However, there is little indication in the existing literature regarding bilinguals' ability to control language selection independently in the input and output pathways. I investigated this aspect of language selection by developing a paradigm that requires both speech and comprehension and combines that language switching at different time-scales for production and comprehension. My aim was to provide answers to a set of basic questions:

1. When a bilingual is set to speak in language x, what effect is there on comprehending in language y relative to language x.
2. Conversely, if one is set to comprehend in language x, how does this affect the relative naming performance in languages x and y?
3. Is there an asymmetry of cross-talk between the pathways, e.g. greater cross-talk from the output settings into the input settings than vice-versa?
4. Is there greater cross-talk in L2 than in L1 in unbalanced bilinguals?

## CHAPTER 2

# IS PREPARATION FOR A LANGUAGE SWITCH LIKE PREPARATION FOR A TASK SWITCH?

### Introduction

Inspired by the emergence and rapid growth of the literature on task switching, researchers interested in selection of language for production in bi/multilingual speakers have sought to identify empirical parallels between task switching and language switching (see Chapter 1). However, a key empirical phenomenon that has been extensively documented in task switching and has been largely neglected (and when not neglected, is controversial) in language switching is the reduction in switch cost with opportunity for (pre-stimulus) preparation. The present chapter contains three behavioural experiments and one ERP experiment that attempted to address this gap in the language switching literature. Before presenting these experiments, I will review the most relevant behavioural and electrophysiological research to date.

#### *Previous studies of preparation for a language switch*

The time taken to reconfigure the task set is one of three suggested sources of the task switch cost, the other two being task-set inertia (TSI) and associative retrieval (cf. Kiesel et al., 2010; Monsell, 2003; Vandierendonck et al., 2010). The reduction in switch cost (RISC) with increasing time for preparation is widely seen as an index of endogenous task-set reconfiguration (TSR, c.f. Rogers & Monsell, 1995; Monsell & Mizon, 2006). In their alternating runs paradigm, Rogers and Monsell (1995) found the task-switch cost to be reduced by about half when the preparation interval was increased from 150ms to 600ms; further increasing the preparation interval led to little extra reduction in switch cost. However, an important limitation of the alternating runs paradigm is that it cannot distinguish between the effects of active preparation and TSI of the switch cost.

A number of task switching studies have systematically varied the cue to stimulus interval (CSI), whilst keeping constant the response to stimulus interval (RSI). Two notable studies are those of Meiran (1996) and Monsell and Mizon (2006). Participants performed a location task in Meiran's (1996) study, with a constant RSI and a variable CSI. In his experiment 4 (see Chapter 1 for further details), Meiran found a reliable RISC effect. Monsell and Mizon (2006) found a robust RISC effect when the probability of a task switch was kept relatively low. In both of these studies and many others a residual cost of switching remained suggesting that only part of the switch cost can be eliminated endogenously. Nevertheless, Verbruggen et al. (2007) found that a combination of a long CSI and a short cue duration resulted in no statistically detectable switch cost (see also the long CSI condition in Astle et al., 2008b) – a result consistent with the 'intention activation' account by De Jong (2000), which treats the residual switch cost as arising from a mixture of trials on which advance TSR is initiated (hence no switch cost) and trials on which advance TSR is not initiated (hence a large switch cost). Accordingly, if one succeeds in getting the subject to initiate TSR on (nearly) all trials, then there should be no residual switch cost.

The RISC effect is a common finding in studies of task switching (cf. Kiesel et al., 2010; Vandierendonck et al., 2010), but in language switching it has not been documented as extensively. To my knowledge, only three studies have examined the RISC effect in language switching (Costa & Santesteban, 2004; Philipp et al., 2007; Verhoef et al., 2009), and their paradigms have not always followed the necessary rigors recommended in the task switching literature for avoiding well-known confounds. In a series of experiments, Costa and Santesteban (2004) investigated differences in performance between balanced and unbalanced bilingual speakers. Although the RISC effect was not one of the primary aims of their study, they reported an effect of CSI on the switch cost for a group balanced bilinguals. Subjects had to name pictures (10 pictures each presented 95 times) in one of two languages; in the first four experiments, the background colour of the picture (red or blue, one for each language) specified the naming language (thus CSI=0). The authors wondered whether simultaneous presentation of the cue and stimulus created a lexical bias which favoured the weaker language. They argued that if the cue was presented in advance of the stimulus participants would have no reason to bias selection towards the weaker language. Hence, in experiment five, the authors presented a separate cue (a red or a blue circle) and varied the CSI between subjects (500 or 800ms). The switch cost

reduced from 47ms (CSI=0ms) to 27ms (CSI=500ms) to 17ms (CSI=800ms). However, because the authors used one cue per language, one cannot be certain whether the observed switch cost was a cue switch or language switch cost, or a mixture (cf. Logan & Bundesen, 2003; Monsell & Mizon, 2006). Furthermore, the CSI=0ms condition came from a separate experiment in which the cues were different from those in the experiment that employed the CSIs of 500ms and 800ms (the colour of the background in the CSI=0ms condition vs. a coloured circle in the other conditions). Moreover, CSI was (perfectly) confounded with RSI – as the CSI increased the RSI increased too, so the reported RISC could be due, at least in part, to the increase in RSI.

In their experiment 1, Philipp et al., (2007) asked their participants to name the digits 1 to 9, in a language cueing paradigm with unpredictable switches between two of the three languages their participants spoke; there was one shape cue per language. All combinations of languages were tested separately, thus participants switched between L1 and L2, or L1 and L3, or L2 and L3. CSI varied within participants (100ms and 1000ms), and the RSI was constant. Philipp et al., (2007) found a reversed RISC effect in the RT data with an increase in the switch cost from 81ms at the shortest CSI to 111ms at the longest CSI.

Verhoef et al. (2009) asked unbalanced bilinguals to name 48 line drawings in either L1 or L2; switches were unpredictable and cued on each trial by the Dutch and British national flag. Two CSIs were used: 750ms and 1500ms; CSI was confounded with RSI. The authors reported no statistical analysis of the RISC effect; numerically, there was a reduction in the magnitude of the switch cost for L1 from 57ms in the CSI=750ms condition to ~31ms in the CSI=1500ms condition. For L2 the switch cost changed only negligibly from the short (34ms) to the long (~31ms) CSI. Thus (besides the confounds of language change with task change and CSI with RSI) it is not clear whether the modest RISC effect of ~15ms (pulling over L1 and L2) was statistically significant. Because the shorter of the two CSIs was rather long, the RISC effect may have been underestimated. Verhoef et al. (2009) also acquired brain potentials, but unfortunately, they have not reported an analysis of ERPs acquired during either of the two CSIs, only an analysis of ERPs time-locked to the stimulus (whose results are described in Chapter 1).

The same group (Verhoef et al., 2009b) have run another language switching study in which they did report the analysis of ERPs time-locked to the language cue. The paradigm and stimuli were the same as in the other study (Verhoef et al., 2009) except that there was only one CSI of 750ms, the cues were coloured rectangles rather than national flags and there were two

cues per task: to unconfound language and cue change the cue changed on every trial. Verhoef et al. (2009b) expected to find in the late part of the preparation interval a switch-induced deflection of positive polarity and parietal scalp distribution (referred to in Chapter 1 as the switch-induced ‘posterior positivity’; Verhoef et al. labelled it ‘P3b’). To their surprise, the investigators did not find a switch-induced posterior positivity. Instead, their analysis revealed a relatively brief switch-related posterior negativity from 200ms to 350ms for L2, but not L1, and a more protracted, longer-latency, switch-induced fronto-central negativity from about 350ms onwards. Verhoef et al. interpreted their earlier effect (the posterior negativity) as reflecting disengaging the now-irrelevant language during a switch, a task supposedly more difficult for L2 than L1 (as their bilingual participants were unbalanced – they were less fluent in L2 than L1). The fronto-central negativity was proposed to reflect the initiation of the currently relevant language.

Verhoef et al. (2009b) suggested three possible reasons for the differences between electrophysiological correlates of preparation for a task switch vs. language switch, especially with regard to the absence of the switch-related posterior positivity in their ERP data. First, they pointed to the fact that in some task-switching ERP studies the probability of a switch was lower than that of a repeat (e.g. Lavric et al., 2008), whereas in their paradigm switches and repeats are equiprobable. However, the majority of ERP studies to date that used task-cueing have, in fact, used designs in which switches and repeats are equiprobable (e.g. Astle et al., 2008b; Nicholson et al., 2006). Second, Verhoef et al. point out that task-switching paradigms have tended to use arbitrary (recently learned) responses, whereas switching languages for production relies on naming using extensively pre-learned (‘natural’, Verhoef et al.’ term) responses. Indeed, I am not aware of any published task-switching study that used non-arbitrary responses; however, an experiment in our laboratory (Elchlepp, Monsell & Lavric, under review) examined task switching between symmetry judgements and word reading identified a robust switch-induced posterior positivity during the CSI on the switch-to-reading trials (which use non-arbitrary responses). Third, Verhoef et al. mentioned the fact that in most task-switching studies responses are shared between tasks (and stimuli), whereas in switching languages for production responses are unique to languages and stimuli. There has been some evidence in task-switching that the posterior positivity is indeed reduced in duration when the response sets of the tasks do not overlap (Astle et al., 2008b).

The differences between the ERP correlates of preparing for a language switch reported by Verhoef et al. (2009b) and those of preparing for a task switch documented previously (see Karayanidis et al., 2010, for a review) and Verhoef et al.'s reasoning regarding the absence of a language switch-related posterior positivity are intriguing, because they contradict the widespread assumption that control processes involved in language selection overlap with those involved in task selection (e.g. Green, 1998; Philipp et al., 2007; Philipp & Koch, 2009). However, a careful inspection of Verhoef et al.'s grand-average ERPs shows that there may have been a language switch-related positivity that may have not reached statistical significance. Furthermore, the later of the two effects identified by Verhoef et al. in the preparation interval (the fronto-central negativity) is very similar to fronto-central negativities reported in a number of task-switching studies that used long (>1s) preparation intervals (e.g., Astle et al., 2008b; Tieges et al., 2007). Thus, perhaps the conclusion that the brain potential correlates of preparing for a language switch are different from those of preparing for a task switch is premature – particularly if one also considers one important design limitation of Verhoef et al.'s (2009b) study – the absence of a measure of the RISC effect (due to the use of a single CSI condition). Indeed, preparation for a task-switch has been argued to be endogenous, voluntary (Rogers & Monsell, 1995; De Jong, 2000; Nieuwenhuis & Monsell, 2003) and there are conditions in which the RISC effect does not materialise in task-switching (e.g. the random RSI condition in Rogers & Monsell, 1995). Thus it is conceivable that Verhoef et al.'s participants were not preparing as much or as effectively as the researchers assumed they were – and there is no performance measure to assess that.

### ***Present investigation***

I discussed four studies that examined preparation for switch of language for production. Of the three behavioural experiments, only one reported a statistically significant RISC effect (Costa & Santesteban, 2004) – however this study suffers from serious methodological drawbacks. First, in this study (and the other two by Philipp et al., 2007, and Verhoef et al., 2009) language change and cue change were confounded. In the task switching literature, it has been shown that the cue change effects can contribute very substantially to the switch cost (cf. Logan & Bundesen, 2003; Monsell & Mizon, 2006) and that increases the preparation interval modulates (reduces) the cue

change cost (Mayr & Kliegl, 2003). Second, the different CSI conditions in Costa & Santesteban (2004) used different cues. Third, the effect of CSI on the switch cost was confounded with that of RSI – both have been shown to modulate the task switch cost (e.g. Meiran, 1996).

It would seem that the language switching literature has lagged behind the methodological developments in task switching. The following experiments are but a small step towards rectifying this: they use an optimised paradigm that addresses the design shortcomings of the language switching experiments discussed above. Using a variant of this paradigm, the last of these experiments (Experiment 4) addresses the issue of the (non)correspondence of brain potential correlates of preparation for a language switch vs. preparation for a task switch. Previous work in our laboratory (Lavric, personal communication) has shown large and early-onset artifacts induced by speech in the EEG acquired in response to stimuli that require vocal responses. Indeed in one study that examined the post-stimulus ERPs in switching language for output subjects were required to respond after a delay to prevent contamination of ERPs with speech-related artifacts (Jackson et al., 2001). However, I considered it critical to obtain a performance measure of preparation (the RISC effect); indeed one crucial limitation Verhoef et al.'s (2009b) ERP study of preparation for a language switch was that it did not obtain such a behavioural measure (see discussion above). I therefore required participants in the ERP experiment to name the stimulus as soon as they saw it and confined the EEG analyses to the ERPs time-locked to the cue onset in the long CSI condition as this should not be contaminated with speech artifact.

The experiments in this chapter also address two other issues that, to my knowledge, have not been previously examined in the language switching literature, though both have been examined in task switching. One of them concerns the effectiveness of the task cue and the relationship between the semantic transparency of the cue and linguistic self-instruction as an integral part of preparation. In task switching, verbal cues have shown to be more effective at eliciting the TSR processes required by a switch (an issue considered at length in Chapter 1). Language switching offers a unique opportunity for examining cue effectiveness, because one can use cues that are likely to be more effective than task cues can ever be. Consider the name of the language spoken in that language as a language cue: not only it is semantically transparent, but it is also extensively pre-learned (over many years prior to the experiment), and it is part of the language that must be selected on a given trial (it has phonological, orthographic, lexical

and semantic associations with words in the respective language). I will explore such ‘super-cues’ and contrast them to less transparent and less familiar cues.

Finally, I will also explore the effect of stimulus-language associations on performance in general and on the switch cost in particular. There is a literature in task switching (reviewed in Chapter 1) on the contribution of stimulus-task associations to the task switch cost. As far as I am aware, the role of stimulus-language associations in switching language for production has not been examined thus far.

The last experiment in this chapter (Experiment 4) is presented in a different format from the preceding experiments: as a manuscript prepared for submission for publication in a peer-reviewed journal (though it has not yet been submitted). The target article type is limited to 2500 words, hence the relatively brief discussion – however, I discuss this experiment at length in General Discussion. Since the manuscript has several authors (whose contribution I acknowledge in the Declaration), the exposition is from the first person plural, rather than first person singular. Because it has to function as a stand-alone paper, it makes no references to other parts of the thesis and contains some (relatively minor) repetition of themes already introduced in the preceding parts of the thesis (this introduction and Chapter 1).

# EXPERIMENT ONE

## TESTING A LANGUAGE-CUEING PARADIGM OPTIMISED FOR INVESTIGATING THE REDUCTION IN THE LANGUAGE SWITCH COST WITH PREPARATION

### Introduction

The current experiment aimed to develop a methodologically optimised paradigm which controls for, and eliminates (where possible), those confounds that have limited the conclusiveness of previous research: confounding the effects of language change with those of cue change (a drawback in Costa & Santesteban, 2004; Philpp et al., 2007; Verhoef et al., 2009); confounding the effects of preparation with those of decay of task-set inertia (a limitation in Costa & Santesteban, 2004; Verhoef et al., 2009; Verhoef et al., 2009b). The experiment uses a language-cueing paradigm: the language on each trial was unpredictable and had to be specified by a language cue. Four cue-stimulus intervals (CSIs) were used to capture both the potential reduction in switch cost with greater opportunity for preparation and the asymptotic (residual) switch cost. Unbalanced English (L1)-French (L2) bilinguals were presented with black and white line drawings and asked to overtly name them. To avoid confounding language change and cue change the current study used two picture cues per language. The response-stimulus interval was held constant so as to avoid confounding preparation effects with possible effects of passive dissipation of TSI. Verbruggen et al. (2007) found that presenting the cue only briefly (64ms) within the CSI eliminated the statistically detectable residual switch cost (see Chapter 1). They argued that participants were forced to process the cue quickly which encouraged effective preparation. In the current experiment, I manipulated cue duration to examine whether the briefer cue results in greater RISC (and possibly no residual switch cost) in language switching too. For half of the trials the cue remained on the screen for the entire trial with the picture to be named subsequently superimposed on the cue, for the other half of the trials the cue appeared for only 100ms of the CSI with the remainder of the CSI filled with a blank screen (see Fig. 2.1). The

unbalanced bilinguals were expected to show a robust, and paradoxically asymmetric, switch cost. Based on the task switching literature and on the reports of Costa and Santesteban (2004) and Verhoef et al. (2009), it was predicted that the magnitude of this switch cost would reduce over successively longer CSIs.

## **Method**

### ***Participants***

Sixteen (11 female, 5 male) English (L1) - French (L2) bilingual speakers, aged between 19 and 22 (mean 21) gave informed written consent to take part in this experiment. Each was paid £7 per hour. Participants reported normal, or corrected to normal vision. They were asked to complete a French language experience questionnaire (Appendix 1) before they took part in order to assess their suitability for the experiment. All of the participants had grown up in British homes but had spent at least one year in a French language country (mean 1.12 years, range 1-2). Participants had started to learn French at school at the mean age of 10.76 years (range 9-11). All participants were studying French at Exeter University at the time of testing and during term time they spoke French on a daily basis. Participants rated themselves according to how well they thought they performed on four key areas of language; speech, reading, writing and listening. Bilinguals scored no more than 8, and no less than 6, out of 10 on any of these components. The mean scores (out of 10) were: speech 7.53; reading, 7.18; writing, 7.12; listening, 7.41. Given these results (in particular the self-rated proficiency and the fact that no participant spent more than 2 years in an L2-speaking country, the bilinguals in this experiment were deemed unbalanced (superior proficiency in L1).

### ***Materials***

One hundred and twenty pictures were selected from the International Picture Naming Project corpus (Bates et al., 2003; <http://crl.ucsd.edu/~aszekely/ipnp/1stimuli.html> [Appendix 2]). Stimuli were presented in 24 blocks, each consisting of 48 experimental trials plus one filler trial. The first trial of a block cannot be classified as a switch or repeat trial and was therefore discarded from the analysis. A filler item was used in this position so as to avoid loss of

experimental items. Thus, the 96 experimental stimuli were presented 12 times each (1176 experimental trials); 24 filler stimuli were each presented once. Experimental stimuli were matched across languages for frequency per million In English using the CELEX database (Baayen, Piepenbrock, & van Rihn, 1993) and in French using the Lexique website ([www.lexique.org](http://www.lexique.org)): there was no reliable difference in the logarithmic frequency per million between English words and their French translations (see Table 2.1;  $t(190) < 1$ ,  $p = n.s.$ ). In a series of experiments using bilingual speakers, Damian, et al., (2010) found that word length did not affect speech onset, therefore the current experiment did not match stimuli for word length either within, or across languages.

	<b>English</b>	<b>French</b>
	Log frequency per million	Log frequency per million
<b>Mean</b>	0.85	0.81
<b>Standard Deviation</b>	0.69	0.64

**Table 2.1:** Mean frequency per million and standard deviation for the stimuli.

The 96 experimental stimuli were randomly divided into two equal lists of 48 items, each list was presented on alternate blocks to ensure a minimum of 49 trials between successive presentations of each image. The stimuli within each list remained the same for all participants and list order was counterbalanced such that half of the participants started with list one and the other with list two. Half of the participants named a particular picture in L1 on its first occurrence and the other half named it in L2. There were two types of trial within this paradigm; successive pictures could be named in the same language as on the previous trial (repeat) or they could be named in the other language (switch trial). Language switched unpredictably with a probability of 1/3. To avoid confounding cue change with language change, the cue changed on each trial even if the language did not. To make this possible, two visual cues per language were used: the Union Flag and a map of the UK, the French Tricolour and a map of France. On half of the trials the cue remained on the screen for the entire trial with the picture to be named appearing on top of the cue ('cue on' condition) for the other half of trials the cue was present on

the screen for only 100ms of the cue to stimulus interval (CSI) ('cue off' condition). The cue on/off variable was held constant within a block but alternated over successive blocks. Participants were reminded at the beginning of each block whether the cue would be present throughout the trial or removed after 100ms. Four CSIs were used: 100ms, 350ms, 750ms, 1500ms. Each CSI was presented an equal number of times throughout the experiment on switch and repeat trials, and for each language; the CSI varied within a block. After the participant responded, a blank screen appeared which varied in duration so as to keep a constant RSI of 2160ms.

### *Apparatus*

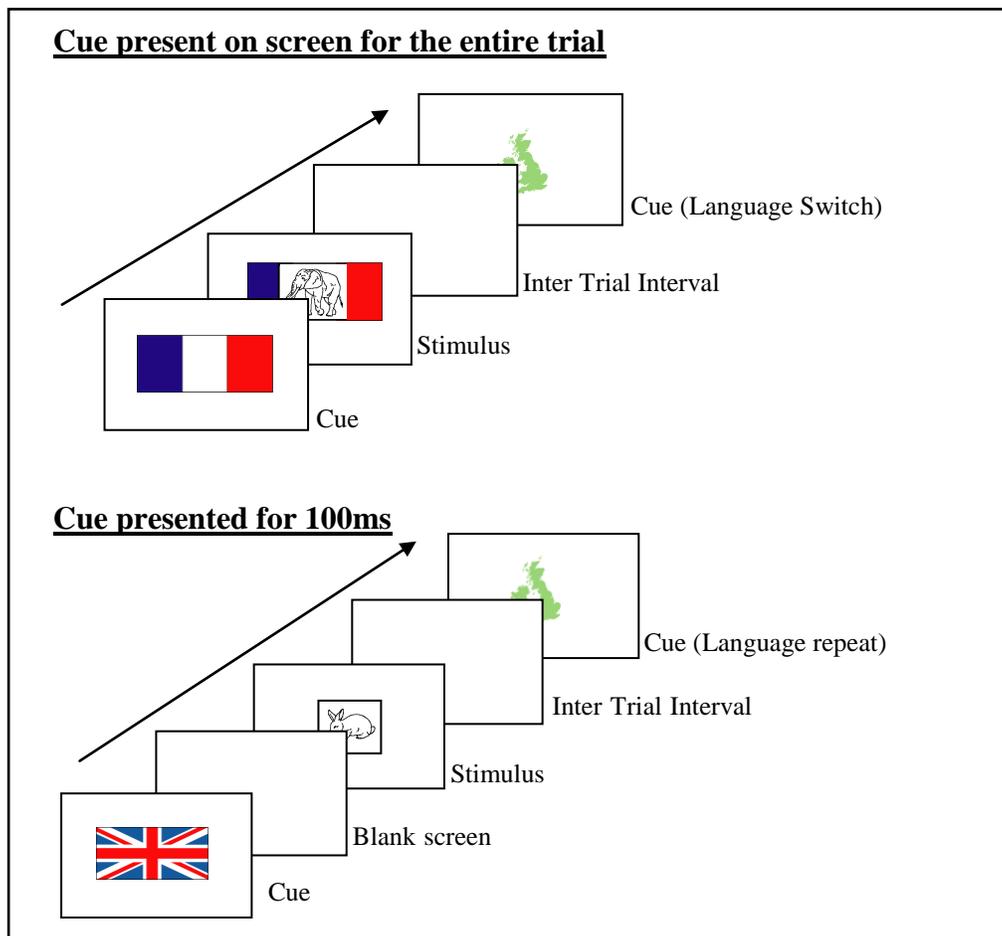
The experiment was designed and stimuli presented using E-Prime (Psychology Software Tools, Sharpsburg, PA, USA). Participants were tested in a quiet room. Stimuli were presented on a 17" colour monitor and naming responses detected via a microphone and a voice key (Psychology Software Tools, Sharpsburg, PA, USA).

### *Procedure*

Before the experiment, participants were familiarised with the cues and the picture stimuli. They were given a few minutes to look through a printed list consisting of all pictures with the names of the pictures printed in L1 and L2 underneath. This was followed by a practice phase, during which participants sat in front of a computer screen and were asked to name each picture in L1 (English). Subsequently, they were shown the pictures a second time and were asked to name each of them in L2 (French). Participants were shown each picture for a third time during a switching practice which had the same design as the paradigm used for testing. It was ensured that there were no pictures for which more than one error was made during practice, otherwise the practice session was repeated. Figure 2.1 shows a typical trial. A fixation cross appeared on the screen prior to the cue, the fixation cross was replaced by a stimulus that remained on the screen for 3s or until the participant responded. A blank screen of varying length appeared after the stimulus ensuring a constant RSI. Participants were asked to respond as quickly as possible whilst maintaining avoiding errors.

## *Analysis*

The first trial of each block was removed from the analysis, as were trials following an error because neither could be classified as a switch or repeat trial. Trials were classified as errors if the participant named the picture in the wrong language even if they switched to the correct language part way through naming, if they used the wrong word in the right language, or failed to make a response. Trials were also removed from the analysis if naming latencies were less than 200ms or longer than 3s. Response times (RT) and error rates were analysed by means of repeated measures ANOVAs with the factors language, transition (switch vs. repeat), CSI, cue (map vs. flag) and cue duration (cue on throughout the trial vs. cue on for 100ms).

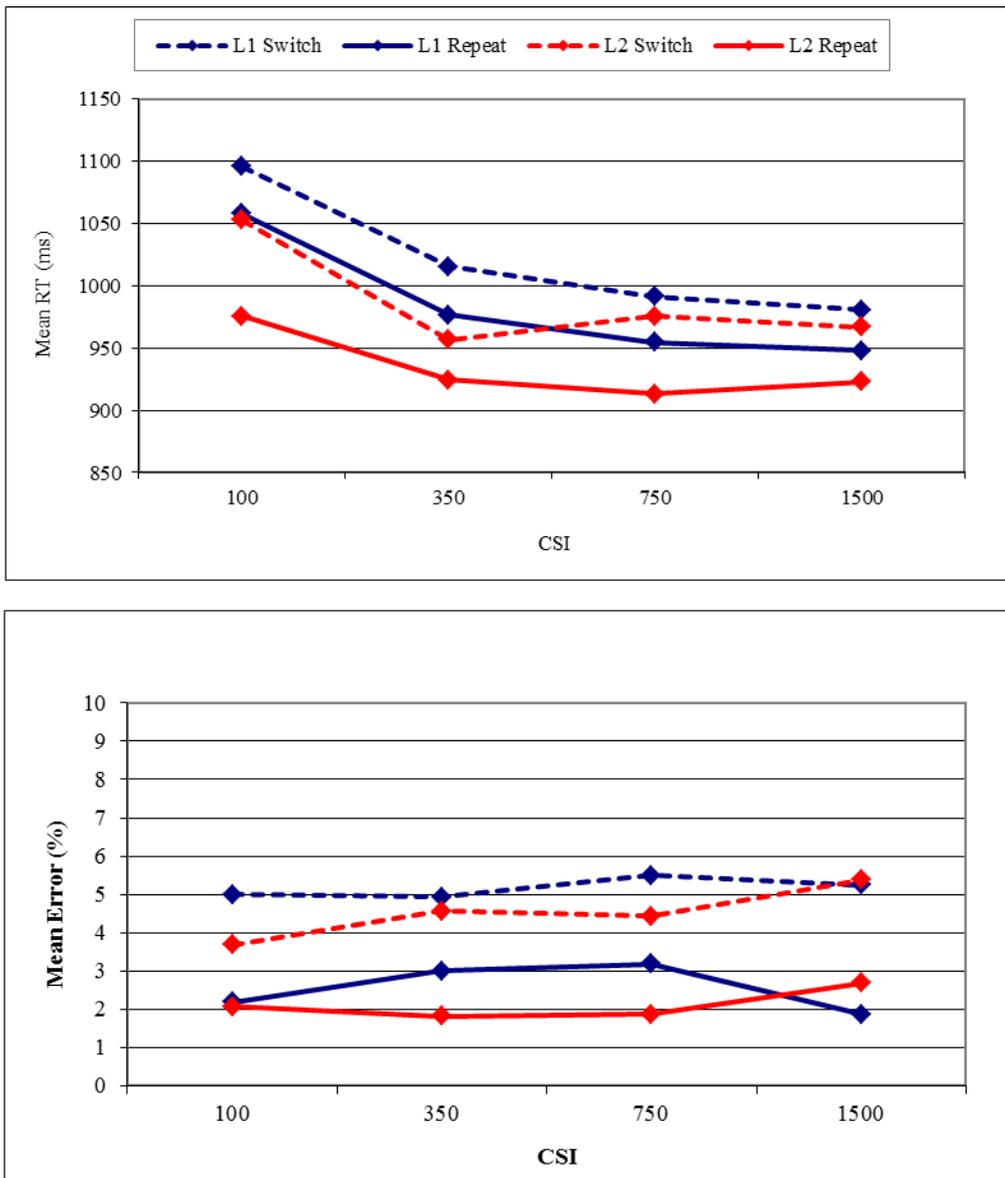


**Figure 2.1.** Time-course of a typical trial. On half of the trials the cue remained on the screen throughout (top), on the other half the cue remained for 100ms with a blank screen for remainder of the CSI (bottom).

# Results

## *Effects of language*

Figure 2.2 shows the mean naming latencies and error rates. The omnibus analysis (which included all of the above factors), showed a reliable main effect of language with pictures named 43ms faster in L2 (961ms) than in L1 (1002ms),  $F(1,15)=7.96$ ,  $p=0.013$ . Participants made similar numbers of errors in L1 (3.9%) and L2 (3.4%), a difference that did not approach statistical significance,  $F(1,15)=1.41$ ,  $p=0.253$ .



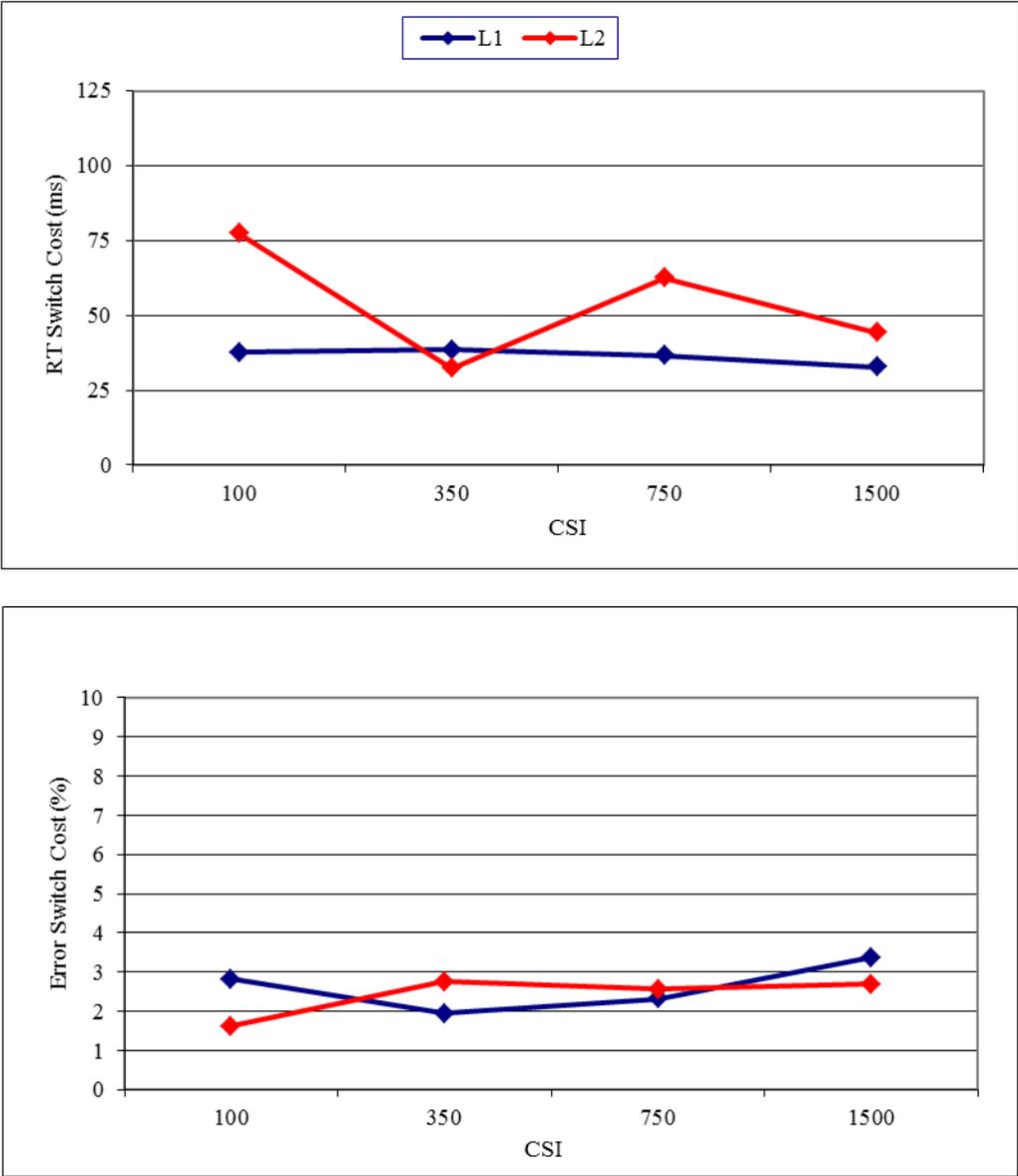
**Figure 2.2.** Mean naming latencies (top) and error rates (bottom) plotted as a function of language, transition and CSI.

There was a reliable interaction in the response latencies involving CSI with language,  $F(3,45)=3.76$ ,  $p=0.017$ . Further analysis revealed that the magnitude of the difference between L1 and L2 naming latencies reduced with increasing CSI; from 60ms at the 100ms CSI to only 20ms at the 1500ms CSI.

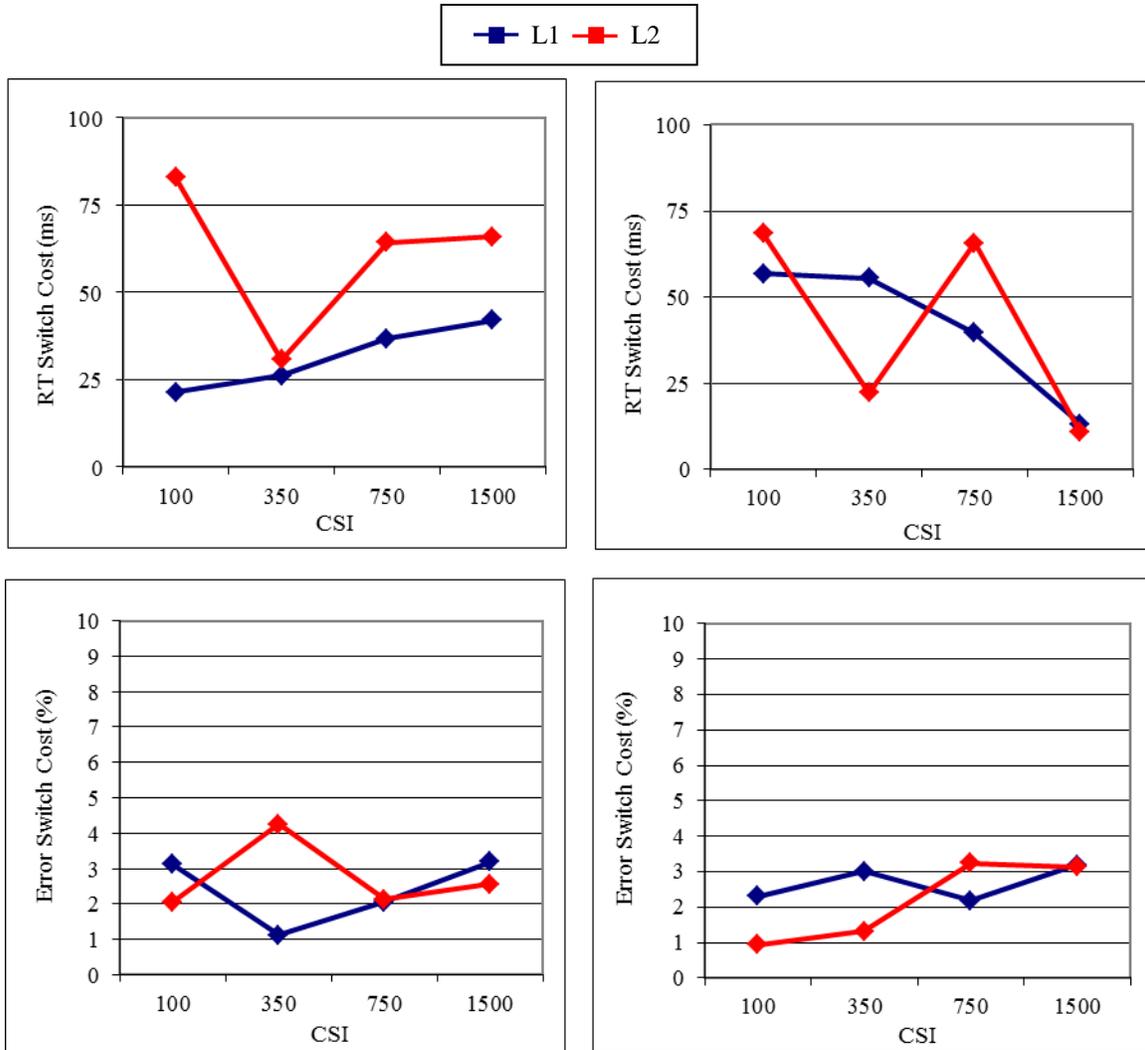
### *Effects of switch*

The omnibus analysis revealed a reliable switch cost (main effect of switch) for both RTs,  $F(1,15)=48.04$ ,  $p<0.001$  and errors,  $F(1,15)=27.49$ ,  $p<0.001$  (see Fig. 2.3). Numerically, it took slightly longer for participants to switch from L1 into L2 (53ms) than from L2 into L1 (36ms) but this switch by language interaction was not significant,  $F(1,15)=1.33$ ,  $p=0.268$ ). The switch cost for the errors was very similar in the two languages: L1 to L2 (2.5%), L2 to L1 (2.3%),  $F(1,15)=0.15$ ,  $p=0.707$ .

One of the key reasons for running this study was to examine whether the language switch cost reduced with preparation in the same way the task switch cost does. There was no reliable reduction in switch cost (RISC) in the omnibus analysis for the RT or the errors (RT,  $F(3,45)=0.99$ ,  $p=0.336$ ; error,  $F(3,45)=0.35$ ,  $p=0.562$ ). However, given the expectation that shortening the cue duration may encourage an earlier onset of reconfiguration of language selection, I also analysed the cue-off condition separately. Analysis of the cue off data revealed a tendency toward a RISC effect, as indicated by a reliable linear trend for the CSI by transition interaction ( $F(1,15)=5.58$ ,  $p=0.032$ ), reflecting linear reduction in switch cost with increasing CSI for the cue-off trials.



**Figure 2.3.** Mean switch cost as a function of CSI and language.



**Figure 2.4.** Switch cost for the cue on condition (left) and cue off condition (right) as a function of CSI and language.

### *Effects of cue*

To unconfound task change from cue change, the current paradigm used two cues per language; the map and the flag of each country. There was little difference in naming latencies between the map (985ms) and the flag (978ms) cues,  $F(1,15)=1.10$ ,  $p=0.310$ , but participants made more errors on the trials cued by the map (4.1%) than the flag (3.1%),  $F(1,15)=5.35$ ,  $p=0.035$ . There was a highly reliable main effect of cue duration in the omnibus RT analysis,  $F(1,15)=14.39$ ,  $p=0.002$ , reflecting the fact that participants named pictures more quickly in the cue off condition

(961ms) than in the cue on condition (1003ms). A reliable interaction involving cue duration with CSI indicated that the magnitude of the difference in naming latencies between the cue on and the cue off conditions increased when more time was available to prepare, from 18ms at the 100ms CSI to 76ms at the 1500ms CSI,  $F(3,45)=3.86$ ,  $p=0.017$ . There was little difference in the numbers of errors made between the two cue durations,  $F(1,15)=0.01$ ,  $p=0.957$ .

There was also a reliable interaction in the RT data involving cue, cue duration and transition,  $F(1,15)=4.58$ ,  $p=0.049$ , reflecting the observation that for the map cue the switch cost was smaller in the cue off condition than the cue on condition, whereas the reverse was the case for the flag cue.

### *Other effects*

Participants named pictures more quickly as the CSI increased,  $F(3,45)=29.72$ ,  $p<0.001$ . There was little effect of CSI on the errors,  $F(3,45)=1.0$ ,  $p=0.404$ .

### *Effects of stimulus associative history*

Pictures were named in either L1 or L2 with at least 49 intervening trials between successive presentations of the same item. An analysis was carried out to investigate whether the language that was last used to name a particular item affected responses on the current trial. Data were broken down according to whether the picture was last named using the same language as the current trial ( $L_x \rightarrow L_x$ ) or in the bilingual's other language ( $L_y \rightarrow L_x$ ).

Pictures were named 18ms more quickly if it was named in the same language as the previous encounter (970ms) than in the bilingual's other language (988ms)  $F(1,15)=4.50$ ,  $p=0.051$ . There was little difference in error rates between naming in the same language (4%) or the bilinguals other language (4.1%),  $F(1,15)=0.454$ ,  $p=0.510$ . The two way interaction involving previous naming language and current naming language was not reliable which indicates L1 and L2 both benefited from seeing the item in the same language as the previous encounter,  $F(1,15)=3.2$ ,  $p=0.093$ .

There was no difference in the magnitude of the switch cost for items that were named in the same language on their previous encounter (40ms) than in the bilinguals other language (40ms). Numerically, the error switch cost for items named in a different language than the

previous encounter was 2.9% and same language encounter was slightly higher at 3.5%, a difference that did not approach significance,  $F(1,15)=0.397$ ,  $p=0.538$ .

## **Discussion**

The current experiment was conducted in English-French bilinguals to investigate the effect of preparation on the cost of switching languages. Participants were asked to name simple line drawings in an unpredictable language-cueing paradigm. This experiment replicated some key findings from the language switching literature. Response latencies displayed a paradoxical language effect with participants naming pictures more quickly in L2 than in their native language. Although this might seem counterintuitive, the paradoxical language effect is very common (e.g. Christoffels, Firk, & Schiller, 2007; Costa & Santesteban, 2004; Jackson et al., 2001; Kroll, Bobb, & Wodniecka, 2006; Verhoef et al., 2009). Because it is only found in a mixed-language context, Kroll et al., (2006) suggested that it reflects a global, experiment-wise, lexical selection bias in favour of L2. The fact that this paradoxical language asymmetry is found even for balanced bilinguals and even in the absence of an asymmetry of language switch costs (e.g. Costa et al., 2006; Gollan & Ferreira, 2009), is seen as an indication that the bias does not reflect the relative strength of L1 and L2, but is motivated by the way the participant perceives the aims of the experiment (e.g., non-native speakers of French may assume the experiment is primarily about their proficiency in French).

In the language switching literature one tends to find reports of paradoxically asymmetric switch costs when the languages are of unequal strength, though this is not universally so (cf. Verhoef et al., 2009b). There was no suggestion of paradoxical asymmetry in these data. Because the proficiency questionnaire was based on self-assessment, it is possible that some of our more modest participants were more fluent than they reported themselves to be, leading to a pattern of results more consistent with balanced bilinguals.

The purpose of the experiment was to develop a methodologically optimised paradigm with which to explore the RISC effect in language switching. Although the switch by CSI interaction was not statistically significant, the linear component of this interaction was reliable for the cue-off condition, indicating that the switch cost did reduce linearly with increasing CSI for trials on which the cue was only presented briefly. The fact that we only observed a RISC

effect in the cue-off condition together with faster naming latencies in this condition confirmed our expectation (based on previous research in task-switching by Verbruggen et al., 2007) that removing the cue from the display encourage more rapid processing of the cue allowing for the reconfiguration of language selection to start earlier in the preparation interval. There was also some evidence that the benefit to performance in the cue-off condition was greater for the map cue (though this did not interact with the RISC effect, only with switch), possibly because the iconic memory (persistence) for the shape of the map when it is no longer presented may be superior to the iconic memory for multi-coloured flag.

A further issue that was examined in this experiment is the effect of stimulus associative history on performance in general and on switch cost in particular. As already discussed in the introduction for the current chapter (and more at length in the Chapter 1), in the task switching literature there have been several reports of stimulus-task bindings influencing RTs, particularly on switch trials leading, for example, to larger switch costs for items that have been previously encountered in the context of the competing task (e.g. Waszak et al., 2003). It was interesting to examine whether similar (stimulus-language) associations form in language switching and whether they influence performance and switch costs. Our sequence structure ensured that there were a minimum of 49 trials between successive presentations of the same item, hence RT and errors could be analysed according to whether the picture was last named using the same language as the current trial ( $L_x \rightarrow L_x$ ) or in the other language ( $L_y \rightarrow L_x$ ). Associative history had some effect on performance: responses were faster and more accurate on trials where the picture was named in the same language as on the previous encounter. With regard to the crucial question of whether associative history impacted on the switch cost, the answer is negative: there was no statistically detectable difference in switch cost between stimuli for which the language on the previous encounter was different vs. the same as on the current trial.

In the current study CSI was varied over trials and as a result participants did not know how long they had to prepare from one trial to the next. There have been mixed findings with the task switching literature as to whether blocked or trial-to-trial variable CSIs provide the best conditions for effective preparation for a change of task. In their alternating runs paradigm, Rogers and Monsell (1995) found no RISC effect when the preparation interval varied on a trial-to-trial basis, but a robust effect when the preparation interval varied over blocks and its length was communicated to participants before each block. This led the authors to conclude that the

uncertainty with regard to the time available for preparation is not conducive to advance task-set reconfiguration. However, subsequently Monsell and Mizon (2006) did find a robust RISC effect in blocks where the preparation interval varied from trial to trial. It must be noted that in the latter example not only the preparation interval, but task switches were unpredictable (the study used task cueing), whereas in Rogers and Monsell's (1995) alternating runs paradigm the task switches were predictable, which, when combined with unpredictable response-stimulus intervals, may have led to some kind of 'dissonance'. In the next experiment I will explore whether having a more predictable preparation interval (by varying CSIs over blocks) might reveal the RISC effect more clearly in language switching.

## **EXPERIMENT TWO**

### **AN INVESTIGATION OF THE REDUCTION IN THE LANGUAGE SWITCH COST IN UNBALANCED BILINGUALS**

#### **Introduction**

In Experiment 2, I sought to further optimise the paradigm in order to examine the reduction in the language switch cost with preparation. First, it is possible that unpredictable preparation intervals discouraged participants from preparing for a language switch (see Experiment 1, Discussion); hence the CSI is blocked in the current experiment, rather than variable over trials as it was in Experiment 1. Second, Experiment 2 examined the possibility that language cues that are more semantically transparent may be more conducive to preparation – indeed in the task switching literature there is some evidence that transparent task cues result in smaller switch costs and, sometimes, superior RISC effect compared to cues that are more opaque with regard to the meaning of the task (see Chapter 1). In the context of language switching, it is difficult to come up with highly transparent non-verbal cues; on the other hand, it seems sub-optimal to use visually presented word cues in a picture naming experiment. Hence, I decided to use auditory cues instead, which can vary in transparency (e.g. name of the language vs. a sound or tune. The transient nature of auditory cues may be a further benefit in the context of the findings of Experiment 1 that visual cues of shorter duration resulted in better performance and were the only cues for which a RISC effect was detected statistically. Third, an important factor that may impact on the presence of the RISC effect is the bilingual's proficiency. It is conceivable (or even plausible) that L2-proficient (balanced) bilinguals have developed superior control mechanisms for selecting language for production and thus may be more capable of initiating the reconfiguration of language selection in advance of the stimulus. Thus, it was decided to examine the role of L2 proficiency over two experiments, by testing unbalanced bilinguals in Experiment 2 and balanced bilinguals in Experiment 3, which would subsequently enable comparisons of the key effects in the two groups.

## Method

### *Participants*

Sixteen unbalanced English(L1)–French(L2) bilingual participants gave informed written consent to take part in this experiment and were paid £10 per hour, with an additional £5 which could be earned via bonus points that were awarded for good performance. Participants reported normal, or corrected to normal vision. All had grown up in a monolingual home and all had started to learn French at Secondary school, aged 11. Participants were aged between 18 and 29 years (mean 21.13 years) and 14 were female. All had lived in French speaking countries for an average of 1.06 years (range 1-2). All participants were studying French at Exeter University at the time of testing and during term time they spoke French on a daily basis. Participants rated themselves according to how well they thought they performed on four key areas of language; speech, reading, writing and listening. Bilinguals scored no more than 8, and no less than 6, out of 10 on any of these components. Mean scores (out of 10) were; speech 7.69; reading, 7.50; writing, 7.06; listening, 7.13.

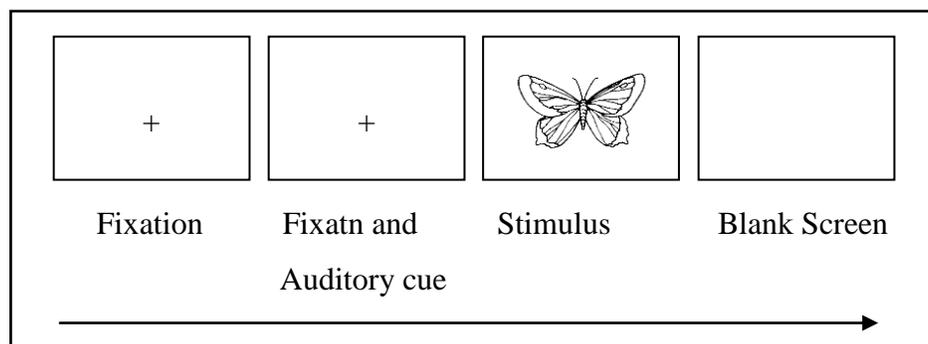
### *Materials*

The same stimuli were presented as in Experiment 1. Two auditory cues per language were used in this experiment: a brief fragment of the English or French National Anthem, or the spoken version of the words “English” or “Français” (spoken by a female native speaker). The cues were all 300ms in duration and thus extended into the stimulus interval for the short CSI condition. The same four CSIs were used as in Experiment 1: 100ms, 350ms, 750ms, 1500ms. The CSI was constant within blocks of 49 trials, but varied over blocks. To encourage effective preparation, participants were told in advance which CSI to expect for the block about to start. The order of the CSIs was balanced across participants so that each CSI was presented in each block an equal number of times. Given the sequential presentation of the CSIs and the two sets of items presented on alternate blocks, each picture could only be presented in two out of the four CSIs (i.e. either CSI 1 and 3, or 2 and 4); this was counterbalanced across participants. After the participant responded, a blank screen appeared which varied in length so as to keep the RSI constant; as in Experiment 1 the RSI was 2160ms. The practice was the same as in Experiment 1,

as so was the number and length of blocks during main part of the experiment, and the probability of a language switch (1/3).

### *Apparatus and Procedure*

The apparatus and procedure were the same as Experiment 1, with one small difference in the trial structure dictated by the change from visual to auditory cues: while the auditory cue was presented, the fixation remained on the screen (see Fig. 2.5).



**Figure 2.5.** Illustration of the time-course of one trial.

### *Analysis*

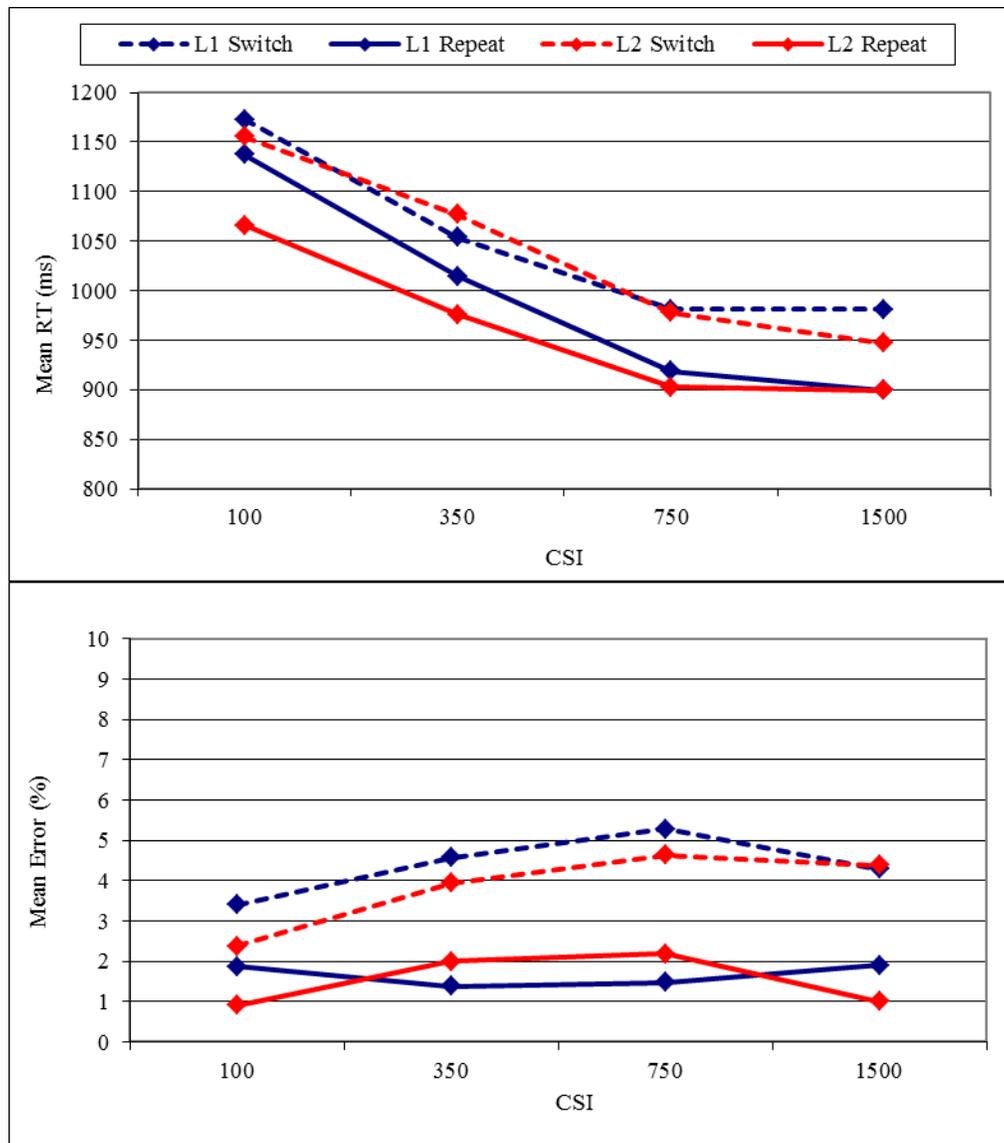
The first trial of each block was removed from the analysis, as were trials following an error, because neither could be classified with confidence as switch or repeat. The classification of naming errors, the criteria for filtering out the very fast and very slow responses and the ANOVA factors were the same as in Experiment 1.

## **Results**

### *Effects of language*

Figure 2.6 shows the mean naming latencies and error rates. The omnibus analysis showed a tendency towards faster naming for L2 (1000ms) than for L1 (1020ms) but this difference was

not reliable,  $F(1,15)=2.21$ ,  $p=0.158$ . There was little difference in the number of errors made in L1 (3.0%) and L2 (2.7%),  $F(1,15)=0.59$ ,  $p=0.454$ .

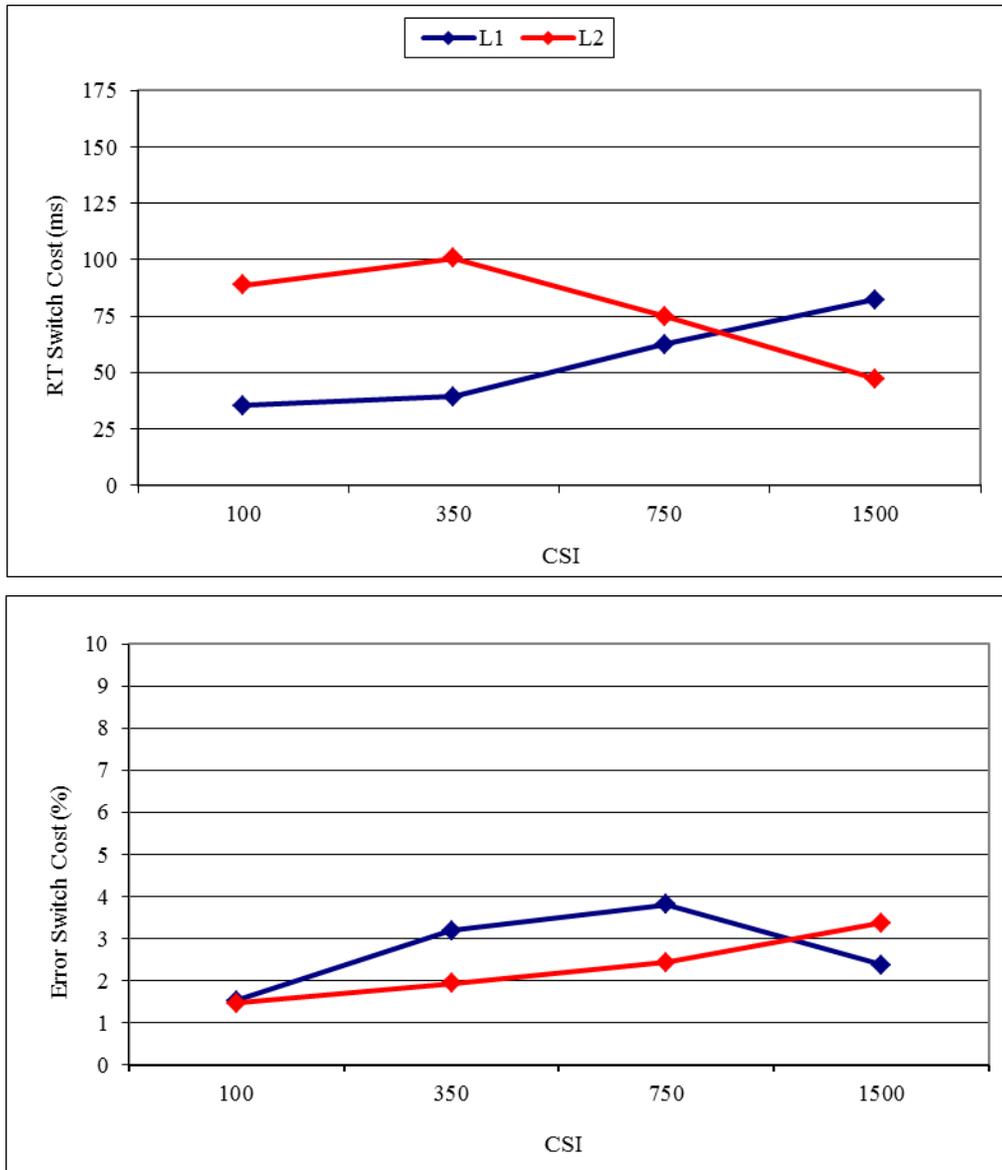


**Figure 2.6.** Mean naming latencies and error rates plotted as a function of language, transition and CSI.

### *Effects of switch*

There was a robust switch cost (66ms) in the latency analysis,  $F(1,15)=40.11$ ,  $p<0.001$ . The switch cost for L2 (78ms) was somewhat larger than for L1 (55ms), but this was not reliable,

$F(1,15)=1.58$ ,  $p=0.228$ . There was a significant switch cost in the errors (4.1% vs. 1.6%,  $F(1,15)=42.97$ ,  $p<0.001$ ). There was a difference in switch cost between L1 (2.7%) and L2 (2.3%), but it did not approach significance,  $F(1,15)=0.56$ ,  $p=0.465$ .



**Figure 2.7.** Mean switch cost as a function of CSI and language.

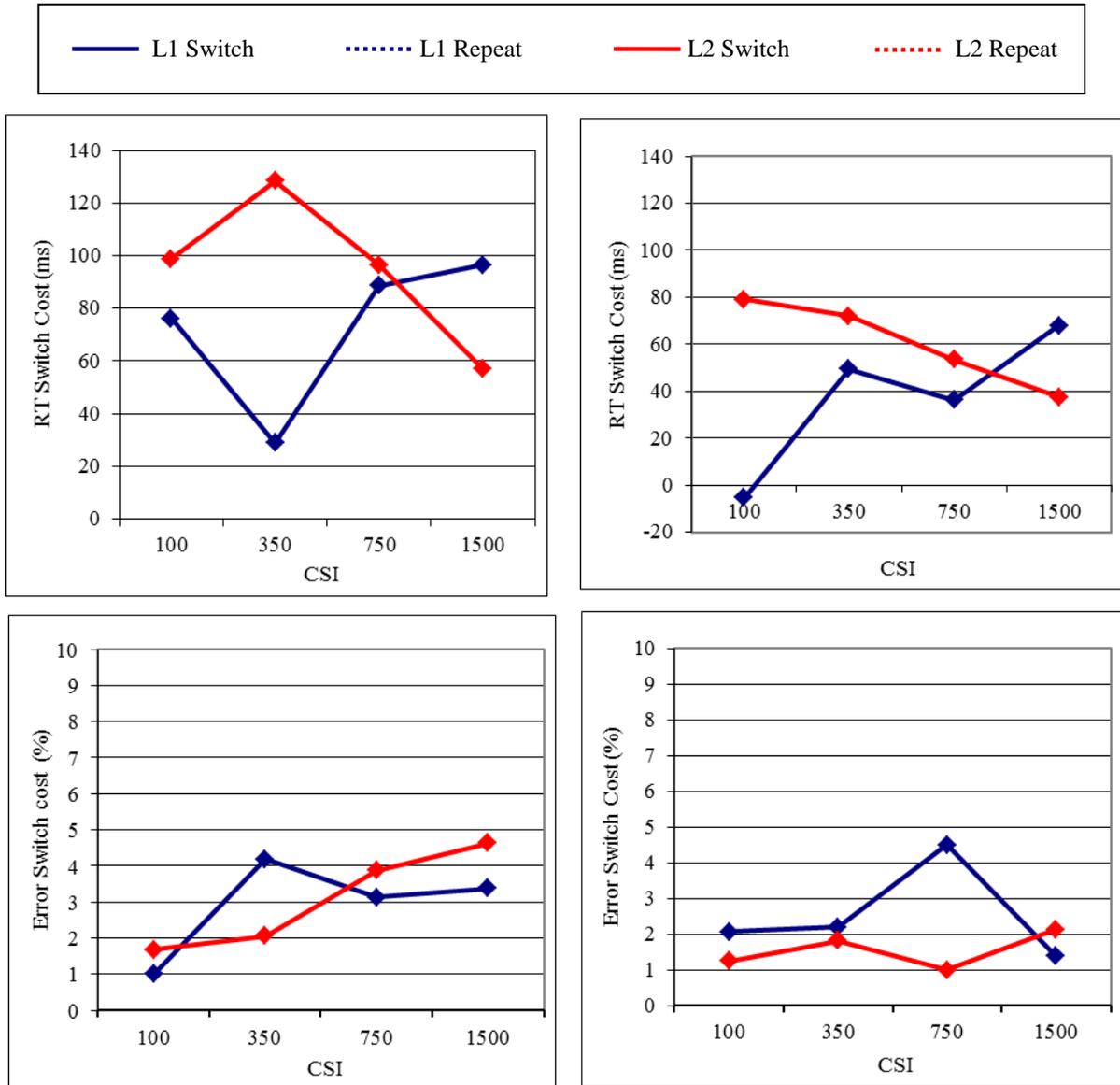
The CSI by transition interaction (a measure of the RISC effect) was not reliable for the latencies,  $F(3,45)=0.095$ ,  $p=0.762$  (see Fig. 2.7). There was however a reliable three way

interaction involving CSI, transition and language,  $F(3,45)=3.02$ ,  $p=0.039$ , which reflected differences in the RISC effect for L1 and L2; the switch cost for L2 decreased and for L1 increased with increasing CSI. Running the analysis by language did not find the RISC effect for L2 to be reliable,  $F(3,45)=1.75$ ,  $p=0.171$ , however there was a significant linear trend,  $F(1,15)=5.20$ ,  $p=0.038$ ; the RISC reversal for L1 was not significant,  $F(3,45)=1.61$ ,  $p=0.215$  (and neither was the linear trend,  $F(1,15)=3.009$ ,  $p=1.03$ ). There was no detectable RISC effect for the errors,  $F(3,45)=1.34$ ,  $p=0.273$ ).

### *Effects of cue*

Pictures were named considerably more quickly and more accurately when preceded by the word cue (RT, 926ms; error, 1.9%) than the anthem cue (RT, 1093ms; error, 3.8%) (RT,  $F(1,15)=56.00$ ,  $p<0.001$ ; error,  $F(1,15)=21.30$ ,  $p<0.001$ ). The magnitude of the RT difference between cue types reduced over successive CSIs from 257ms at the shortest CSI to 74ms at the longest CSI (cue by CSI interaction,  $F(3,45)=30.06$ ,  $p<0.001$ ). A cue by language by CSI interaction indicated that the magnitude of the difference between L1 and L2 naming latencies for word and anthem cue trials varied over CSIs,  $F(3,45)=3.27$ ,  $p=0.034$ . For anthem cue trials, the magnitude of the L1-L2 difference successively reduced over all four CSIs,  $F(3,45)=3.9$ ,  $p=0.026$ . For word cued trials the magnitude of the L1-L2 difference reduced over the first three CSIs, but increased at the longest CSI.

The RT switch cost was much larger for anthem cue trials (83ms) than word cue trials (49ms),  $F(1,15)=8.10$ ,  $p=0.012$  (see Fig. 2.8).



**Figure 2.8.** RT (top) and error (bottom) switch cost for anthem cue trials (left) and word cue trials (right).

***Other effects***

Pictures were named more quickly with increasing CSI,  $F(3,45)=31.23$ ,  $p<0.001$ . Fewer errors were made at the shortest and longest CSIs (100ms, 1500ms) than the two intermediate intervals (350ms, 750ms),  $F(3,45)=4.27$ ,  $p=0.011$ .

### *Effects of stimulus associative history*

As in experiment 1, the data were analysed according to whether the picture was last named in the same language as the current trial or in the participants other language. Responses were faster and more accurate on trials where the picture was named in the same language as on the previous encounter (989ms; 2.4%) than in the other language (1025ms; 3.2%) (RT,  $F(1,15)=35.41$ ,  $p<0.001$ ; error,  $F(1,15)=10.50$ ,  $p=0.005$ ). Numerically, the benefit of naming a picture in the same language as before was larger for L1 (46ms) than for L2 (26ms) but this difference was not reliable,  $F(1,15)=1.28$ ,  $p=0.276$ .

There was a cue by previous language interaction for the latencies,  $F(1,15)=6.04$ ,  $p=0.027$  and errors,  $F(1,15)=5.64$ ,  $p=0.031$ . The performance benefit from naming the picture in the same language as the previous trial, relative to the other language was greater for anthem cue trials (49ms, 2%) than for word cue trials (23ms, 0%). There was a three way interaction for the latencies between current naming language, previous naming language and cue,  $F(1,15)=5.42$ ,  $p=0.034$ . Analyses by cue revealed that naming latencies were shorter when the item was previously named in the same language than in the other language, apart from L2 word cued trials where there was little difference between the same language and different language trials.

There was virtually no difference in the magnitude of the switch cost for items that were named in the same language on their previous encounter (62ms) than in the bilinguals other language (70ms),  $F(1,15)=0.72$ ,  $p=0.410$ . The error switch cost was somewhat larger if the language on the previous encounter was different 2.8% vs. the same 2.2%, but this effect did not approach significance,  $F(1,15)=1.74$ ,  $p=0.207$ .

## **Discussion**

Experiment 2 used a paradigm that contained three substantive changes compared to that used in Experiment 1: a predictable CSI which varied over blocks rather than over trials and auditory (rather than visual) cues. In addition, the manipulation of cue transparency replaced that of cue duration.

Consistent with the outcomes from Experiment 1, participants' responses showed a tendency toward a paradoxical language effect (shorter naming latencies in L2 than in L1) though not

reliably so. As already discussed in Experiment 1 (see Discussion), this finding is quite common. As in Experiment 1, there was no reliable asymmetry of switch costs and the numerical trends in the latencies (switch cost  $L2 > L1$ ) and errors ( $L1 > L2$ ) were contradictory.

The primary goal was to determine whether language switching shows RISC effects as robust as those seen in task switching (and thus the predictable CSI in the current experiment was meant to encourage advance language selection). Overall, the reduction in the magnitude of the switch cost was not reliable in the main analyses but RISC interacted with language; numerically, the magnitude of the switch cost for L1 increased, whereas the magnitude of the switch cost for L2 decreased, with increasing time available for preparation. Neither the L1 RISC reversal nor the L2 RISC was reliable, but the linear component of RISC for L2 was statistically significant.

The transparency of the cue affected performance, with much faster and more accurate responses being made when the language was cued by the word than by the national anthem. When participants had more time to prepare, the magnitude of this difference was reduced. The switch cost for word cue trials was almost half that of the anthem cue trials. Taken together, it seems that the word cue was a much more effective language cue than the national anthem. The difference between in switch cost between the word and anthem cues was particularly striking at the shorter CSIs, suggesting that even a short preparation interval was sufficient for the word cue to lead to very rapid reconfiguration of language selection. With such small switch costs at the short CSIs, it is unsurprising that the word cues did not reveal a greater RISC effect, which is indexed as a reduction in switch cost with increasing CSI. It is important to consider what makes the current word cues effective. At least three factors suggest themselves. First, task switching experiments have previously revealed semantically transparent task cues to result in smaller switch costs (see Chapter 1). Second, the name of the language is something bilinguals may use themselves (in inner speech) or encounter in the context of daily interactions and or studies or professional activity (e.g. one might be prompted to speak out some content in English with the phrase “In English please...”). Third, the fact that the cues had to be comprehended in the language that had to be selected for output was likely to lead to extra activation of the output language due to processing input in that language – assuming some level of cross-talk between input and output (see Chapter 4 for relevant data on this very issue). Thus, the transparency of the word cues used in the present experiment is likely to be multifaceted.

As in Experiment 1 we explored the effects of stimulus-language associations on performance. The effects of these associations on overall performance were even clearer than in Experiment 1, with naming latency being prolonged if the response language on the previous encounter with a specific picture was different from the language to be used on the current trial. However, there was no indication that these stimulus-language bindings affected switches disproportionately.

## **EXPERIMENT THREE**

### **AN INVESTIGATION OF THE REDUCTION IN THE LANGUAGE SWITCH COST IN BALANCED BILINGUALS**

#### **Introduction**

There are at least three reasons for examining the role of proficiency in the context of the current investigation. First, it is conceivable that balanced bilinguals may have developed more effective control processes involved in selection of language for output. Indeed some argued that the lack of asymmetries of switch cost in individuals who are highly proficient in L1 and L2 when they switched between L1 and a weaker L3 is evidence that balanced bi/multilinguals develop language selection mechanisms that are qualitatively different to those in unbalanced bi/multilinguals (Costa & Santesteban, 2004). Thus, it seems important to determine whether balanced bilinguals may be more capable of selecting the language in advance of the stimulus and reconfiguring this selection when the language switches; hence one might expect a more robust RISC effect in balanced bilinguals relative to unbalanced bilinguals. Second, in Experiment 2 (with unbalanced bilinguals) the evidence for a RISC effect was confined to L2. If this reflects a strategic effect of biasing selection towards L2, there should be no such biasing in balanced bilinguals. Third, one might expect that, because balanced bilinguals have had more experience switching between languages, they may have used more extensively the name of the language as an internally-generated cue – hence it is possible that the robust effect of cue transparency observed in Experiment 2 may be even more pronounced in balanced bilinguals to the extent that the switch cost may be altogether eliminated for the word (language name) cues.

## Method

### *Participants*

Twenty four native speakers of German who were also highly proficient speakers of English gave informed written consent to take part in this study. Participants were aged between 18 and 47 (mean 30); 16 were female. They were paid £10 per hour, with an additional £5 which could be earned via bonus points that were awarded for good performance. Participants reported normal, or corrected to normal vision. Some had grown up in a bilingual home and had learnt English from a young age (mean, 8.6 years; range 1-14) and all had lived in English speaking countries for an average of 10.17 years (range 1-31). English proficiency was assessed using a self-assessment questionnaire (Appendix three). Participants were either studying at Exeter University or working in an English speaking environment at the time of testing. Participants spoke English every day and German at least two to three times a week with the majority speaking German every day. Participants rated themselves according to how well they thought they performed on four key areas of language: speech, reading, writing and listening. They scored no less than 8 out of 10 on any of these components: speech 9.11; reading, 9.61; writing, 9.17; listening, 9.61.

### *Apparatus, materials, and procedure*

The apparatus, stimuli, the cues, CSIs and procedure were the same as in Experiment 2, except for the pair of languages (German and English, instead of English and French) and the cues for the German language (the word “Deutsch” and the beginning of the German national item replaced) were added along with the German names for the pictures (Appendix four). The picture names were matched on log frequency/million (see Table 2.2;  $t = 0.21$ ) using the CELEX database (Baayen et al., 1993). The French language cues and the French word names for the pictures (from Experiment 2) were not used.

	<b>English</b>	<b>German</b>
	Log frequency per million	Log frequency per million
<b>Mean</b>	0.8	0.7
<b>Standard Deviation</b>	0.70	0.65

**Table 2.2:** Mean frequency per million and standard deviation for the stimuli.

### *Analysis*

The trial selection and exclusion parameters were the same as in Experiment 2.

## **Results**

### *Effects of language*

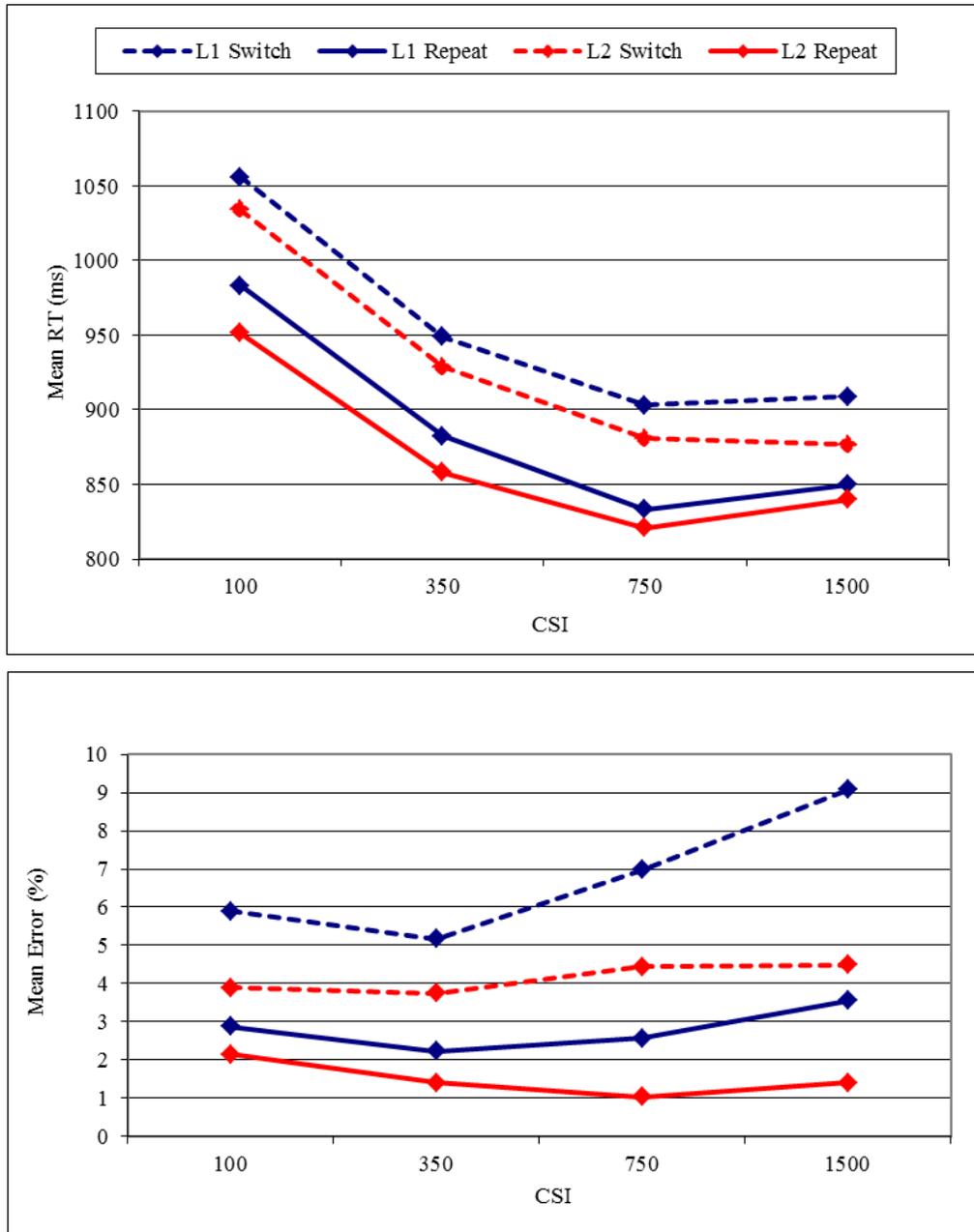
Figure 2.9 shows the latency and error rate as a function of transition, CSI and language. The omnibus analysis revealed that pictures were named more quickly and more accurately in L2 (899ms, 2.9%) than L1 (921ms, 4.8%) (RT,  $F(1,23)=6.52$ ,  $p=0.018$ ; error,  $F(1,23)=25.75$ ,  $p<0.001$ ).

### *Effects of switch*

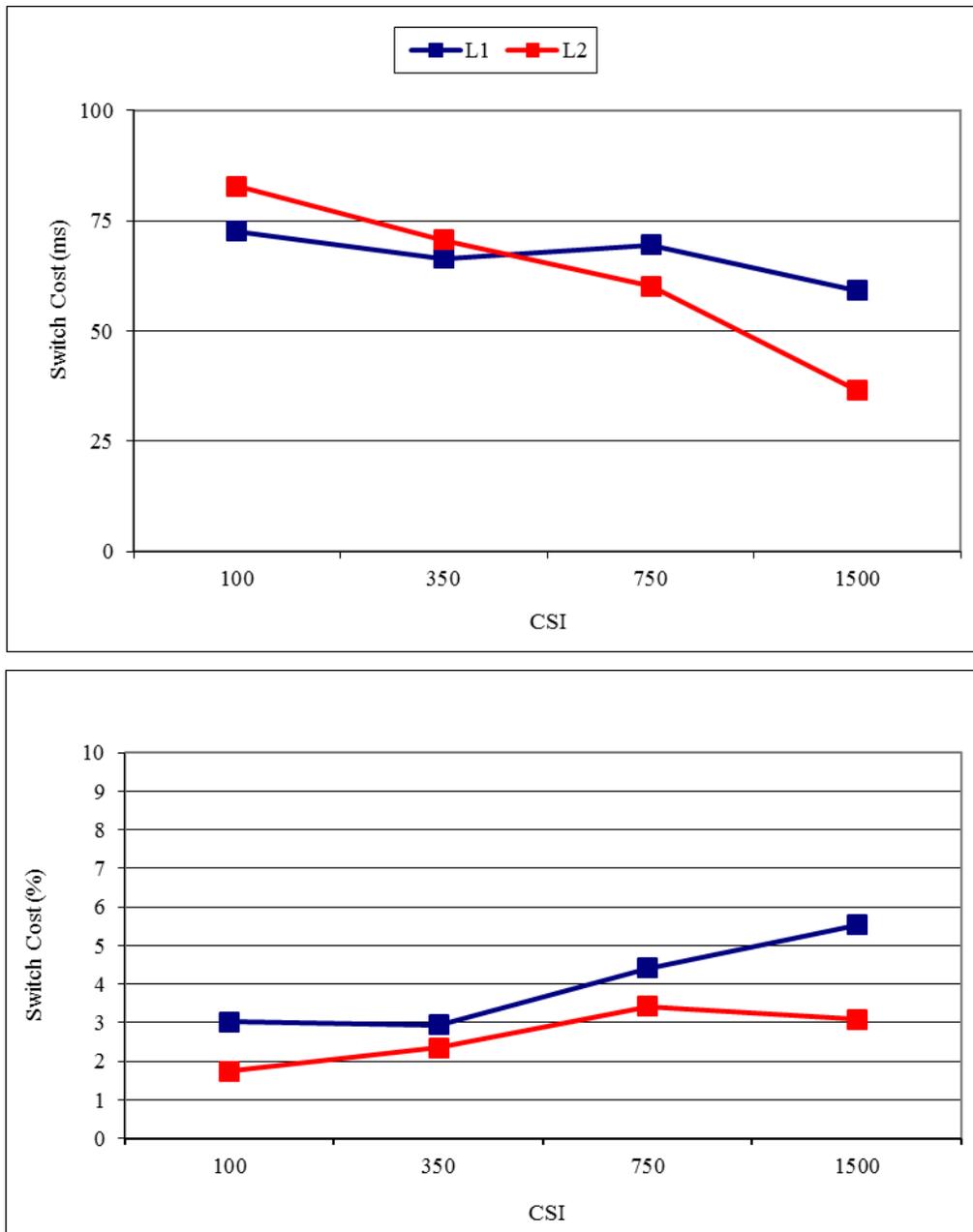
There was a reliable RT switch cost of 65ms, with slower responses on language switch trials than on language repeat trials,  $F(1,23)=100.30$ ,  $p<0.001$  (see Fig. 2.10). The RT switch cost was nearly symmetrical (L1, 62ms; L2, 67ms),  $F(1,23)=0.308$ ,  $p=0.584$ . There was a reliable interaction in the RT data involving transition with CSI,  $F(3,69)=3.31$ ,  $p=0.025$ . A reliable linear trend indicates a RISC effect,  $F(1,23)=8.78$ ,  $p=0.007$ .

There was a reliable switch cost in the error data (5.5% vs. 2.1%),  $F(1,23)=64.21$ ,  $p<0.001$ . Numerically, the error switch cost was greater in L1 (4.0%) than L2 (2.7%), an effect that narrowly missed statistical significance,  $F(1,23)=3.37$ ,  $p=0.079$ . A reliable interaction

between transition and CSI reflected a reversed RISC effect with the magnitude of the error switch cost increasing in successive CSIs,  $F(3,69)=4.30$ ,  $p=0.013$ .



**Figure 2.9.** Mean latencies and error rates plotted as a function of language, transition and CSI.



**Figure 2.10.** The switch cost as a function of language and CSI.

*Effects of cue*

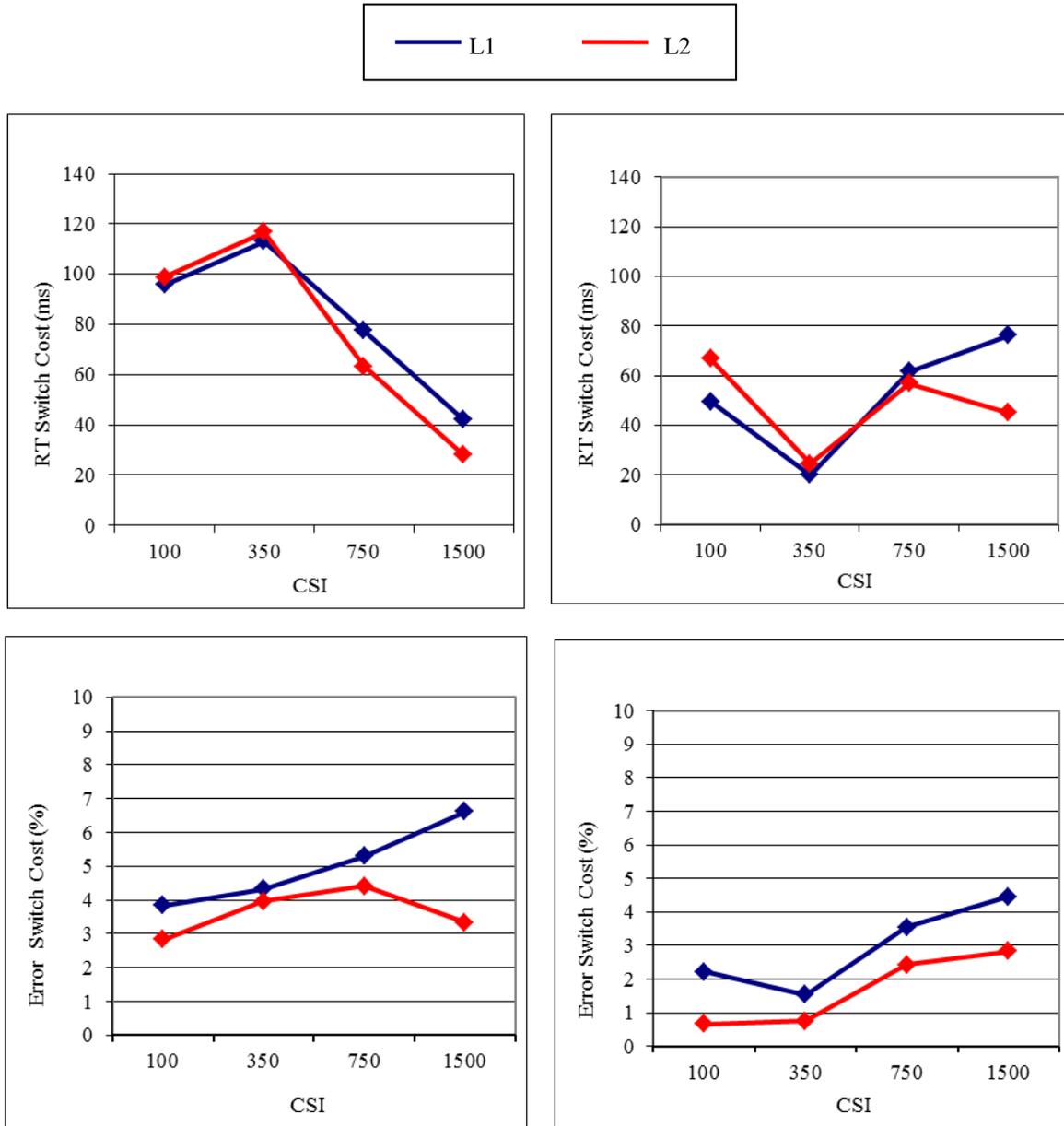
Pictures were named more quickly and more accurately when preceded by the word cue (854ms; 2.7%) than the anthem cue (965ms; 4.9%) (RT,  $F(1,23)=62.26$ ,  $p<0.001$ ; errors,  $F(1,23)=25.00$ ,

$p < 0.001$ ). The magnitude of the word-anthem difference reduced over successive CSIs from around 200ms at the shortest CSI to around 45ms at the longest CSI,  $F(3,69)=29.71$ ,  $p < 0.001$ . There was a two-way interaction for latencies between cue and language,  $F(1,23)=6.95$ ,  $p=0.015$ . Further investigation revealed that there was little effect of language on naming latencies on word cue trials (L1, 857ms; L2 852ms;  $F(1,23)=0.27$ ,  $p=0.608$ ), but on anthem cue trials, pictures were named around 40ms faster in L2 (945ms) than L1 (984ms),  $F(1,23)=10.66$ ,  $p < 0.001$ .

The reaction time and error switch costs for anthem cue trials (mean 80ms; error 4.3%) was larger than for word cue trials (mean 50ms; error 2.3%) (RT,  $F(1,23)=7.50$ ,  $p=0.012$ ; errors,  $F(1,23)=7.58$ ,  $p=0.011$ ; see Fig. 2.11). There was a transition by CSI by cue interaction in the latencies,  $F(3,69)=12.25$ ,  $p < 0.001$ ) which suggested differences between cues in the magnitude of the RISC effect. Analyses by cue revealed reliable CSI by transition interactions for word cue trials,  $F(3,69)=4.92$ ,  $p=0.004$ , and anthem cue trials,  $F(3,69)=9.64$ ,  $p < 0.001$ . There was a reliable linear trend in the anthem cue data,  $F(1,23)=21.43$ ,  $p < 0.001$ , which suggests a reduction in the magnitude of the switch cost from the shortest to the longest CSI. There was no clear RISC effect for the word cues – the significant CSI by transition interaction for word cues was due to a cubic trend,  $F(1,23)=12.015$ ,  $p=0.002$  (see figure 2.11).

### *Other Effects*

Pictures were generally named more quickly with increasing CSI, however, at the longest CSI latency increased slightly,  $F(3,69)=19.06$ ,  $p < 0.001$ . There was a tendency for fewer errors to be made at the 350ms CSI (3.2%) than the other three CSIs (100ms, 3.8%; 750ms, 3.8%; 1500ms, 4.7%),  $F(3,69)=4.58$ ,  $p=0.009$ .



**Figure 2.11.** RT (top) and error (bottom) switch cost for anthem cued trials (left) and word cued trials (right).

*Effects of the stimulus associative history*

Pictures were named 42ms faster when last encountered in the same language (885ms) than in the other language (927ms),  $F(1,23)=54.87$ ,  $p<0.001$ . Responses were also more accurate with fewer errors being made on same-language trials (3.4%) than when the language was different

from the language of the last encounter (4.2%),  $F(1,23)=8.53$ ,  $p=0.008$ . The interaction for the naming latencies between previous naming language and current naming language approached significance,  $F(1,23)=3.20$ ,  $p=0.087$ , reflecting the fact that the effect of associative history was greater for L2 than L1 (49ms vs. 34ms).

There was an interaction in the reaction time between previous language and cue,  $F(1,23)=9.68$ ,  $p=0.005$ : the reaction benefit of naming a stimulus in the same language as that on the previous encounter was greater for the anthem cue trials (57ms) than the word cue trials (26ms). There was a three way interaction in the latencies involving previous language, cue type and current language,  $F(1,23)=8.605$ ,  $p=0.007$ , reflecting the fact that the modulation of associative history by cue were greater for L2 than for L1.

There was a small difference in the magnitude of the switch cost for items that were named in the same language on their previous encounter (66ms; 3.4%) than in the other language (71ms; 3%). However these differences did not approach significance for either latency ( $F(1,23)=0.487$ ,  $p=0.492$ ) or error rate ( $F(1,23)=0.807$ ,  $p=0.378$ ).

## **Comparing the unbalanced and balanced bilinguals**

The data from experiments two and three lend themselves to a comparison with L2 proficiency as a between subjects factor. In what follows I report only the key interactions involving the between-subjects factor L2 proficiency.

There was a reliable interaction between language and L2 proficiency in the error data,  $F(1,38)=7.38$ ,  $p=0.010$ . Further analyses revealed that unbalanced bilinguals made similar numbers of errors in L1 (3.0%) and L2 (2.7%), whereas balanced bilinguals made more errors in L1 (4.8%) than L2 (2.8%). There was a reliable interaction between cue and L2 proficiency in the RT data,  $F(1,38)=4.92$ ,  $p=0.033$ . The magnitude of the difference in naming latencies between word and anthem cue trials was larger for the unbalanced bilinguals, (166ms; anthem, 1093ms; word, 927ms) than for the balanced bilinguals (111ms; anthem, 965ms; word, 854ms).

Transition did not reliably interact with L2 proficiency and neither did transition and CSI together. However, there was a significant four-way interaction between cue, transition, CSI and L2 proficiency,  $F(3,114)=4.60$ ,  $p=0.004$ . This interaction likely reflected the greater differences

in the RISC effects elicited by the two cues in the balanced bilinguals than in the unbalanced bilinguals (for details see the analyses of the two groups).

## **Discussion**

Experiment 3 used an identical paradigm, stimuli and set up (but a different pair of languages) to those in Experiment 2 to examine language switching in balanced bilinguals (in Experiment 2 unbalanced bilinguals were investigated). This enabled the investigation of the role of the relative L1 vs. L2 proficiency on the RISC effect, as well as on several other phenomena reported in language and/or task switching: global language asymmetry, switch cost asymmetry, the effect of cue transparency and that of stimulus-language associations.

Both naming latencies and error rates revealed, as expected, a robust switch cost. For RTs there was a robust, statistically significant, RISC effect; however the presence of an increase in switch cost with increasing CSI for the errors raises the possibility that the RISC effect for RTs was caused by changes in the response criterion (and the resulting speed-accuracy trade-off) on the long CSI switch trials (faster responses that were more error-prone). As expected, unlike unbalanced bilinguals (Experiment 2), balanced bilinguals did not show an increase in RT switch cost with a longer CSI in L1 that accompanied the RISC effect in L2. However, this difference between the groups (the RISC effect by language by group interaction) did not approach significance. Thus, there did not seem to be robust differences between balanced and unbalanced bilinguals either in the magnitude of the switch cost or ability to reduce the switch cost with opportunity for preparation. Possible reasons are considered in General Discussion following further investigation of the behavioural effect of preparation along with its putative brain potential signature in Experiment 4.

Like the unbalanced participants, the balanced group showed a clear bias towards (superior overall performance in) L2 for both RT and errors – for the errors this bias was even larger in the balanced group further supporting the notion that the L2 bias seems to be independent of the relative proficiency in L1 vs. L2 (see Discussion for Experiments 1). The analysis of naming latencies in balanced bilinguals revealed, as expected, no detectable asymmetry of switch cost. There was a weak trend for paradoxical asymmetry in the error rates.

As in the unbalanced bilinguals, in balanced bilinguals there was a robust effect of the language on the previous encounter with the respective picture – with faster responses and a lower error rate for stimuli that were named the previous time in the same language – and, as in the unbalanced group, this associative history effect did not seem to contribute reliably to (interact with) the switch cost.

Referring back to the three questions asked in Introduction to Experiment 3, the results lead to the following answers. First, the RISC effect found in balanced bilinguals did not exceed that in unbalanced bilinguals – with the added complication of a reversed switch cost in the error rates in the balanced group. Second, although numerically the RISC effect was somewhat greater in L2 than L1 in the balanced bilinguals, the difference was less pronounced than in the unbalanced group. Third, cue transparency modulated the switch cost (it was greater on anthem cue trials) in both groups of participants with no detectable difference between them. Moreover, the effect of cue transparency on the overall performance (pulled over switch and repeat trials) was reliably greater for the unbalanced group. Thus, the effects of relative L1 vs. L2 proficiency were few and far between. It is possible that the two groups of participants tested in Experiments did not differ sufficiently with regard to L2 proficiency, that the students studying German at Exeter are highly proficient in German and that, conversely, (some) of the German-English bilinguals from Experiment 3 were not as highly proficient as they rated themselves to be. The lack of objective proficiency measures makes it impossible to firmly evaluate these possibilities. These and related issues are considered again in General Discussion.

## **EXPERIMENT FOUR**

### **ARE THE ELECTROPHYSIOLOGICAL CORRELATES OF PREPARING FOR A LANGUAGE SWITCH THE SAME AS THOSE OF PREPARING FOR A TASK SWITCH?**

#### **ABSTRACT**

Over the last decade or so, there has been growing interest in the extent to which task switching and language switching recruit overlapping control processes. Yet, preparation for a switch, considered in task switching to be the clearest index of top-down control, has been under-explored in language switching. In a picture naming paradigm containing unpredictable language switches (with language specified by a cue on every trial) we found preparation for a switch to elicit a brain potential that is strongly reminiscent of a known EEG ‘signature’ of preparation for a task-switch: a protracted positive-polarity potential over the posterior scalp. As in task-switching, its amplitude predicted performance and the switch cost, indicated by our ERP analyses contingent on RT distributions. This similarity of electrophysiological correlates of preparing to switch tasks and preparing to switch languages suggests substantial overlap in the top-down selection of task-set vs. language for production.

## Introduction

Intrigued by evidence that frequent language switching in bilinguals might enhance domain-general control mechanisms and even boost the resilience to neurodegeneration (Bialystok, Craik, & Freedman, 2007; Bialystok, Craik, Green, & Gollan, 2010), researchers have explored the parallels between language switching and task switching in the laboratory. Many of the key behavioural phenomena documented in task switching (for reviews, see Kiesel, Steinhauser, Wendt, Falkenstein, Jost, Philipp, & Koch, 2010; Monsell, 2003; Vandierendonck, Liefoghe, & Verbruggen, 2010) have also been reported in language switching. Switching the language (just as switching the task) results in a detriment in performance relatively to repeating it – the ‘switch cost’ (e.g., Costa & Santesteban, 2004; Jackson, Swainson, Cunnington, & Jackson, 2001); there is also a language (and task) ‘mixing cost’: on repetition trials that are part of blocks also containing switches performance is worse than in ‘pure’ blocks containing no switches (e.g., Christoffels et al., 2007; Koch, Prinz, & Allport, 2005). An intriguing finding is the ‘paradoxical’ asymmetry of switch cost: greater cost of switching from the non-dominant language to the dominant one than vice-versa (Meuter & Allport, 1999); the paradoxical asymmetry is also found in switching between more practised and less practised tasks (e.g., Allport, Styles, & Hsieh, 1994; Yeung & Monsell, 2003). A further empirical phenomenon first documented in task switching is that of the ‘n-2 repetition cost’ (or ‘backward inhibition’): if A, B and C are three tasks, performance on the third trial will be worse in the sequence ABA than in the sequence ABC, presumably as a consequence of having to overcome the inhibition of the task-set from two trials ago (Mayr & Keele, 2000). Backward inhibition has also been reported for language switching (Philipp, Gade, & Koch, 2007; Philipp & Koch, 2009). That switching languages and switching tasks results in similar empirical effects suggests highly overlapping control processes responsible for selection of task-set and language for output. However, more recent investigations have also given some reason for caution regarding the generality of the control mechanisms. For instance, the paradoxical asymmetry of task switch costs has been observed in individuals who have not shown an asymmetry of switch costs in their stronger vs. weaker language, such as highly-proficient speakers of two languages who are less proficient in the third language (Calabria, Hernández, Branzi, & Costa, 2012).

We focus here on a brain potential extensively documented in task switching and seen as the clearest yet ‘signature’ for endogenous (top-down) control of task-set. Behaviourally,

advance (pre-stimulus) warning of the task to be executed results in a reduction in switch cost, suggestive of advance task-set reconfiguration (e.g. Rogers & Monsell, 1995; Monsell & Mizon, 2006; Verbruggen, F., Liefoghe, B., Vandierendonck, A., & Demanet, J., 2007). The correlate of such advance task-set control seems to be a switch-induced event-related brain potential during the late part of the preparation interval, often referred as ‘posterior/parietal positivity’ due to its polarity and scalp distribution: its magnitude predicts the reduction in switch cost within and over individuals (Karayanidis, Provost, Brown, Paton, & Heathcote, 2011; Lavric, Mizon, & Monsell, 2008; Elchlepp, Lavric, Mizon, & Monsell, 2012). Strikingly, the only electrophysiological study to date that investigated preparation for a language switch (Verhoef, Roelofs & Chwilla, 2009b) found no sign of the posterior switch-induced positivity reported in virtually all ERP studies of preparation for a task switch. Verhoef et al. outlined several possible reasons for the absence of the posterior positivity, focusing principally on differences in the nature of stimulus-response (S-R) mappings between language switching and task switching: in most task switching studies the participant uses a small set of freshly learned arbitrary S-R rules (e.g.; press button with right index finger if the letter is a vowel), whereas language switching tends to involve naming pictures (or sometimes digits) using over-learned responses from a vast vocabulary; in task switching multiple stimuli from two/more tasks are mapped onto the same set of responses, whereas in language switching responses tend to be unique to individual stimuli and languages.

Here we examined whether the key neurophysiological signature of advance control in task switching (posterior positivity) is indeed absent in language switching: this absence raises further doubts about the domain-generalty of control processes involved in selecting task-set and language. In doing so, we adapted the task-cueing paradigm (e.g., Meiran, 1996), in which the task is specified on each trial by a cue. A non-trivial challenge in task-cueing is that one cannot simply use one cue for each task, because the cue would always repeat on task repeat trials and always change on task switch trials, resulting in a confound between the cue repetition benefit and the task switch cost (e.g., Logan & Bundesen, 2003; Monsell & Mizon, 2006). One solution is to use two cues per task and change the cue on every trial, even when the task is repeated – which also provides the opportunity to manipulate the cues. In task-switching cues that are non-arbitrary or semantically transparent (e.g. the word ‘colour’ for a colour discrimination task) result in a smaller switch cost than arbitrary cues (Arbuthnott & Woodward, 2002). Furthermore,

transparent verbal cues result in smaller task-switch costs than other relatively transparent (e.g. image) cues (e.g., Lavric et al., 2008), suggesting the effectiveness of linguistic labels in activating the appropriate task-set. Language switching provides the opportunity to investigate the effect of using what one might call ‘supercues’: the name of the language – not only is such a cue verbal and maximally transparent, it is also extensively encountered by every bilingual (and possibly used by some as an internally-generated cue). We explored the possibility that such ‘supercues’ may activate the relevant language so effectively (even on a switch trial) that there may not be further need for/benefit from top-down control.

## **METHOD**

### ***Participants***

Sixteen right-handed German(L1)-English(L2) bilinguals (13 females; mean age= 31.9; SD=10.2), highly fluent in both languages, gave informed written consent to participate and were remunerated £20. All participants have previously completed (one week to four weeks earlier) a testing session using the same task and materials (but without EEG).

### ***Stimuli and task and procedure***

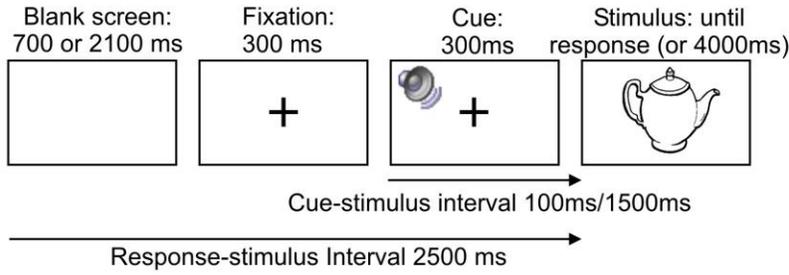
The stimuli were 120 black-and-white drawings of everyday objects from the International Picture Naming Project (Bates et al., 2003; <http://crl.ucsd.edu/~aszekely/ipnp/1stimuli.html>), which had to be named in L1 or L2. The language, which changed unpredictably, was specified on each trial by a transparent cue (the spoke word “Deutsch” or “English”) or an opaque cue (speeded-up beginnings of the German and British national anthems). The cue-stimulus interval (CSI) varied (100ms or 1500ms) over blocks, but was constant within a block. The cue changed on every trial to minimise cue priming effects. Switches were relatively rare (1/3) to ensure sensitivity to the switch-repeat contrast by discouraging premature (pre-cue) preparation for a switch (cf. Monsell & Mizon, 2006). A subset of 96 pictures, which were subsequently analysed, were presented in 24 blocks of 48 trials. Their names were matched on log frequency/million (German, 0.7; English, 0.8;  $t = 0.21$ ) using CELEX (Baayen, Piepenbrock, & van Rijn, 1993). The remaining 24 pictures were presented on a start-up trial of every block (unclassifiable as

switch/repeat, hence not analysed). The 96 test stimuli were divided into two equal lists presented on alternate blocks to ensure at least 49 trials between successive presentations of each stimulus. Half of the participants started with one list and half with the other; half of the participants named a particular picture in L1 on its first occurrence and half in L2. Each test stimulus was presented 12 times (4 on a switch trial and 8 on a repeat trial).

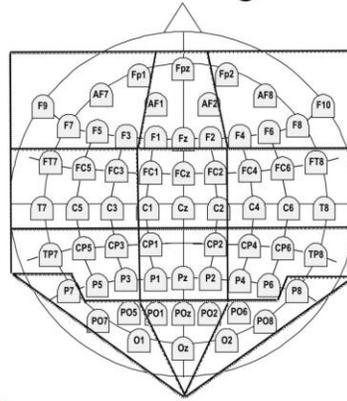
### ***EEG/ERPs***

The EEG was sampled continuously at 500Hz with a bandpass of 0.016-100Hz with reference at Cz and ground at AFz from 62 10-10-positioned scalp electrodes (ActiCap, BrainProducts, Munich, Germany) plus two earlobe-electrodes. Following 40Hz offline lowpass-filtering and re-referencing to averaged earlobes, the long CSI EEG was segmented into 1600ms-epochs comprising the CSI plus a 100ms pre-cue baseline. Epochs containing ocular, muscle, movement or other artifacts were excluded from the ERP analysis. Trials corresponding to the first trial of each block, errors, trials following an error, very fast (<200ms) and very slow (>3000ms) responses were excluded from the behavioural and ERP analyses.

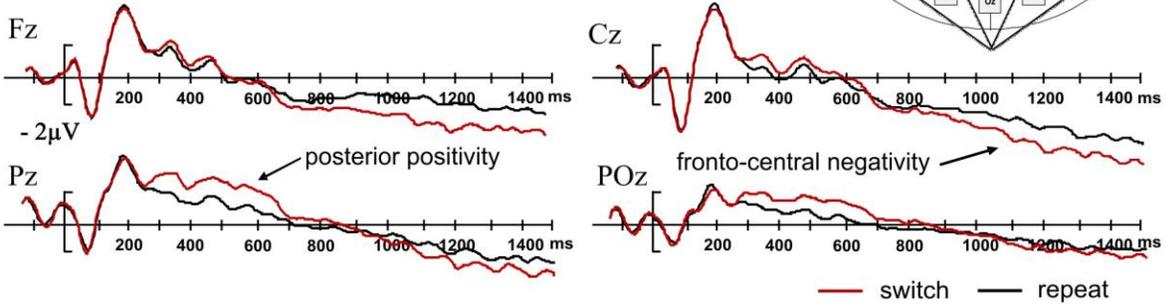
### A. Trial structure



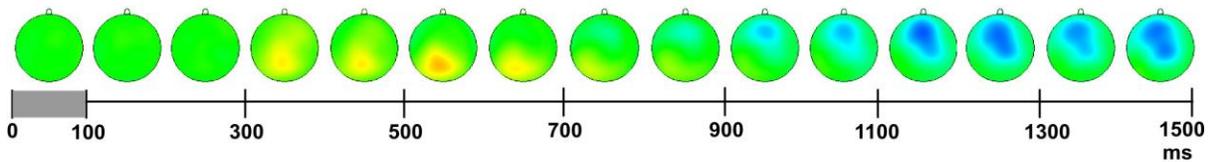
### B. Electrode regions



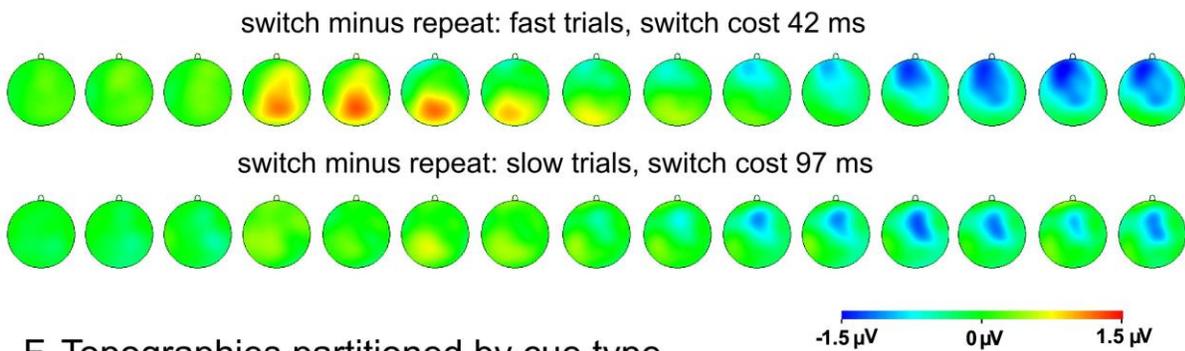
### C. ERPs



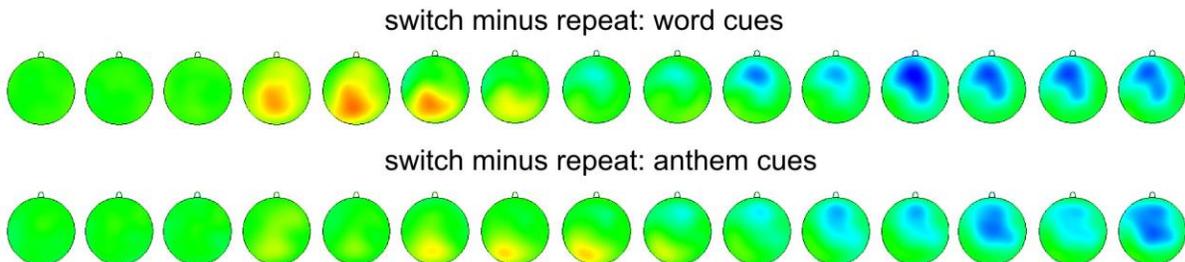
### D. Topographies: switch minus repeat



### E. Topographies partitioned by fast and slow responses (median split)



### F. Topographies partitioned by cue type



**Figure 2.12. A.** Illustration of the optimised language-cueing design. On each trial an auditory language cue preceded the stimulus. The cue-stimulus interval (CSI) was manipulated independently of the response-stimulus interval thus matching the two CSI conditions for possible effects of language ‘inertia’ from the previous trial (cf. Meiran, 1996). **B.** The scalp regions for which ERPs were averaged to yield the ANOVA factors *anterior-posterior* (4 levels) and *laterality* (3 levels). **C.** ERP waveforms in a representative subset of midline electrodes. **D.** The scalp distribution of the switch-repeat difference averaged for every 100ms; the greyed-out interval on the horizontal axis was not analysed, the remainder of the CSI was analysed in 200ms time-windows. The scale is the same as in panel E below. **E & F.** Scalp distribution of the switch-repeat difference partitioned by RT (E) and by cue (F).

## RESULTS

### *Behavioural results (see Table 2.3)*

Mean and median latencies and error rates were subjected to switch (2) by CSI (2) by language (2) by cue (2) ANOVAs. Responses were faster and less error prone for: repeats than switches (the switch cost<sup>2</sup>,  $F_{\text{mean}}(1,15)=45.33$ ,  $p<0.001$ ;  $F_{\text{med}}(1,15)=38.90$ ,  $p<0.001$ ;  $F_{\text{err}}(1,15)=14.58$ ,  $p=0.002$ ), word cue trials than anthem cue trials ( $F_{\text{mean}}(1,15)=48.74$ ,  $p<0.001$ ;  $F_{\text{med}}(1,15)=38.03$ ,  $p<0.001$ ;  $F_{\text{err}}(1,15)=19.15$ ,  $p=0.001$ ), and in the long CSI than the short CSI ( $F_{\text{mean}}(1,15)=59.22$ ,  $p<0.001$ ;  $F_{\text{med}}(1,15)=44.01$ ,  $p<0.001$ ;  $F_{\text{err}}(1,15)=1.80$ ,  $p=0.200$ ). Naming latencies were longer in L1 than in L2 ( $F_{\text{mean}}(1,15)=13.29$ ,  $p=0.002$ ;  $F_{\text{med}}(1,15)=11.77$ ,  $p=0.004$ ). The switch cost was substantially larger for the anthem cue trials than the word cue trials and larger in the latencies for L1 than L2 (a ‘paradoxical asymmetry’,  $F_{\text{mean}}(1,15)=7.05$ ,  $p=0.018$ ;  $F_{\text{med}}(1,15)=6.16$ ,  $p=0.025$ ). Although, there was no significant overall reduction in switch cost with increasing CSI, the significant switch by CSI by cue interaction ( $F_{\text{mean}}(1,15)=23.39$ ,  $p<0.001$ ;  $F_{\text{med}}(1,15)=33.71$ ,  $p<0.001$ ) and follow-up analyses by cue showed the RT switch cost to reduce for the anthem cue trials, significantly for medians ( $F_{\text{mean}}(1,15)=3.64$ ,  $p=0.076$ ;  $F_{\text{med}}(1,15)=8.24$ ,  $p=0.012$ ), but increase for the word cue trials ( $F_{\text{mean}}(1,15)=24.74$ ,  $p<0.001$ ;  $F_{\text{med}}(1,15)=13.66$ ,

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<sup>2</sup> The subscripts used for the F statistics stand for the mean RT, median RT and error analyses.

p=0.002). The advantage for the word cues relative to the anthem cues reduced in the long CSI for RT (cue by CSI interaction,  $F_{\text{mean}}(1,15)=71.68$ ,  $p<0.001$ ;  $F_{\text{med}}(1,15)=52.30$ ,  $p<0.001$ ).

<b>Factor</b>	<b>Mean RT (ms)</b>	<b>Median RT (ms)</b>	<b>Mean Error rate (%)</b>
<b>Switch</b>	switch, 997ms; repeat, 928ms; switch cost, 69ms	switch, 929ms; repeat, 852ms; switch cost, 77ms	switch, 3.2%; repeat, 1.1%; switch cost, 2.1%
<b>L1</b>	switch, 1020ms; repeat, 984ms; switch cost, 36ms	switch, 976ms; repeat, 918ms; switch cost, 58ms	switch, 5.1%; repeat, 2.6%; switch cost, 2.5%
<b>L2</b>	switch, 987ms; repeat, 934ms; switch cost, 53ms	switch, 915ms; repeat, 855ms; switch cost, 60ms	switch, 4.5%; repeat, 2.2%; switch cost, 2.3%
<b>CSI</b>	short CSI, 1011ms; long CSI, 914ms	short CSI, 938ms; long CSI, 842ms	short CSI, 2.0%; long CSI, 2.4%
<b>Cue</b>	word, 910ms; anthem, 1015ms	word, 845ms; anthem, 936ms	word, 1.4%; anthem, 3.0%
<b>Language</b>	L1, 981ms; L2, 944ms	L1, 909ms; L2, 872ms	L1, 2.5%; L2, 1.8%
<b>Word cue</b>	switch, 936ms; repeat, 883ms; switch cost, 53ms	switch, 876ms; repeat, 815ms; switch cost, 61ms	switch, 7.7%; repeat, 1.9%; switch cost, 5.8%
<b>Anthem cue</b>	switch, 1058ms; repeat, 973ms; switch cost, 85ms	switch, 983ms; repeat, 888ms; switch cost, 95ms	switch, 4.5%; repeat, 1.5%; switch cost, 3%
<b>Word sw. cost</b>	short CSI, 31ms; long CSI, 75ms	short CSI, 39ms; long CSI, 82ms	short CSI, 0.8%; long CSI, 1.6%
<b>Anthem sw. cost</b>	short CSI, 98ms; long CSI, 70ms	short CSI, 117ms; long CSI, 72ms	short CSI, 3.03%; long CSI, 3.09%

**Table 2.3.** Mean RT, median RT and error rate for each factor and key interactions.

### ***ERP results***

Temporal and spatial data-reduction was performed by averaging time-points for nearly the entire CSI (100-1500ms<sup>3</sup> following cue onset) into seven consecutive 200ms time-windows and electrodes within scalp regions along the anterior-posterior and laterality dimensions (see Fig.1B). ANOVA found a highly switch by time-window significant interaction,  $F(6,90)=11.14$ ,  $p<0.001$ , suggesting differential effect of switching over time. The scalp distribution of the switch-repeat difference (see Fig. 2.12D) and follow-up ANOVAs for each time-window revealed a robust switch-induced positivity over the posterior scalp at ~300-700ms (main effect of switch, 300-500ms,  $F(1,15)=10.83$ ,  $p=0.005$ ; 500-700ms,  $F(1,15)=4.9$ ,  $p=0.043$ ) followed by a switch-induced negativity over the frontal and central scalp regions at ~1100-1500ms following cue onset (main effect of switch, 1100-1300ms,  $F(1,15)=4.8$ ,  $p=0.043$ ; 1300-1500ms,  $F(1,15)=4.68$ ,  $p=0.047$ ; see Fig. 2.12C&D).

In task-switching the magnitude of the posterior positivity predicts effective preparation: ERP analyses based on RT distributions (Karayanidis et al., 2011; Lavric et al., 2008) have found the positivity to be substantial on trials with fast responses (and a small switch cost) and small (or delayed until after the stimulus) on trials with slow responses (and a large switch cost). The language-switch-induced positivity observed here mirrors this pattern (see Fig. 2.12E): it is robust for the trials (50%) with the fastest responses and substantially smaller in magnitude for the remaining half of the trials<sup>4</sup>. An ANOVA (with factors as in Table 2, but with fast-slow replacing language<sup>5</sup>) on the two time-windows during which the posterior positivity was reliable (300-500ms and 500-700ms) found a reliable switch by fast-slow by time-window interaction,  $F(1,15)=5.61$ ,  $p=0.032$ . Follow-up analyses for each time-window revealed a significant switch

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<sup>3</sup> No switch vs. repeat effects were previously reported in the first 100ms following cue onset for either task switching or language switching.

<sup>4</sup> To ensure that in the ERP analysis based on RT distributions the ‘fast’ vs. ‘slow’ contrast is not confounded by other factors (e.g. having more word cue trials among trials with fast responses), the RT median split was first done by the smallest cell of the design (e.g. switch L1 word cue) and then some cells were averaged as appropriate (e.g. average of all switch cells for the fast end of the distribution). A more fine-grained analysis (with smaller quantiles) was not feasible because of insufficient ERP epochs per quantile.

<sup>5</sup> Simply adding a further factor to the analysis (fast-slow) would have resulted in an inadmissibly low number of ERP epochs per cell. Because in the ERP analysis switch did not interact with factor language, it was removed from the analysis containing factor fast-slow.

by fast-slow by laterality interaction at 300-500ms,  $F(2,30)=3.64$ ,  $p=0.038$ ; ANOVAs for each laterality level revealed that on the right side of the scalp the positivity was reliably larger for the fast-response than for the slow-response trials (switch by fast-slow interaction,  $F(1,15)=5.22$ ,  $p=0.037$ ).

The observation that in the short CSI word cues resulted in a much smaller switch cost than anthem cues suggests a much earlier onset of control processes involved in language selection on word cue trials. One might therefore expect a much earlier onset of the posterior positivity following word cues than following anthem cues. This was indeed the case (see Fig. 2.12F): an ANOVA on the earliest (300-500ms) and latest (700-900ms) time-windows in the posterior positivity range found a significant switch by cue by time-window interaction,  $F(1,15)=6.77$ ,  $p=0.02$ . Follow-up time-window analyses by revealed for the word cue a significant main effect of switch for the 300-500ms time-window,  $F(1,15)=17.34$ ,  $p=0.001$ , but no significant effects involving switch in the 700-900ms time-window. For the anthem cue, there were no switch effects at 300-500ms, whereas at 700-900ms there was significant switch by anterior-posterior interaction,  $F(3,45)=11.04$ ,  $p<0.001$ ; follow-up ANOVAs for the anterior-posterior regions revealed a reliable main effect of switch in the occipital scalp region,  $F(1,15)=6.07$ ,  $p=0.026$ .

## DISCUSSION

The present investigation concerns an extensively documented brain potential, widely viewed as the most likely electrophysiological correlate of top-down control during a task switch (cf. Karayanidis et al., 2003; 2011; Lavric et al., 2008), yet to date absent in the research that has examined preparation for a language switch (Verhoeef et al., 2009b). Our ERPs revealed a robust deflection induced by a language switch that bore all the hallmarks of the posterior positivity reported in task-switching: positive polarity, posterior parieto-occipital scalp distribution, onset at ~400ms following cue onset, protracted time-course extending >200ms. Furthermore, ERP analyses based on RT distributions showed that, like the posterior positivity associated with a task switch (Karayanidis et al., 2011; Lavric et al., 2008), the language-switch-related positivity was considerably larger on trials with a small switch cost (fast-response trials) than on trials with a large switch cost (slow-response trials), indicating it is not epiphenomenal but predictive of

performance. The posterior positivity was followed by a protracted fronto-central negativity for switches, whose amplitude was not as clearly related to performance; late switch-related negativities with similar onset, duration and scalp distribution have been previously reported in task-switching studies that used long preparation intervals (e.g., Astle, D., Jackson, G. M., & Swainson, R., 2008b; Tieges, Snel, Kok, Plat, & Ridderinkhof, 2007). We therefore conclude that preparation for a language switch and preparation for a task switch result in similar ERP effects and, when effective, are reflected by the same electrophysiological signature: the posterior protracted ERP positivity. This suggests substantial overlap in control processes involved in anticipatory selection of task-set and of language for production.

However, one aspect of our results is unusual in relation to the task-switching literature: the spoken words “English” and “Deutsch” resulted in a very small switch cost at a CSI of only 100ms and there was no performance benefit of preparation for these trials (the switch cost actually increased for the word cue trials at the longer CSI) – in contrast, for the less transparent anthem cues, the switch cost was large in the short CSI and reduced at the long CSI, which is the pattern one typically observes in task switching. As already mentioned, our word cues are not only highly semantically transparent, but also likely to be extensively learned (‘internalised’) by the subjects long before they come to the lab. Such ‘supercues’ are not commonly employed in task switching – where tasks tend to be novel and the cue-task associations are only established during the experiment). In fact, language switching may provide a unique opportunity to examine their effect on performance. Our results suggest that the effect of ‘supercues’ is two-fold: (1) effective and timely recruitment of top-down control processes involved in selection; (2) associative activation of the target language, which is rapid and automatic, but also transient. The former is suggested by the robust and protracted switch-induced ERP positivity during the long CSI, the latter by the very small switch cost on the short CSI trials. We assume the associative activation process to be transient, hence the increase in switch cost in the long CSI. In contrast, a recently learned cue relies (nearly) exclusively on the slower top-down mechanism for selection.

## **CHAPTER THREE**

### **CAN BILINGUALS SET THEMSELVES INDEPENDENTLY FOR SPEECH AND COMPREHENSION?**

**Note:** Chapter 3 is presented in the format of a manuscript prepared for submission for publication in a peer-reviewed journal. Because the manuscript has several authors (whose contribution I acknowledge in Acknowledgements), the exposition is from the first person plural, rather than first person singular. Because it has to function as a stand-alone paper, it makes no references to other parts of the thesis and contains some repetition of themes already introduced in the preceding parts of the thesis (Chapters 1 and 2).

## **ABSTRACT**

In the language switching literature one critical aspect of control of language selection has been largely neglected: whether bilinguals can ‘set themselves’ independently for input and output. Unbalanced and balanced bilinguals switched between naming numbers in their first (L1) or second (L2) language in predictable runs of three trials, whilst also categorising auditory word probes presented unpredictably during the naming runs. The language of the auditory probes (L1 or L2) was the same for a series of 17 naming runs, but alternated over blocks. In two experiments we found evidence of a ‘language match’ effect on categorisation performance: the response was faster when the language of the auditory probe coincided with the language of the naming run during which the probe was presented, suggesting ‘leakage’ of control settings from output selection into input selection. L2 proficiency did not reduce the cross-talk substantially. There was little input-to-output cross-talk, judging by the absence of a language match benefit for naming – this asymmetry of cross-talk between input control and output control may be experience/practice-related. With regard to the relation between input and output pathways for speech, our results support models with independent lexica, but reciprocal connections.

## INTRODUCTION

Bi/multilingualism is increasingly common. Due to globalisation, the number of people whose command of one or more languages is at least comparable to that of their mother tongue is on the rise. But the growing interest in the bilingual mind is not motivated solely by prevalence. Increasingly, there is evidence for the tantalising possibility that language selection in bilinguals may have rather profound effects on one's cognitive system (e.g., Bialystok, Craik, Green, & Gollan, 2010; Colzato et al., 2008) extending beyond language processing per se into more 'general' control processes that ensure goal-directed prioritisation of behaviour in the face of interference/conflict from irrelevant stimuli and responses (Miller & Cohen, 2001). Bilingualism may even increase one's resilience to brain degeneration in dementia (e.g., Bialystok, Craik, & Freedman, 2007).

The synergy between the psycholinguistic and cognitive control approaches to bilingualism has received further impetus from research into task-set control, particularly the emergence of modern task switching paradigms (e.g., Meiran, 1996; Rogers & Monsell, 1995), in which one is presented on each trial with a stimulus that affords two tasks and asked to perform one task on some trials and another task on other trials; the task can thus change or repeat from one trial to another. These paradigms have also been used in language switching (e.g., Costa & Santesteban, 2004; Jackson, Swainson, Cunnington, & Jackson, 2001; von Studnitz & Green, 1997; 2002; Verhoef, Roelofs, & Chwilla, 2009). Several phenomena have been documented in language switching – which have empirical parallels in task switching. A change of language typically results in a 'switch cost' (Meuter & Allport, 1999), as does a change of task (Meiran, 1996; Rogers & Monsell, 1995). The cost of switching tasks is usually substantially reduced with opportunity for preparation (e.g. Rogers & Monsell, 1995; Lavric, Mizon & Monsell, 2008; Monsell & Mizon, 2006; Verbruggen, Liefoghe, Vandierendonck, & Demanet, 2007), and the reduction is interpreted as indexing endogenous (top-down) activation of a task-set (e.g. Monsell & Mizon, 2006). Similarly, advance warning (cuing) of which language is to be used sometimes (Costa & Santesteban, 2004, but see Philip, Gade, & Koch, 2007), results in a reduction in the language switch cost, which is similarly taken as evidence for the role of endogenous (top-down) control in language selection.

Another parallel that has received intense scrutiny (especially in language switching), is the observation that the switch cost is often larger when switching to the ‘stronger’ (more familiar or practised) language than to the ‘weaker’ one (e.g., Meuter & Allport, 1999; Costa & Santesteban, 2004), as is also true for task switching (Allport, Styles, & Hsieh, 1994; Yeung & Monsell, 2003). This ‘paradoxical asymmetry’ of switch costs has tended to be regarded in the bilingualism literature as a reflection of lexical inhibition (Green, 1998), which has to be more vigorous on trials on which the ‘weak’ language must be used, to prevent competition from the lexical entries of the ‘strong’ language and which persists into the subsequent trial (Meuter & Allport, 1999). Alternative accounts of the paradoxical asymmetry have been put forward in both language switching and task switching (e.g., Verhoef et al., 2009; Yeung & Monsell, 2003) – they are based on the notion that the ‘strong’ language/task has a high level of activation and thus competes for selection when switching to, or when repeating, the weaker task/language, whereas the weak task/language only competes for selection when switching to the strong task – thus response latencies associated with repeating the strong task/language are disproportionately fast due to the absence of competition. (For yet more accounts of the paradoxical asymmetry, see Bryck & Mayr, 2008, and Schneider & Anderson, 2010).

Further empirical overlap between language switching and task switching includes: the ‘mixing cost’ – inferior performance on repeat trials in blocks containing switches relative to trials in single-language (or single-task) blocks; the ‘n-2 repetition cost’ (or ‘backward inhibition’) – a detriment in performance caused by having to go back to the language/task used two trials ago – arguably the clearest evidence so far for the existence of inhibition at the level of language/task set (Philipp et al., 2007; Philipp & Koch, 2009; Mayr & Keele, 2000; Schuch & Koch, 2003); the effects of repeating the response made on the preceding trial – which improves performance on task/language repeat trials and hinders performance on task/language switch trials (e.g., Rogers & Monsell, 1995; Von Studnitz & Green, 2002).

In addition to these empirical phenomena that span specific domains of switching (though see, for example, Calabria, Hernández, Branzi, & Costa, 2012, for a dissenting view on the overlap in the factors causing switch cost asymmetries in language switching and task switching), researchers have also examined phenomena specific to language switching. One important observation is that the cost of changing the language for output is substantial, whereas changing the input language results in either a relatively trivial cost or no cost at all (Caramazza

& Brones, 1980; Dufour & Kroll, 1995; Eckhardt & Feldman, 1984; Von Studnitz & Green, 2002). This difference is qualified by another difference documented in visual word recognition: the switch cost is larger when one is asked to decide if a string is a word or a non-word (lexical decision task) in a particular language, than when lexical decision is not language specific (a string that is a word in either language would be categorised as ‘word’) (Thomas & Allport, 2000). A factor that may explain the above differences in switch cost between input and output, or between language-specific lexical decision and language general lexical decision is the amount of conflict the stimulus might elicit. Investigations of switching the language for output tend to use picture naming or digit naming tasks, in which the stimuli are bi(multi)valent – they afford different responses in the languages under consideration; confining selection to the target language is crucial and one can see how endogenous control may play an essential role there – indeed, the reported reduction in the language switch cost with (pre-stimulus) preparation (Costa & Santesteban, 2004; Verhoef et al., 2009) is evidence for endogenous selection ahead of lexicalisation. In contrast, in switching of receptive language, the stimulus tends to specify the response relatively unambiguously, except for cognate homophones which have the same pronunciation across languages, or when the category of the stimulus changes as a function of language, as in language-specific lexical decision. One may therefore not require top-down selection of input, except when the input is ambiguous. For example, to do the task of semantic categorisation, one can allow meaning to be activated regardless of the lexical vehicle, and there is no obvious need to select; in this task the switch cost is trivial or absent (cf. Von Studnitz & Green, 2002). In fact, one can think of situations in which top-down selection of the input language is disadvantageous – for instance when the language of the input is uncertain and one must identify it.

This leads to the question of whether one can select the output language irrespective (or independently) of the input language and vice-versa. It is not uncommon for bilingual speakers to concurrently use two languages during a conversation, a phenomenon known as ‘code switching’. This might result in a situation where a person speaks in one language but their conversational partner chooses to reply in another. In an informal conversational setting skilled bilinguals do not seem to experience obvious difficulties from having their input language set to  $L_x$  whilst their output language is set to  $L_y$ . However, beginners find simultaneous translation (extempore interpreting) very challenging. The present set of experiments investigated the

dynamics of the interaction between selection of expressive language and receptive language in conditions where the two can change independently. To explore the selection of expressive language, we employed an ‘alternating runs’ paradigm (cf. Rogers & Monsell, 1995; Jackson et al., 2001), in which the participant has to alternate between naming digits in two languages, in this case with predictable runs of three trials per language. In addition to this output language task, the participant was presented at unpredictable intervals with spoken word stimuli which had to be categorised semantically; the (input) language of these auditory ‘probes’ was constant within a block of ~50 naming trials (but changed over blocks), and the participant was informed of the input language in advance.

We reasoned that if one is able to apply language selection settings independently for input and output streams, then there should be little cross-talk between the settings and performance in one stream should be unaffected by the language settings in the other – for example, categorisation performance should not be affected by whether the naming language in the run during which the auditory probe is presented is the same or different from the language of the probe. Conversely, if selection settings cannot be applied independently to input and output, then one would expect some degree of coupling or ‘leakage’ of settings between input and output. One might expect such leakage to manifest itself as a ‘language match effect’ – to return to the example of classifying an auditory probe, performance should be better if the language of the probe matches the language of the naming run during which the probe is presented. One can also think of intermediate cases. In particular, it is conceivable, indeed plausible, that the bilingual’s endogenous control of selecting expressive language might be superior to that of selecting receptive language, because the former is more obviously (and more often) needed than the latter (see above discussion of differences in language switch costs in input and output tasks). In the latter scenario, one may expect input selection to be more susceptible to leakage of the output settings than the other way around – a stronger influence of the output selection parameters on input selection than vice-versa.

The questions above are related to a long-standing line of enquiry in the psycholinguistic and working memory literatures regarding the relation between lexical input and output pathways for speech. Two and a half decades ago, Monsell (1987) reviewed the then-available evidence in relation to six possible degrees of integration between these pathways: 1) separate; 2) separate with sublexical input-output links; 3) separate with sublexical input-output and output-

input links; 4) common sublexical but separate lexical representations; 5) separate sublexical but common lexical representations; 6) common sublexical and lexical representations. The evidence that is inconsistent with the extremes (models 1 and 6 above) has not been hard to come by. Neurologically normal individuals can easily shadow nonsense speech and there are patients who can repeat real words that they cannot comprehend (Bramwell, 1987/1984; Symonds, 1953; Warrington, 1975). In addition, Kohn and Friedman (1986) discussed two patients, HN and LL, who were both unable to comprehend a spoken word but could do so once it had been written it down. When asked to write down aurally presented words, patient LL tended to regularise the spelling of irregular words suggesting he may rely on a sublexical connection between the input and the output pathways (model 2). However, HN was able to correctly spell aurally presented irregular words which might indicate preserved lexical access, perhaps relying on a post-lexical links or shared processing stage between the input and the output pathways (models 3-6).

Priming studies have found that auditory identification is facilitated by the silent generation of a word's phonology (Gipson, 1984; 1986, Monsell, 1987), but not by counting the number of syllables (Gipson, 1984; 1986). Such findings are less compatible with models containing shared lexical representations such as models 5 and 6, and more consistent with models 3 and 4 which contain separate lexica connected by reciprocal input-output links. Though little evidence differentiates the latter two models, cases of anomia (production deficit with preserved comprehension) and word meaning deafness (comprehension deficit with preserved production) indicate that input and output phonology can be differentially impaired and this is not easily accommodated by model 4's shared sublexical representations. Thus, Monsell (1987) tentatively favoured model 3 with separate, yet reciprocally connected, sublexical representations. The outcomes from the current investigation may provide further evidence on the integration between input and output pathways for speech. For example evidence of cross-talk of selection settings between input and output would rule out separate pathways (model 1 above). Asymmetry of cross-talk (input-output vs. output-input) would speak against shared lexical representations (models 5 and 6).

## EXPERIMENT 5

In Experiment 5, English-French bilinguals were asked to alternate every three trials between naming visually presented numbers in French and English. At the same time, they had to be ready to perform semantic categorisation of an auditory probe word, – an object-name – which might replace the presentation of a visual number at any of the three positions in a run unpredictably. For a block containing 17 naming runs, the auditory probes were all spoken in one language, which might, depending on the current output run, be the same or different to the language which the participant was prepared to speak in that run. In some blocks the input language was English, in others French. We examined naming and categorisation performance as a function of naming (output) language, categorisation (input) language and position in the naming run.

## METHOD

### *Participants*

Sixteen English (L1) - French (L2) bilingual speakers, from the University of Exeter, most of whom studied for degrees in French language, provided informed written consent to take part in the study. Participants had a mean age of 23, ranging from 18 to 66; 12 were females.

### *Stimuli and tasks*

Participants were asked to name numbers 1-52 presented as numerals; 1-20 were test items (which were subsequently analysed) and 21-52 were used on filler trials (see below). The language alternated in runs of three trials (cf. Rogers & Monsell, 1995). The trial sequence was divided into 20 blocks each containing 16 such runs (48 trials) plus a warm-up run that could start at any of the three positions (randomly), resulting in a block length of 48 to 51 trials. In every block 12 visual numbers were replaced by auditory ‘probe’ stimuli (spoken words), denoting objects that had to be categorised as larger or smaller than a football. The language of the probes remained the same throughout a block but alternated over blocks. The language of the

probes in the first block was counterbalanced over participants. Participants were informed of the language of the probes before each block started. During a block probes were presented randomly at different positions in the naming run with the constraint that there could not be more than one probe per run. No digit was presented on the trial on which a probe was presented. Thus, a naming run could consist of two number (naming) trials and a categorisation trial, or three naming trials. If the categorisation trial was in position 1 or 2 of the run, then the numbers on the remaining naming trials were fillers; if the categorisation trial was in position 3 of the run, the naming trial in position 1 of the next run was a filler. This resulted in 20 naming trials per block (400 overall) that contained the subsequently analysed numbers 1-20, with each of these presented 20 times during the session.

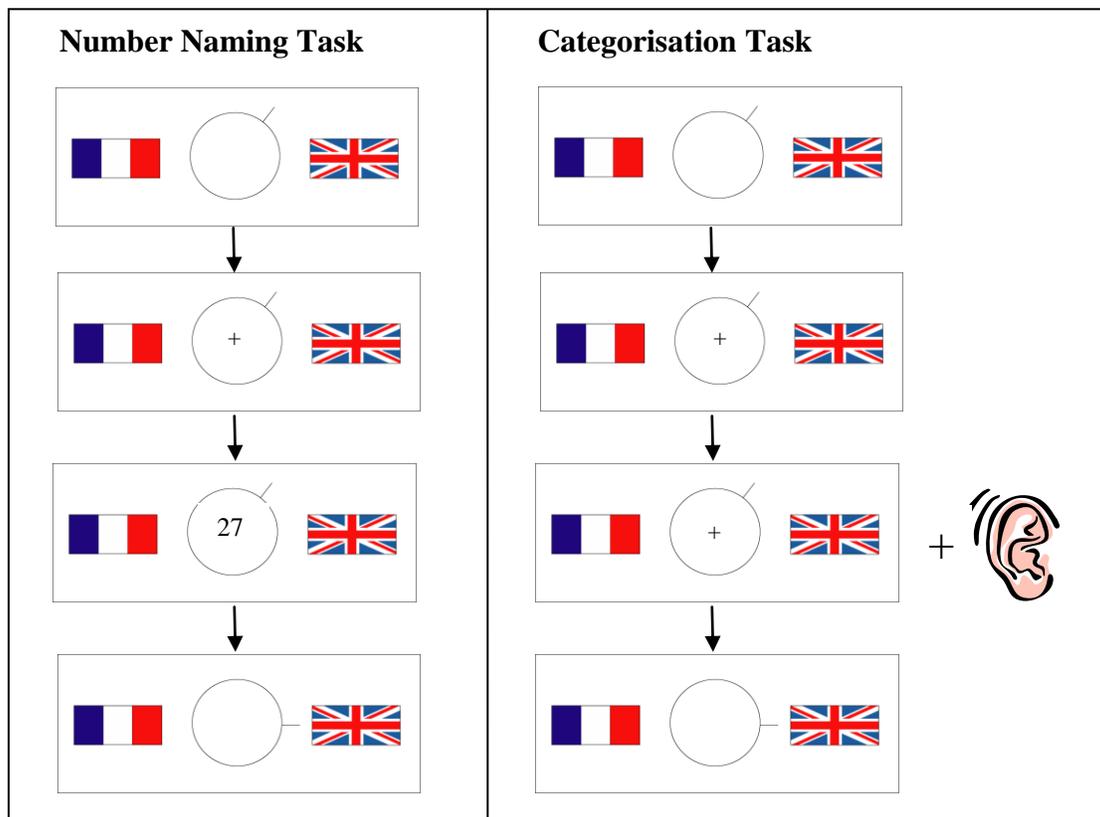
The probes were forty English concrete nouns and their French translations spoken by native speakers (one female speaker for each language; see Appendix five). The nouns were matched across languages for log frequency per million (English, 1.44; French, 1.50,  $F(1,78)=0.20$ ,  $p=0.653$ ) and spoken word duration (English, 600ms; French, 630ms;  $F(1,78)=0.75$ ,  $p=0.389$ ) and randomly divided into two lists with half of the items presented to each participant in L1 and half in L2. Half of the participants heard a particular word in English and half heard the same word in French. There were 240 probe trials overall, thus each probe was presented six times during the experiment – twice for each position in the naming run.

### ***Procedure***

On each trial, the number was presented centrally on a 17” CRT monitor using E-prime (Psychology Software Tools Inc, Pittsburgh, USA). It was surrounded by a redundant cue (see Fig. 3.1) consisting of a circle with six arms (only one of which was visible at any time), three arms pointed toward the Union Flag to indicate that the number should be named in English and three arms pointed toward the Tricolour to indicate that the number should be named in French. The trial started with a 1000ms blank screen in which the arm indicated the relevant language and run position. A fixation cross was then displayed for 500ms then replaced by the number to be named; the response-stimulus interval was thus 1500ms. A voice key triggered by speech onset recorded response times; the vocal response was also recorded digitally on a dictaphone. On some trials no number was displayed and instead the participant heard a probe word via a set of headphones and responded to the word’s category by pressing one of two keys on a standard

keyboard with the index finger of either hand. The next arm clockwise was then shown and the naming run proceeded to the next position irrespective of whether the stimulus was a number or an auditory probe.

Prior to the testing phase participants were familiarised with the cues and stimuli. Participants were given a printed list of the English words they would hear in the experiment with the French translation alongside. This was followed by a practice phase in which they heard each word in the language it would be presented in the experiment (20 in English and 20 in French) and were asked to repeat it. Subsequently participants were presented with each word for a second time and asked to categorise it as larger/smaller than a football. A third and final part of practice consisted of two blocks of naming/categorisation using the same design as in main part of the experiment (see above).



**Figure 3.1.** The structure of one trial. The cue consisted of a ‘clock hand’ line pointing to one of six positions. The fixation was either replaced by the number to be named (left hand panel) or

remained on the screen while participants heard an auditory probe. After a response was detected the line “ticked” clockwise to indicate the next run position.

### *Analysis*

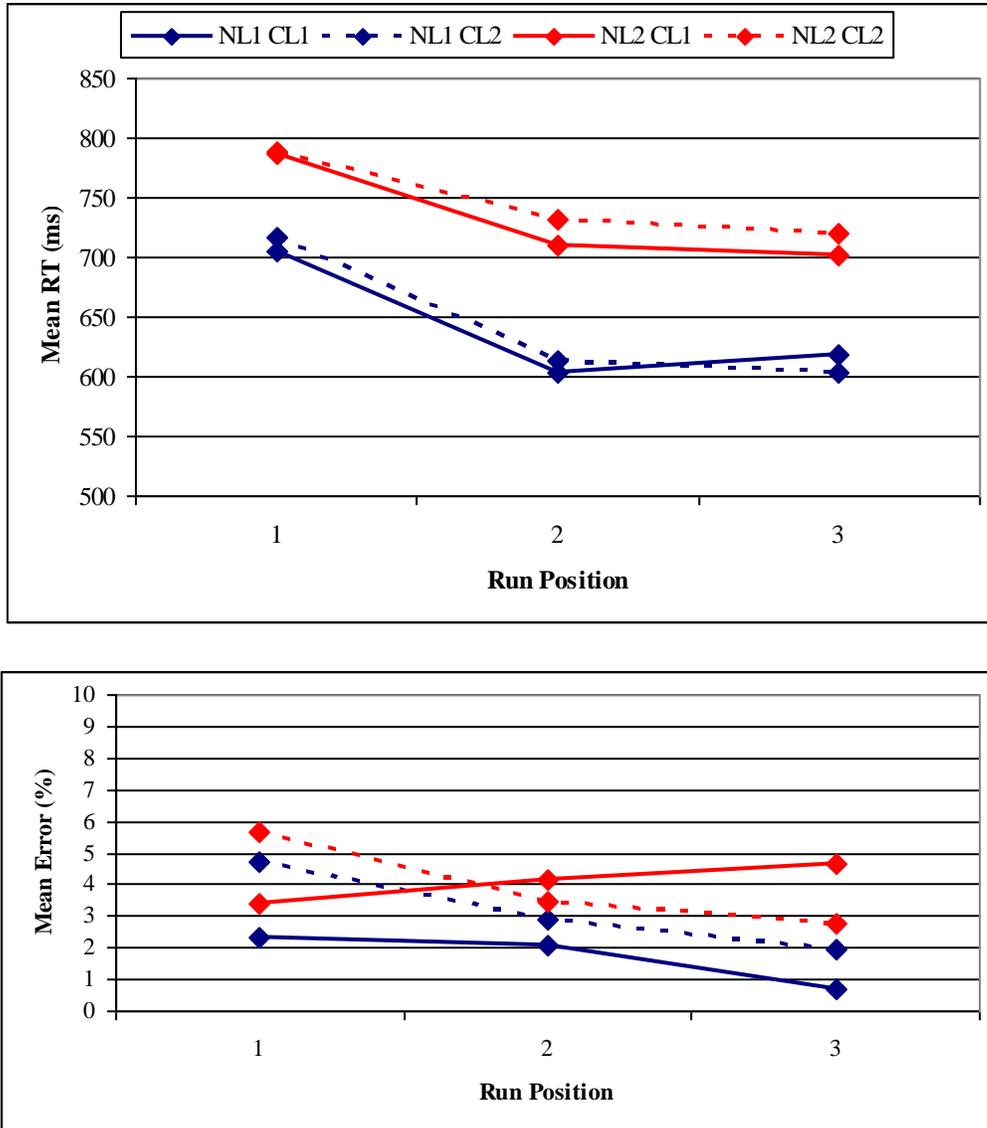
Trials following an error were discarded as these could not be safely classified as ‘switch’ or ‘repeat’. Naming trials were classified as errors if the participant named the digit in the wrong language even if they switched to the correct language part way through naming, or if they failed to make a response. Trials were also removed from the analysis if naming latency was less than 250ms or over 3s, or if categorisation RT were less than 500ms or over 5s. Response times (RT) and error rates were analysed by means of repeated measures ANOVAs with the factors input language (L1, L2), output language (L1, L2) and run position (1-3). If a match in the naming language and categorisation facilitates performance, this should be reflected in a statistically significant crossover interaction between naming language and categorisation language (e.g. better L1 naming performance during L1 categorisation blocks than during L2 categorisation blocks as well as better L2 naming performance during L2 categorisation blocks than during L1 categorisation blocks).

## RESULTS

### *Naming performance*

Figure 3.2 shows data plotted as a function of naming language, categorisation language and run position. Overall, naming was 97ms faster in L1 (643ms) than in L2 (740ms),  $F(1,15)=27.56$ ,  $p<0.001$ . There was a significant main effect of run position with longer naming latencies,  $F(2,30)=46.64$ ,  $p<0.001$ , reflecting the cost of switching the naming language (there was only a 4 ms difference in naming latencies between run positions 2 and 3,  $F(1,15)=0.71$ ,  $p=0.413$ ). The data were collapsed over run positions 2 and 3 to yield a switch-repeat contrast. As expected, the main effect of switch was highly reliable,  $F(1,15)=60.26$ ,  $p<0.001$ . Numerically, there was paradoxical asymmetry of switch costs – a larger switch cost in L1 (102ms; switch 711ms; repeat 609ms) than in L2 (71ms; switch 787ms; repeat 716ms), however the switch by language interaction did not reach significance,  $F(1,15)=3.05$ ,  $p=0.101$ .

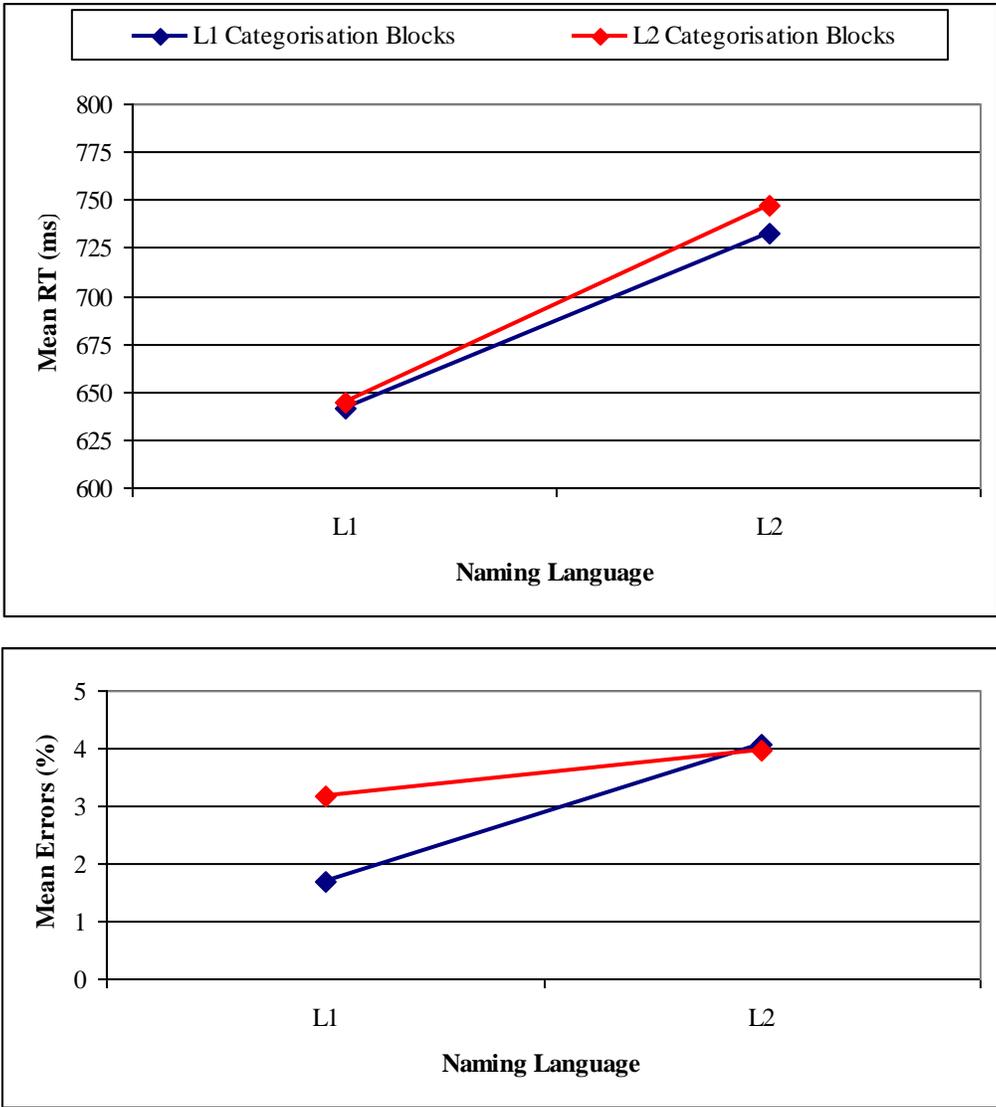
The error analysis revealed that responses were more accurate in L1 (2.43%) than in L2 (4.0%),  $F(1,15)=4.61$ ,  $p=0.049$ . Although participants made fewer errors at successive run positions, this difference was not reliable,  $F(2,30)=1.74$ ,  $p=0.192$ . The data were collapsed over run positions 2 and 3 to give a switch-repeat contrast; the switch did not reach significance,  $F(1,15)=3.19$ ,  $p=0.094$ . It was numerically greater for L1 (1.6%) than for L2 (0.8%), but the switch by language interaction was not reliable,  $F(2,30)=3.05$ ,  $p=0.101$ . Run position interacted significantly with categorisation language,  $F(2,30)=6.44$ ,  $p=0.005$ , reflecting a larger error switch cost for naming during L2 categorisation blocks (position one, 5.19%; position two, 3.16%; position three, 2.36%) than during L1 categorisation blocks (position one, 2.84%; position two, 3.11%; position three 2.68%).



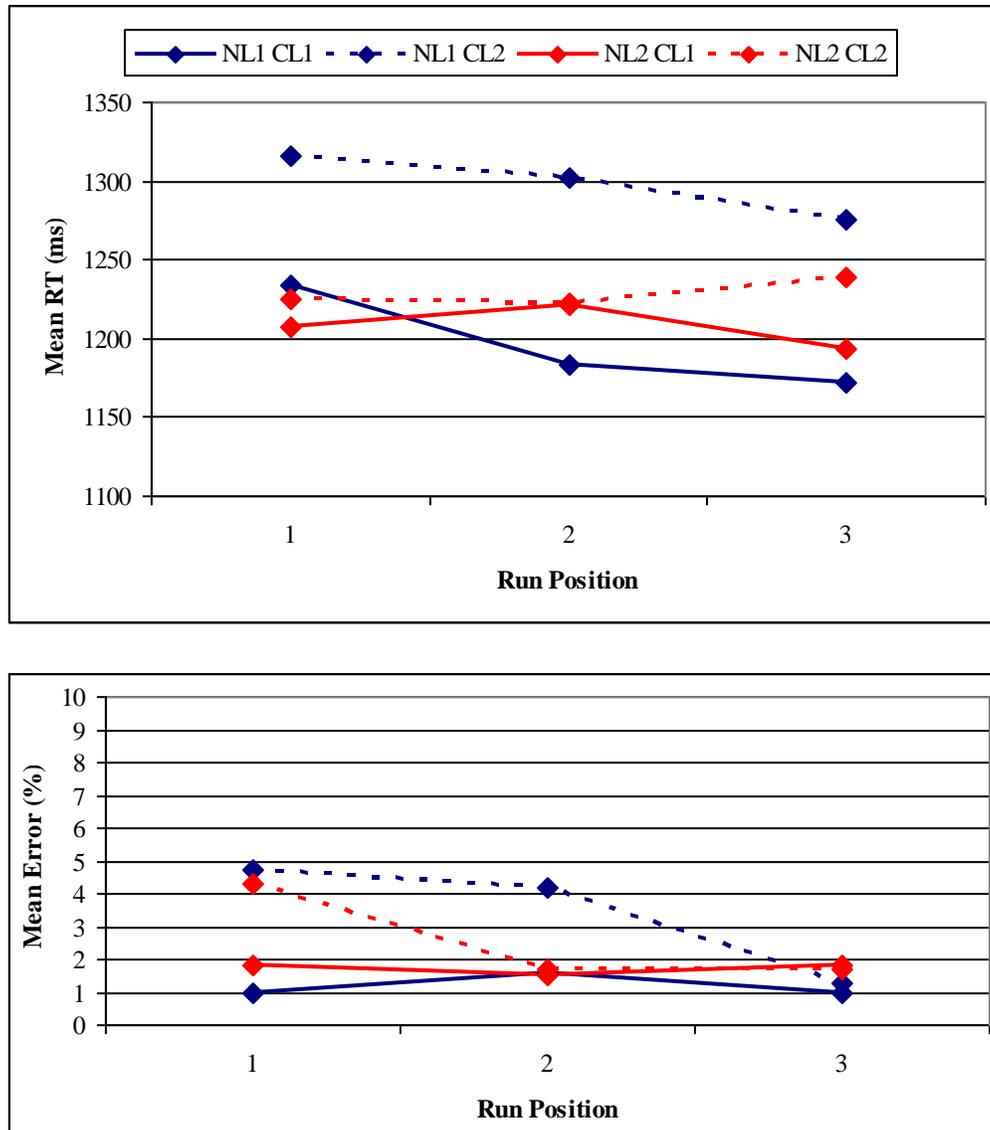
**Figure 3.2.** Naming latencies and error rates as a function of run position, naming language (NL) and categorisation language (CL).

*Effects of a language match on naming (see Fig. 3.3)*

Naming latencies did not seem to benefit when the language of the naming run was the same as that of the auditory probes (naming language by categorisation language interaction,  $F(1,15)=0.86$ ,  $p=0.368$ ). In the error analysis, there seemed to be some benefit in L1, with little or no difference in L2, however the naming language by categorisation language interaction did not reach significance,  $F(1,15)=3.16$ ,  $p=0.096$ .



**Figure 3.3.** The interaction between naming language and categorisation language (potentially indicative of a language match effect) for naming latencies and error rates.

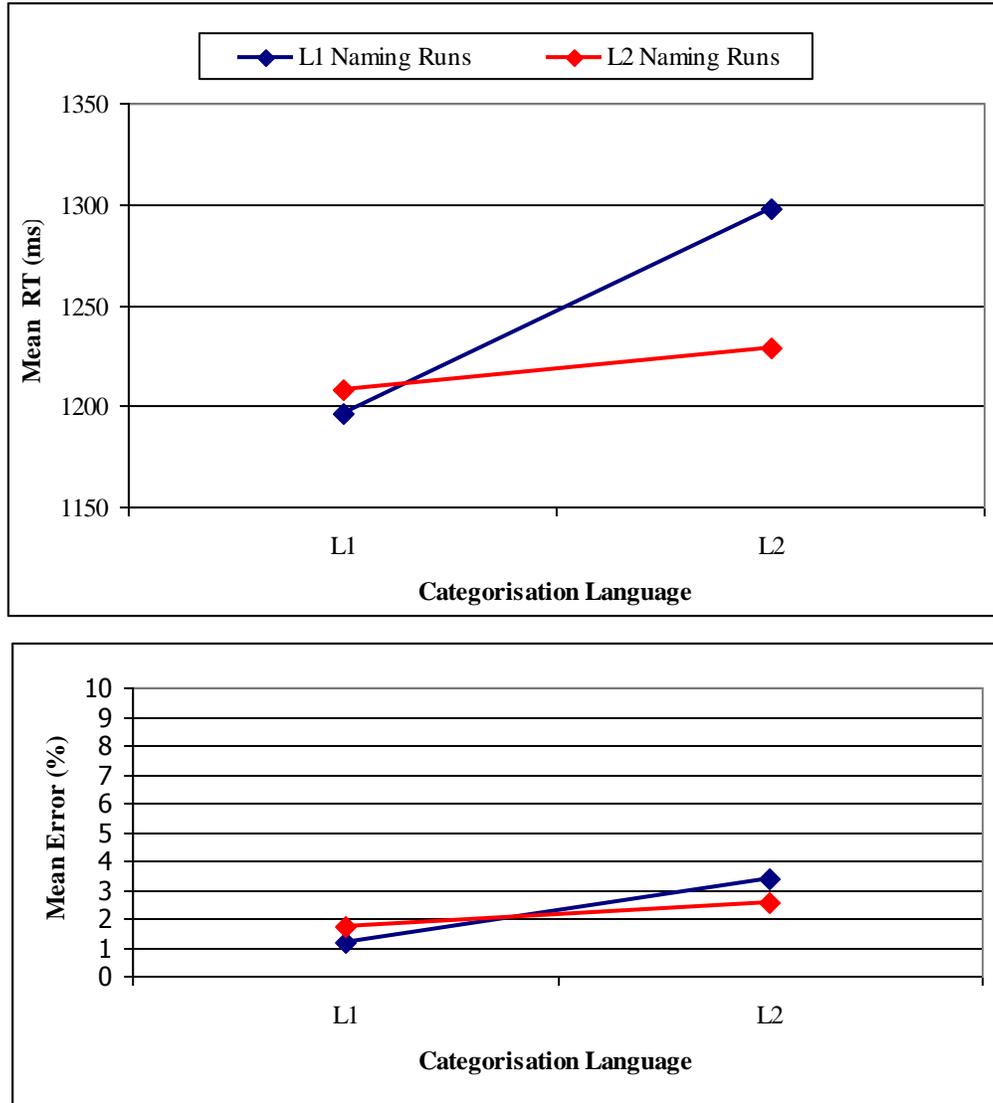


**Figure 3.4.** Categorisation RTs and error rates as a function of run position, naming language (NL) and categorisation language (CL).

### *Categorisation Performance*

Figure 3.4 shows the categorisation RTs and error rates. Overall, probes were categorised more quickly in L1 (1202ms) than L2 (1263ms),  $F(1,15)=12.54$ ,  $p=0.003$ , but this is qualified by an interaction with the concurrent naming language (see below effects of language match). Probes were also categorised more accurately in L1 (1.5%) than in L2 (3.0%),  $F(1,15)=4.72$ ,  $p=0.046$ .

Numerically, responses were faster when probes were presented later in the naming run, although this difference was not reliable,  $F(2,30)=1.25$ ,  $p=0.299$  (position one, 1246ms; position two, 1232ms; position three, 1220ms). Categorisation was more accurate with increasing run position (position one, 3.0%; position two, 2.2%; position three, 1.4%,  $F(2,30)=4.60$ ,  $p=0.030$ ).



**Figure 3.5.** The interaction between naming language and categorisation language (potentially indicative of a language match effect) for categorisation RTs and error rates.

### *Effects of a language match on categorisation*

Figure 3.5 shows categorisation latencies and error rates for probes that appeared during a naming run in the same language (language match) or in the other language (language mismatch). There was a reliable crossover interaction between categorisation language and naming language,  $F(1,15)=9.17$ ,  $p=0.008$ , indicative of a language match effect. Categorisation errors also showed a crossover interaction consistent with a language match benefit; however the categorisation language by naming language interaction was not significant,  $F(1,15)=1.19$ ,  $p=0.293$ .

## **DISCUSSION**

Our design combined switching of expressive language with categorisation of spoken words with the aim of determining whether one can exert control over language selection for output and input independently. The predictable character of the alternating runs paradigm (used in the number naming task) coupled with the long preparation (response-stimulus) interval encouraged advance selection of expressive language. The identity of the input language was also highly predictable, being varied only between blocks, encouraging setting oneself for the relevant input language during each block.

The analysis of the naming performance found the familiar ‘switching’ effects: a switch cost that was robust for both latencies and error rates, and a numerical trend for the switch cost to be ‘paradoxically’ asymmetric (see Introduction). However, the key outcome was in the input (categorisation) task: RTs were faster if the language of the probe matched that of the naming run, suggesting ‘leakage’ of the control parameters of output selection into input selection. The leakage was asymmetric with regard to the input vs. output pathways: whilst input selection was susceptible to cross-talk, the only match effect in the output (naming) task was a non-significant trend in the errors.

One effect of the input language on naming was the presence of a larger switch cost during blocks in which the input language was L2. This may reflect more general limits of control ‘resources’ and the fact that setting oneself in L2 may have been more demanding for

these participants who appeared to be ‘unbalanced’ with regard to the relative proficiency in L1 vs. L2. The fact that categorisation accuracy was lower early in the naming run (and RT slightly longer) may also reflect competition for a limited pool of control resources.

Returning to the match effect observed in categorisation, we note that it was considerably greater for L2, consistent with the input settings being more susceptible to effects of cross-talk for the (presumably) weaker L2. Although we did not assess the bilinguals’ L2 proficiency, the superior performance in L1 for both naming and categorisation is evidence that they were indeed unbalanced. An interesting (and important) question is how L2 proficiency may interact with the match effect we observed. Extensive practice in communicating and switching between languages might make the control of input less vulnerable to the ‘leakage’ of settings from control of output, reducing the match effect in L2 to the level of L1, or even eliminating the match effect altogether. In Experiment 6, we examine these possibilities by comparing balanced and unbalanced bilinguals using the same experimental approach. Testing unbalanced bilinguals also provides the opportunity to replicate the language match effect in the categorisation task.

## EXPERIMENT 6

In the current experiment, two groups of bilinguals – unbalanced English-German bilinguals and balanced German-English bilinguals – were tested using the same design as that in Experiment 5.

### METHOD

#### *Participants*

Thirty two bilingual participants gave informed written consent and were paid £7 per hour to participate. There were two groups of participants. The ‘unbalanced’ group consisted of sixteen English-native English-German bilinguals (12 females), aged between 18 and 24 (mean 20.5), most of whom were British students studying for a degree in German at the University of Exeter. They started learning German before or in secondary school or slightly earlier (mean age 11.5 years; range 7-16) and had all lived in German-speaking countries for an average of 1.75 years (range 1-6). The ‘balanced’ group consisted of sixteen German-native German-English bilinguals (11 female) aged between 18 and 44 (mean 28), all of whom started learning English before or in secondary school (mean 11 years; range 2-14) and had lived in English speaking countries for an average of 11 years (range 1-14).

Proficiency was assessed using a self-assessment questionnaire<sup>6</sup>. Unbalanced bilinguals reported speaking English (L1) every day and German (L2) at least two to three times a week, with the majority speaking German (L2) every day. Balanced bilinguals reported speaking English (L2) every day and German (L1) at least two to three times a week with the majority speaking German (L1) every day. The self-assessment also included self-ratings of proficiency in L2 speaking, reading, writing and listening. The mean scores out of 10 were: unbalanced group, speech 7.6; reading, 7.2; writing, 6.2; listening, 7.4; balanced group, speech 9.2; reading, 8.9; writing, 8.8; listening, 9.1. The difference between the two groups was significant for all four

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<sup>6</sup> Due to a hardware fault, the proficiency data from 5 subjects (four from the unbalanced group, one from the balanced group) were lost; the proficiency statistics are thus reported for the remaining 27 participants. The naming and categorisation data (collected from all 32 participants) confirm the differences between groups in the relative command of L1 vs. L2 (see Results).

measures; speech,  $t(25)=6.67$ ,  $p<0.001$ ; reading,  $t(25)=4.63$ ,  $p<0.001$ ; writing,  $t(25)=3.62$ ,  $p=0.005$ ; listening,  $t(25)=5.33$ ,  $p<0.001$ .

### *Stimuli, tasks and procedure*

The tasks and visual stimuli were the same as in Experiment 5, except that the filler numbers were the multiples of ten from 30 to 90 (this was done to avoid possible complications from the fact that for some numbers in German the units are named first, e.g. 25 is read as “five and twenty”). The cue was the same as in Experiment 5, only with the German flag replacing the French one. The auditory probes were 40 English words and their German translations, spoken by native speakers (one female speaker for each language), see Appendix six. The words were matched across languages for mean lexical log frequency (English, 1.2; German, 1.1;  $F(1,78)=1.57$ ,  $p=0.214$ ) and spoken duration (English, 695ms; German, 700ms;  $F(1,78)=0.45$ ,  $p=0.833$ ). The sequences of trials, procedure and practice sessions had the same structure as in Experiment 5. The naming and categorisation data were analysed in the same way as in Experiment 5, except that we now report the analysis for each of the two groups (unbalanced and balanced), as well as interactions of interest from an omnibus ANOVAs run with an extra (between-subjects) factor: group.

## **RESULTS**

### *Naming performance*

#### *Effects of Language*

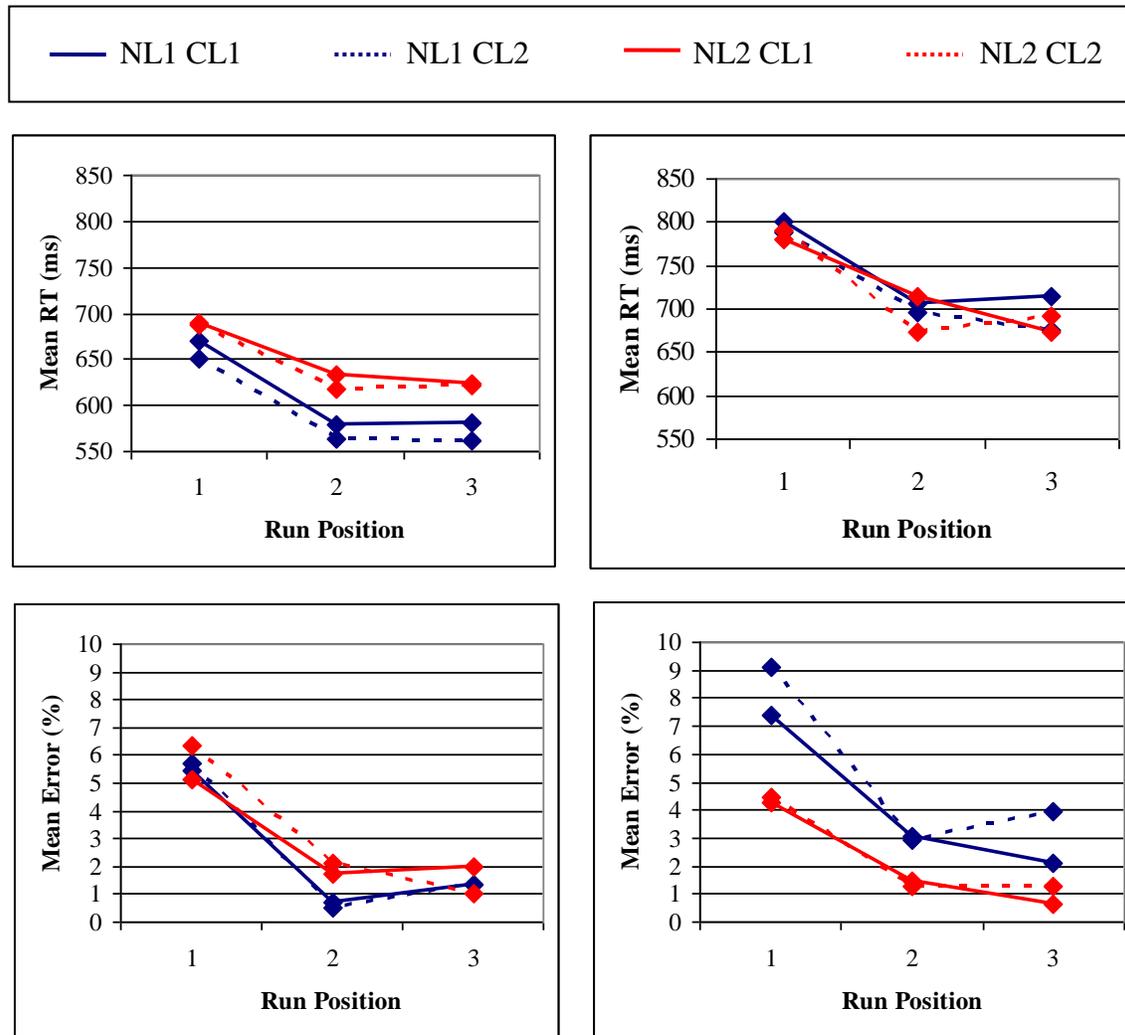
In the unbalanced bilinguals, naming latencies were 45ms shorter in L1 (600ms) than L2 (645ms),  $F(1,15)=22.43$ ,  $p<0.001$ . In the balanced group, this difference was non-significantly reversed: L1, 730ms; L2, 720ms;  $F(1,15)=2.44$ ,  $p=0.139$ , resulting in a significant naming language by group interaction in the omnibus analysis,  $F(1,30)=22.98$ ,  $p<0.001$ . The unbalanced bilinguals also made (non-significantly) fewer errors in L1 (2.5%) than in L2 (3.1%), whereas the balanced group made significantly more errors in L1 (4.7%) than in L2 (2.2%),

$F(1,15)=11.48$ ,  $p=0.004$ . This led to a reliable naming language by group interaction,  $F(1,30)=4.67$ ,  $p=0.039$ .

### *Effects of run position/switch*

Figure 3.6 shows naming latencies as a function of run position and categorisation language for both groups. There was a highly significant main effect of run position in both groups for naming latencies (unbalanced,  $F(2,30)=97.57$ ,  $p<0.001$ ; balanced,  $F(2,30)=28.52$ ,  $p<0.001$ ), as well as errors (unbalanced,  $F(2,30)=32.35$ ,  $p<0.001$ ; balanced,  $F(2,30)=21.14$ ,  $p<0.001$ ). The data were collapsed over run positions two and three to yield a switch-repeat contrast which also enabled tests of asymmetry of switch costs for the two languages. For both groups there were robust switch costs for latencies (unbalanced, 77ms,  $F(1,15)=112.52$ ,  $p<0.001$ ; balanced, 97ms,  $F(1,15)=36.47$ ,  $p<0.001$ ) and error rates (unbalanced, 4.3%;  $F(1,15)=48.45$ ,  $p<0.001$ ; balanced 4.23%,  $F(1,15)=25.15$ ,  $p<0.001$ ). Neither the analysis containing three run positions, nor the one that averaged over positions 2 and 3 revealed reliable switch by group interactions (all run positions,  $F(2,60)=1.17$ ,  $p=0.308$ ; averaged over run positions 2 and 3,  $F(1,30)=1.34$ ,  $p=0.257$ ).

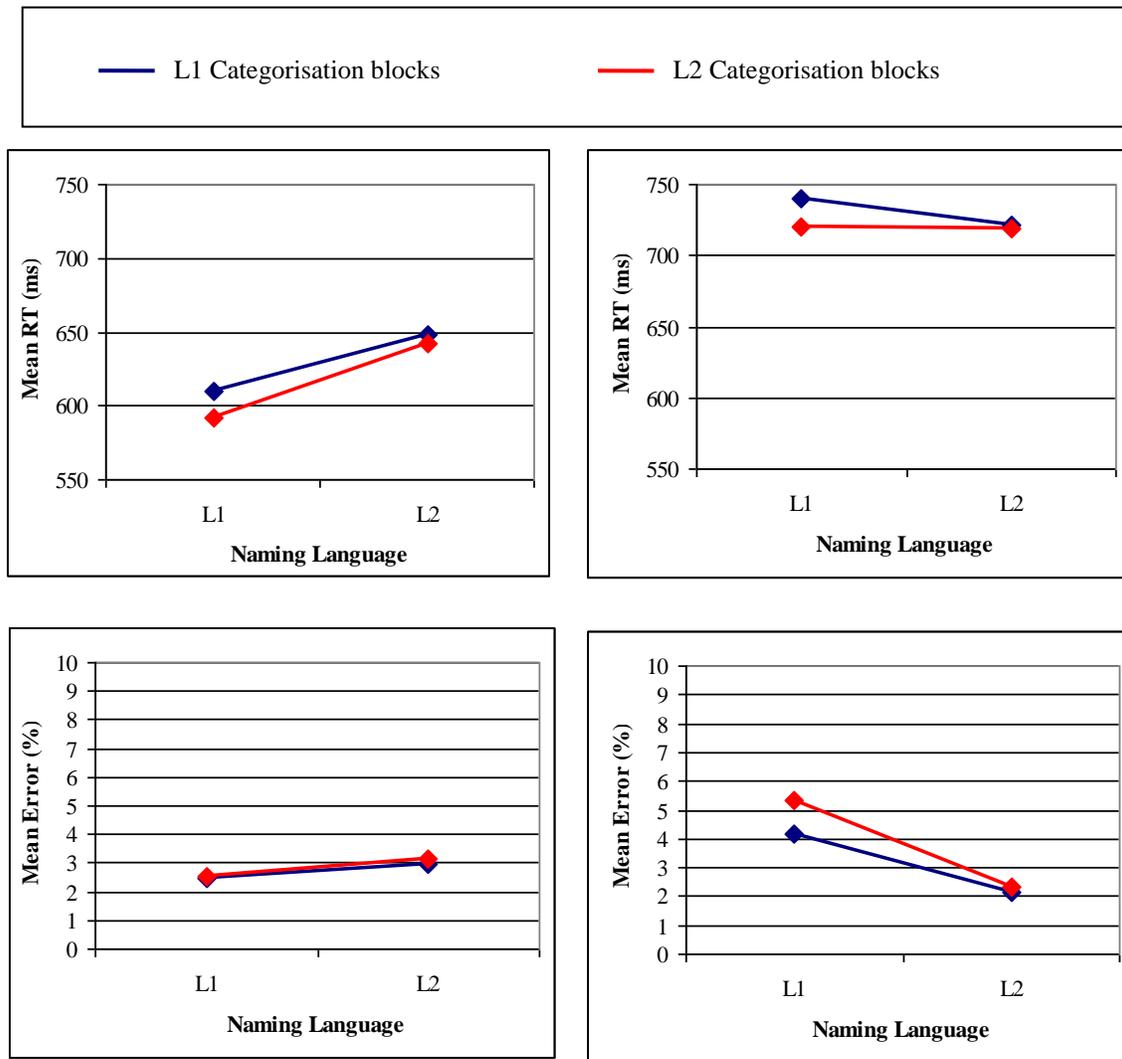
In the latency data, the switch by naming interaction was reliable for the unbalanced group,  $F(1,15)=6.29$ ,  $p=0.024$ , reflecting a larger switch cost in L1 (90ms cost; switch, 660ms; repeat, 570ms) than in L2 (63ms cost; switch, 688ms; repeat, 625ms). For the balanced group there was no difference between the switch cost for L1 (97ms cost; switch, 795ms; repeat, 698ms) vs. L2 (97ms cost; switch, 785ms; repeat, 688ms),  $F(1,15)=0.01$ ,  $p=0.927$ . This tendency for a stronger asymmetry of switch cost in the unbalanced group than in the balanced group (the switch by naming language by group interaction) did not reach significance,  $F(1,30)=2.06$ ,  $p=0.162$ . In the error data, the asymmetry of switch cost was not detectable in the unbalanced group (L1, 4.6%; L2, 4.0%,  $F(1,15)=0.95$ ,  $p=0.399$ ), but approached significance in the balanced group (L1, 5.2%; L2, 3.2%,  $F(2,30)=3.58$ ,  $p=0.078$ ); the interaction between switch, naming language and group was not significant,  $F(1,30)=0.90$ ,  $p=0.412$ .



**Figure 3.6.** Naming latencies and error rates for the unbalanced (left) and balanced (right) bilinguals as a function of run position, naming language (NL) and categorisation language (CL).

*Effects of categorisation language and language match*

Both groups had shorter naming latencies in blocks in which auditory probes were presented in L2 than in L1 (a main effect of categorisation language: unbalanced, CL1, 629ms; CL2, 617ms;  $F(1,15)=4.27$ ,  $p=0.057$ ; balanced: CL1, 731ms; CL2, 719ms;  $F(1,30)=10.48$ ,  $p=0.003$ ); unsurprisingly, the categorisation language by group interaction was not reliable,  $F(1,30)=0.01$ ,  $p=0.933$ .



**Figure 3.7.** The interaction between naming language and categorisation language (potentially indicative of a language match effect) for naming latencies and error rates for the unbalanced (left) and balanced (right) groups.

There was no suggestion of a language match benefit in the unbalanced bilinguals (see Fig. 3.7); if anything, there was a non-significant trend for a mismatch benefit for the latencies,  $F(1,15)=3.41$ ,  $p=0.085$  (errors,  $F(1,15)=0.03$ ,  $p=0.858$ ). In the balanced group the non-significant trend for a language match benefit in the error rates,  $F(1,15)=1.43$ ,  $p=0.247$ , was accompanied by a reversal in the latencies,  $F(1,15)=2.70$ ,  $p=0.122$ . In the balanced group there was a reliable three way interaction in the reaction data involving naming language, categorisation language

and run position,  $F(2,30)=5.82$ ,  $p=0.008$ , indicating a difference in the language match effects over successive run positions (see Fig. 3.5). There was a mismatch advantage (i.e. naming in Lx was slower when categorising in Lx than in Ly) or no difference for both languages in all run positions apart from L2 naming in run position 2 which was faster during L2 categorisation blocks than L1 categorisation blocks.

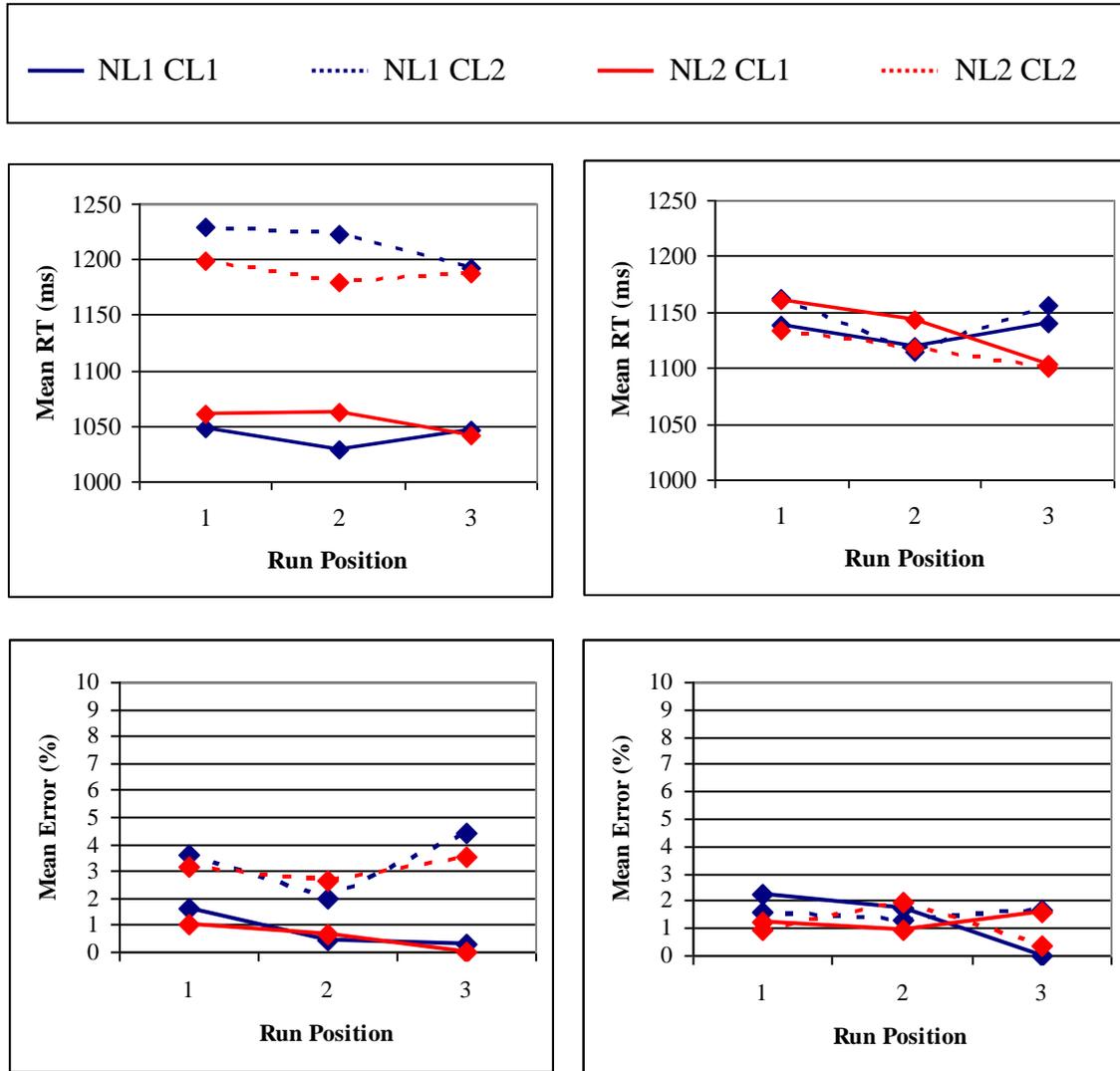
### ***Categorisation performance***

#### *Effects of categorisation language*

The unbalanced bilinguals made faster responses to auditory probes spoken in L1 (1048ms) than in L2 (1202ms),  $F(1,15)=73.74$ ,  $p<0.001$  and fewer errors in L1 (0.7%) than in L2(3.2%),  $F(1,15)=9.41$ ,  $p=0.008$ ; neither effect was present in the balanced group (L1, 1135ms, 1.30%; L2, 1131ms, 1.31%; RT,  $F(1,15)=0.04$ ,  $p=0.844$ ; error,  $F(1,15)=0.81$ ,  $p=0.371$ .) which resulted in reliable interactions between categorisation language and group for the RTs,  $F(1,30)=40.15$ ,  $p<0.001$ , and errors,  $F(1,30)=8.12$ ,  $p=0.008$ .

#### *Effects of run position/switch*

Categorisation RTs and error rates for each group are shown in the Figure 3.8 as a function of run position and naming language. In both groups there was a tendency for responses to be slower and more error-prone if probes were presented on run position one of a naming run than on run positions two or three, though the main effect of run position was significant only for the RTs in the balanced group (balanced group: RT,  $F(2,30)=3.72$ ,  $p=0.036$ ; errors,  $F(2,30)=1.84$ ,  $p=0.177$ ; unbalanced group: RT,  $F(2,30)=1.04$ ,  $p=0.367$ ; errors,  $F(2,30)=2.22$ ,  $p=0.126$ ). There were no interactions involving run position and group that were significant or approached significance.

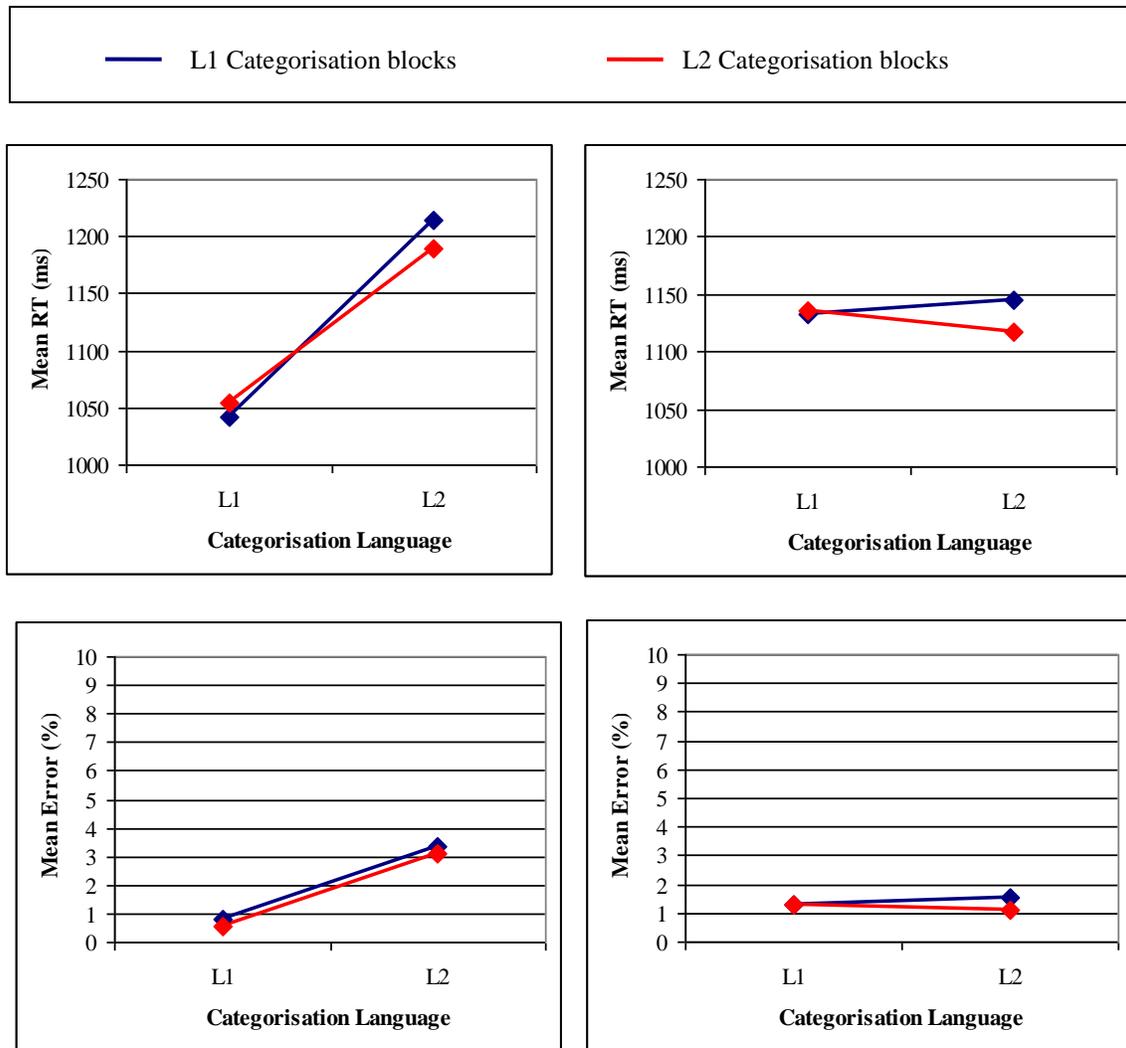


**Figure 3.8.** Categorisation RTs and error rates for the unbalanced (left) and balanced (right) bilinguals as a function of run position, naming language (NL) and categorisation language (CL).

*Effects of naming language and language match*

Probes were categorised more quickly when presented in naming runs of the same language (unbalanced, L1, 14ms; L2, 26ms; CL by NL interaction,  $F(1,15)=8.24$ ,  $p=0.012$ ; balanced, L1, 3ms; L2, 27ms; CL by NL interaction,  $F(1,15)=2.48$ ,  $p=0.136$ ). This language match effect (see Fig. 3.9) was also reflected in the omnibus ANOVA as a reliable categorisation language by naming language interaction,  $F(1,30)=8.80$ ,  $p=0.006$ ). Although this language match effect did

not reach significance for the balanced group over languages, L2 categorisation for this group was superior during L2 naming runs than during L1 naming runs (main effect of NL,  $F(1,15)=10.173$ ,  $p=0.006$ ); for L1 the match small match benefit was not significant. In the error analyses, the categorisation language by naming language interaction was not reliable (unbalanced,  $F(1,15)=0.00$ ,  $p=0.985$ ; balanced,  $F(1,15)=1.45$ ,  $p=0.247$ ).



**Figure 3.9.** The interaction between naming language and categorisation language (potentially indicative of a language match effect) for categorisation RTs and error rates for the unbalanced (left) and balanced (right) groups.

## **DISCUSSION**

In Experiment 5 categorisation of the auditory probes was superior if the language of the probe matched with that of the naming run. The aim of the current experiment was two-fold. First, we aimed to replicate the presence of the match effect in the unbalanced bilinguals. Second, we aimed to establish whether extensive and frequent use of L1 and L2 in balanced bilinguals reduces or eliminates this language match effect. An affirmative answer could be taken as evidence that the control of input language in balanced bilinguals becomes less susceptible to leakage from the settings of selection for production.

Several findings were strongly reminiscent of those of Experiment 5: there were robust effects of language switching in naming for both groups and paradoxical asymmetry of switch cost in the unbalanced group; categorisation performance was worse early in the naming run (on the switch trial) than later in the run (on the repeat trials) – though in Experiment 6 this was reflected most clearly in categorisation RTs (in the balanced group), rather than in the error rates as in Experiment 5. Most importantly, though numerically smaller than in Experiment 5, there was a language match effect in the categorisation RTs. The crossover interaction between naming language and categorisation language was present in both groups, though reliably so only for the unbalanced group; in the balanced group there was a significant match benefit for L2 accompanied with a small and non-significant numerical match benefit for L1; the match benefit in L2 had the same magnitude in the two groups.

## **GENERAL DISCUSSION**

One of the paradigms of choice for investigating language selection mechanisms in bilinguals and the potential role of endogenous (top down) control has been the language switching paradigm. A number of empirical phenomena have been documented in language switching; some of these empirical effects concern differences between change of receptive language and change of expressive language (see Introduction). However, one important aspect of language selection that has been neglected is the extent to which selection for input and selection for output overlap. Thus, the main question asked by the current study is whether bilinguals can ‘set themselves’ for input and output independently.

To answer this question we used a design in which number naming in one of two languages indexed output selection and semantic categorisation of spoken words indexed input selection or “tuning”. To encourage endogenous control of language selection, language changed predictably: across runs of three trials for the output task with a long response-stimulus interval to enable preparation (alternating runs, e.g. Rogers & Monsell, 1995; Jackson et al., 2001), but remaining constant for the input task over a relatively long blocks of trials (~50). Inasmuch as bilinguals have the ability to set themselves up independently for input and output, the fact that the language changed orthogonally in our output and input tasks should have served as an incentive to manifest this ability. We reasoned that if one can have independent control settings for input vs. output selection, then there should be little/no cross-talk between these settings. Conversely, evidence of leakage of control settings would suggest that input and output languages cannot be selected independently.

Before we discuss the evidence relevant for the issue of cross-talk of input and output selection settings, it is worth noting that, although the current design is a departure from conventional language switching paradigms, it yielded the familiar behavioural effects of language (and task) switching. There was a very robust effect of run position in the naming task and, like in previous research that employed the alternating runs paradigm (e.g., Rogers & Monsell, 1995), the cost of changing the language was confined to the first trial in the run. Consistent with the language switching literature, the switch cost was paradoxically asymmetric in the unbalanced bilinguals (e.g., Costa & Santesteban, 2004; Jackson et al., 2001). The presence of these basic language switching phenomena reassures us that our naming task tapped into the control processes typically recruited by language switching and task switching.

The key outcome of the study is the presence of a language match effect in the categorisation task: responses were faster when the language of the auditory (spoken word) probe was the same as that of the naming run. This effect was present in both experiments and (at least for L2) for both balanced and unbalanced bilinguals in Experiment 2. The match effect was substantially larger in L2 than in L1 – and this asymmetry of the match effect over languages was not reduced by L2 proficiency (in balanced bilinguals). In contrast to the categorisation data, there was no statistically detectable benefit of naming in the same language as that of the categorisation task (vs. in the other language). This suggests greater leakage of control settings from output selection into input selection than vice-versa. As we discussed in

Introduction, there may be more need for the bilingual to evolve an effective endogenous mechanism for output selection than for input selection. First, it is easy to think of situations for which early selection would be disadvantageous (e.g. when one attempts to determine whether the input is in one language or another). Second, there are often phonological cues (and orthographic or even alphabet/script-related cues for visual input) that are likely to drive bottom-up selection of the input language. We therefore view the presence of a language match benefit in categorisation, but not naming, as a consequence of the fact that bilinguals are more capable of exerting effective/robust control over their output language than over their input language. One potential objection to this conclusion is that bilinguals may be capable of exerting effective control over the selection of input language, but our input task did not require such selection – our participants could let the spoken words activate the relevant meaning automatically. We already discussed the characteristics of the design that were likely to encourage top-down selection: switching tasks and languages, switching both input and output languages, the orthogonality of the time-courses of language switching for the input and output tasks, the slow and predictable alternation of the input language. We would argue that if these conditions were insufficient to encourage (attempts at) endogenous selection, then it is difficult to think of conditions in the bilingual’s daily linguistic environment that would.

Our results also have implications for the long-standing line of enquiry into the relation between input and output pathways to speech. Returning to the classification of degrees of integration between the input and output pathways proposed by Monsell (1987; see Introduction), our results are not consistent with models that assume completely separate pathways (model 1), otherwise one should not observe language match effects. The fact that the effects of output on input were greater than the other way around speaks against models lacking output-input links (models 1 and 2), but also possibly against models that have one (integrated) input-output lexicon (models 5 and 6). This leaves, as in the original discussion by Monsell (1987), models 3 and 4 (separate lexica but reciprocal links between pathways), with little evidence in the current data to decide between them.

To conclude, our investigation sought to answer the question “can bilinguals set themselves independently for input vs. output?”. Our results point to a negative answer, with the qualification that the ‘contamination’ of input selection parameters by output selection parameters is greater than vice-versa. This leaves open an important issue – that the extent to

which selection in one pathway is independent from the other may be shaped by experience/practice/expertise. Our language match effect did not (clearly) distinguish between unbalanced and balanced bilinguals – but that could be because even balanced bilinguals may not need very often to control selection in the input pathway. But, there may be individuals for whom it is often critical to exert tight control over the input: would they be more able to ‘seal’ it to prevent cross-talk from the output pathway? Research on simultaneous translators might provide the answer.

## CHAPTER FOUR

### GENERAL DISCUSSION

In this thesis I sought to answer two main questions, which is reflected in the simple structure of the empirical part of the thesis – with one chapter dedicated to each question. In what follows, I summarise and discuss the answers my experiments have (or have not) provided to each of these questions.

#### *Is preparation for a language switch like preparation for a task switch?*

The first part of the thesis investigated whether a bilingual speaker can prepare for a change of language in the same way one prepares for a change of task. First, I attempted to deal with the fact that the language switching literature has not always been sensitive to methodological developments in task switching. I sought to develop a behavioural paradigm that would address known methodological problems, some of them still prevalent in the language switching literature. It seemed particularly important to address the confounds of cue change and task change and of active preparation with passive decay of inertia (see Chapter 1). There were other important methodological aspects related to the optimality of the design, including the sensitivity to the switch-repeat contrast as a function of the switch probability, the need for more than two preparation intervals for estimating the preparation function and the residual (asymptotic) switch cost, the type of cue and the optimal cue duration that would result in effective preparation for a language switch. Based on the task switching literature that has dealt with the above (and other) issues (e.g., Meiran, 1996; Monsell & Mizon, 2006; Verbruggen et al., 2007), I chose a set of parameters and tested them in my first experiment.

Experiment 1, in which I tested unbalanced English-French bilinguals, did not reveal a robust reduction in the language switch cost with increasing the preparation interval (CSI). Only for the trials on which the cue was taken off the screen after a relatively brief presentation interval was there modest evidence of a RISC effect – although the critical interaction between switch and CSI was not significant, the linear component of this interaction was. After Experiment 1, it seemed that further optimisation of the paradigm could pay off. One factor

reported in some task switching studies that seemed to influence preparation was trial-to-trial predictability of the preparation interval. Indeed, Rogers and Monsell (1995) found that an unpredictable preparation interval is not conducive to advance TSR and does not result in a RISC effect (though see Monsell & Mizon, 2006 for a different result in task-cuing). I therefore modified this aspect of the paradigm and varied the CSI over blocks in the subsequent experiments. Furthermore, in task switching there is evidence that semantically transparent cues (especially word cues) often result in better performance, lower switch costs and, sometimes, in superior preparation effects (e.g., Elchlepp et al., 2012, found preparation effects with univalent stimuli only following word cues). The potential use of linguistic cues also provided the opportunity for contrasting them to cues that were less transparent. Thus, I also modified the cuing parameters of the design.

Following these changes, I conducted Experiment 2. Despite all the efforts, the RISC effect remained somewhat elusive – it was present numerically for L2, but was (non-significantly) reversed in L1 and the statistical evidence for its presence in L2 came only from the linear trend in the switch by CSI interaction. A further potentially important factor to consider was L2 proficiency. It seemed likely that in the group of bilinguals tested in Experiment 2 (whom I classified as unbalanced based on their self-assessed proficiency and time spent in a L2-speaking country) the trend for a reversed RISC in L1 reflected some sort of bias towards L2 (or towards preparing for L2). Since there was no reason to expect such an effect in balanced bilinguals, it seemed potentially informative to test a balanced group. Furthermore, to my knowledge, the only published report of a (statistically significant) RISC effect in switching the language for output has originated in Costa and Santesteban's (2004) experiments with balanced bilinguals. It therefore seemed conceivable, even plausible, that L2 fluency might modulate the bilingual's ability to apply effective top-down control to language selection.

Hence, I decided to test a (more) balanced group of bilinguals in Experiment 3. The paradigm remained unchanged (from Experiment 2), the only difference being the change of L1 and L2 – this change was dictated by demographics: it was difficult (or nearly impossible) to find in the relatively small city of Exeter a suitable (and sufficiently large) sample of balanced English(L1)-French(L2) bilinguals; I therefore tested German(L1)-English(L2) bilinguals. The naming latency data in Experiment 3 were encouraging – there was a numerically robust (and statistically significant) RISC effect and there was no suggestion of reversed RISC in L1.

Subsequent analyses showed that the RISC effect in the latency data was driven primarily by the semantically opaque (anthem) cue, for which the effect was rather large (a reduction from the shortest to the longest CSI of over 60%). However, the error rates showed a reversed RISC which was also statistically significant. The opposing trends in the switch by CSI interaction for latency and error rate complicate interpretation, because they leave the possibility that the observed reduction of switch cost for latencies was, at least to some extent, due to response criterion differences on the switch trials in the long CSIs vs. short CSI (subjects may have been more cautious in the short CSI switch trials, hence longer latencies and smaller error rates). Alternatively, on some switch trials in the long CSIs participants may have lost the iconic memory of the auditory cue (whose duration was only 300ms), which may have resulted in a higher proportion of language selection errors. It does not seem that the data can distinguish between these interpretations.

At that juncture (after Experiment 3), one could subscribe to one of (at least) three different conclusions regarding the RISC effect in the first three experiments. One could say that (1) the RISC effect in switching language for speech is mercurial and less robust than in task switching because subjects in language switching exert less top-down control during the preparation interval. Another conclusion would be that (2) advance top-down control is applied, but it is less effective in reducing the language switch cost than the task switch cost because of the way cognitive control processes interact with linguistic processes (lexical selection). Finally, one could conclude that (3) there is advance top-down control in language switching, which is as effective as in task switching, but that, despite the efforts, I still have not identified the optimal paradigm for detecting its effects. As I was pondering over these interpretations, Verhoef et al. (2009b) published a language switching experiment, whose paradigm shared many features with mine (Introduction to Chapter 2 contains a detailed description of the study). Crucially, contrary to their expectation, Verhoef et al. failed to find during preparation for a language switch the EEG/ERP component believed by many to be the ‘signature’ of preparing for a task switch – the switch-induced posterior preparation positivity (see Chapter 1). Furthermore, Verhoef et al.’s interpretation of this apparent discrepancy between language switching and task switching was that the posterior positivity may reflect response-related preparatory processes, which are not required in language switching. Thus, Verhoef et al.’s results could be seen to support the view (1) above – namely that (some of) the reconfiguration processes that can be done in advance in

task switching are not required in language switching, hence the absence of the switch-induced posterior positivity in Verhoef et al.'s data (and the elusive RISC effects in my experiments).

However, a careful inspection of Verhoef et al.'s ERPs does show some switch-related posterior positivity (at least numerically) with an onset consistent with the task switching ERP literature. Hence, I decided to test in Experiment 4 for the presence of the posterior positivity using a slightly modified version of the paradigm developed in Experiments 2 and 3. The only substantive change to the paradigm was the removal of the two intermediate CSIs to increase the number of trials per cell for the ERP analysis. The key finding of the ERP experiment (Experiment 4) was that, contrary to Verhoef et al.'s (2009b) report, preparing to switch the language elicited a robust posterior positivity (compared to repeating the language). The positivity had a very similar scalp distribution and time-course to that observed in task switching. For the anthem cue, the positivity was evident from ~450-500ms following the cue onset, which is typical in task-switching. For the word cue, the positivity had an earlier onset (~250-300ms) and was somewhat larger in amplitude (though the latter was not evident in the statistical analyses by time-window). Further analyses of the ERPs based on RT distributions showed that, as in task switching, this language switch-induced positivity was larger on trials with fast responses and a small switch cost than on trials with slow responses and a large switch cost. The ERPs during the CSI also revealed a switch-induced fronto-central negativity, which followed the posterior positivity (with an onset at ~1000-1100ms following cue onset). Negativities with a similar scalp distribution have been reported in task switching studies, particularly in studies that employ long CSIs (of 1s or more). The magnitude of the negativity was also somewhat reduced on the slow response trials, but the reduction was not as pronounced as it was for the posterior positivity, nor was it statistically significant. The behavioural results from Experiment 4 were consistent with those in Experiment 3, with a RISC confined to the anthem cue (significantly so in the median<sup>7</sup> analysis). Word cues showed a reversal of the RISC effect – a result not too dissimilar from that seen in Experiment 3 for the word cues.

Now I will return to the three different interpretations of the outcomes from Experiments 1-3 (see above). The pattern of switch-related ERP effects (which is highly reminiscent of the effects of preparation for a switch in task switching) is not consistent with conclusion (1).

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<sup>7</sup> I have run median analyses for all four experiments in chapter 2. I chose not to report them for Experiments 1-3 in the interests of readability and because there were no substantive differences between the two analyses.

Inasmuch as the posterior positivity (and perhaps the fronto-central negativity) reflect(s) top-down control, such control does appear to be exerted when one prepares to change the language for speech. However, it is not clear whether these results can decide between conclusions (2) and (3). On the one hand, the analysis of the positivity based on RT distributions suggests that the processes it reflects do result in effective reconfiguring of the language selection settings. On the other hand, for one of the cues (the word cue) opportunity to exert control results in no better (even somewhat poorer) performance relative to the condition when the preparation interval is only 100ms. The analysis I provided in the Discussion of Experiment 4 was that word cues may activate the target language associatively (and automatically), but also trigger top-down selection (hence the robust positivity following the word cues). If one assumes the associative mechanism to be highly effective but transient, one may be able to explain the lack of a RISC effect (or even a reverse RISC) for the word cue trials: on the long CSI trials activating the target language might rely more (or exclusively on) top-down selection.

To conclude, I would answer the question posed in the title of Chapter 2 by stating that the control mechanisms recruited during preparation for a language switch are likely to overlap with (be equivalent to) those recruited during preparation for a task switch. However, what remains unclear is whether top-down control is as effective in language selection as it is in task selection. There is a further (separate) aspect of Experiments 1-3 that merits discussion: the contribution of stimulus-language associations to the language switch cost. An influential line of thought in task switching attributes (at least part of) the switch cost to associative ‘reactivation’ of task-sets by stimuli via stimulus-task bindings (see Chapter 1). The experimental design used in Chapter 2 enabled a comparison of trials on which the language was the same as on the last encounter with the same stimulus with trials on which the language was different from the language used on the last encounter with the same stimulus. I was also able to examine whether this effect of associative history was greater on switch trials than on repeat trials. The results from this analysis were clear: associative history had a robust effect on performance (in some cases comparable in magnitude to the switch cost), however it did not interact with language switching. This means that in selecting language for production, the stimulus-language bindings do not seem to contribute to the switch cost.

Though clear-cut, the latter finding may seem nevertheless surprising in relation to the task switching literature. The mechanism by which associative history is thought to modulate the

task switch cost is via the interaction with task-set inertia – the stimulus activates the irrelevant task-set more strongly on a switch trial because the irrelevant task-set is more active due to task-set inertia. To explain the present result, one would either have to conclude either that there is no strong interaction between stimulus-language bindings and inertia or that there is no inertia of language selection settings. The former seems more likely. It is also worth mentioning that, although the dominant narrative in the literature is that stimulus associative history contributes to the switch cost, its empirical basis has come from a relatively small set of experiments conducted by one group of researchers. Monsell (2007, presentation at EPS July meeting; manuscript under review) also investigated the effects of stimulus-task bindings, and (like me) found clear effects on performance, but no effects on switch cost (i.e. associative history did not affect the switch trials more than it affected the repeats). Thus, one should perhaps cautiously conclude that associative history interacts with the switch cost, but only under specific circumstances (whose boundary conditions are to be determined).

### ***Can bilinguals set themselves independently for speech and comprehension?***

The second part of the thesis was also concerned with top-down control of language selection – though a different aspect of it. I have been interested in the extent to which one is able to select the language for production while also ‘tuning’ to a conflicting auditory input. In the psycholinguistic literature on speech production and comprehension, as well as the working memory literature, there is a long-standing line of study of the relation between the input and output pathways (presented in detail in Chapters 1 and 3). However, in the bilingualism and language control literatures this theme is almost absent. For instance, in language switching, there has been research into the cost of switching language for input (and its comparison to switching language for output) (e.g. Jackson et al., 2004; Thomas & Allport, 2000; Von Studnitz & Green, 2002), but the concurrent control of input and output language has not, to my knowledge, been investigated thus far.

In the last two experiments of my thesis, I adapted the alternating naming runs paradigm (e.g. Jackson et al., 2001) by adding an additional auditory semantic categorisation task: on an unpredictable subset of trials auditory probe words replaced the visual numbers about to be named. Depending on the perspective one takes, this can be seen as dual-tasking situation (at the time when the probe is heard, one is still preparing to name the number), or a task switching

situation (one switches from naming to categorisation and the switch is cued by the onset of the auditory stimulus). Regardless of which of these perspectives is adopted, I reasoned that if one is capable of independently selecting the language for naming and tuning for the input language, there should be no benefit when the input and output languages match relative to when they do not. Conversely, if the control settings for output ‘leak’ into tuning for input (or vice-versa), this should reveal a language match effect.

The results were relatively clear: both experiments revealed a language match effect (superior performance when input and output languages matched then when they did not) for the input task – semantic categorisation. There was little indication of a match effect in the output task – number naming. This central result seems to suggest greater leakage of output selection settings into tuning for input than the other way around, which I tentatively interpreted as an effect of practice/experience – outside the laboratory, selection for input is rarely critical, whereas selection for output often is. The latter consideration may also explain why L2 fluency did not seem to modulate the language match effect in categorisation in Experiment 6 – balanced bilinguals may not be more often in the situation of a critical need to select the language for input than unbalanced bilinguals. There is however one group of individuals for whom selection for input is rather crucial – simultaneous translators. If I am to continue this line of research, they certainly hold some important answers. In addition to the asymmetry of cross-talk between input and output, there was also some asymmetry between languages – as one might expect the match effect was greater for L2, probably due to the more rapid bottom-up selection (via the phonological and lexical cues contained in the probe) when the input language was L1.

The results from Experiments 5 and 6 are also ‘new evidence for an old debate’ – they have relevance for the issue of the relation between pathways for comprehension and production (cf. Monsell, 1987; see Chapter 1 and Introduction to Chapter 3). The presence of a match effect is inconsistent with models postulating completely separate pathways, and the asymmetry of cross-talk (leakage only in one direction) is inconsistent with models postulating a shared lexicon used by both the input and the output pathways. My data also speak against separate pathways with input-output links but without output-input links; indeed the leakage of output settings into input selection (which presumably led to the match effect in the categorisation task) could not occur without an output-input link. This seems to leave two possible relationships between input and output (of the six outlined originally by Monsell, 1987): separate lexical and sublexical

representations but with reciprocal sublexical links, or separate lexical, but common sublexical links. I do not see how my present data are able to decide between them.

### ***Where does one go from here?***

I regard the research described in this thesis as only a beginning. And, as with any beginning, there is scope for improvement/optimization. One methodological aspect of this research that I view as most in need for improvement is the assessment of proficiency in bilinguals. The development and application of an objective measure of proficiency both for L1 and L2 would be something I would start with if I would continue to examine the role of proficiency. With regard to the two specific research topics described in the thesis, here are some considerations on potentially fruitful ways forward.

If I continue the research into preparation for a language switch, I would first attempt to address the increase in the error switch cost with CSI in experiments 2-4. To deal with the possibility of fading iconic memory for the cue I would return to visual cues and keep them on throughout the CSI (previous task switching experiments have detected large RISC effects using cues that remained on display throughout the cue-response interval). The clear differences between the word cues and anthem cues, as well as the pattern of performance with word cues over CSIs, suggest that the effect of word cues may be complex and that mixing them with less effective cues may elicit extra strategies and variability in the participant's performance, thus leading to poorer estimate of the RISC effect. Therefore to examine the robustness of the RISC effect, it may be best to start by using language cues that do not differ as much in their effectiveness (whilst keeping other features of the design of experiments 2-4 constant).

With regard to the cross-talk between input and output settings, one important question that remains is whether one would still find 'leakage' of selection settings in circumstances where controlling input becomes critical to performance. For example, it would be useful to run the design of Experiments 5 and 6 but intersperse among the auditory probes some non-cognate homophones – words that have very similar phonology, yet different meanings, in the two languages. This would serve as an incentive for the participant to exert stricter control over the input. It would also be very interesting to examine the performance of individuals who separate the selection of input and output 'for a living' – simultaneous translators, though they are not easy to come by as subjects.

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# APPENDIX ONE

## Second Language Experience Questionnaire

I am investigating how bilingual speakers process different languages. It is important that I know how much experience you have had with each of your languages. Please answer each of the following questions carefully. For some, you can write your answer directly after the question (click once in the grey box and start typing), for multiple choice questions use your mouse to click in the box next to the relevant answer.

1. What is your name?

2. What is your age?

- 17 – 20
- 21 – 24
- 25 – 30
- 31 – 34
- 35 – 40
- 40 +

3. How old were you when you started to learn French?

4. How many years have you lived in countries where English/French is the main language that is spoken?

English speaking countries          years

French speaking countries          years

5. Please rate your current fluency in French for each of these skills from one to ten; 1 being not fluent, 10 being very fluent, (please only tick one box per line)

	Not Fluent								Very fluent	
	1	2	3	4	5	6	7	8	9	10
Listening	<input type="checkbox"/>									
Speaking	<input type="checkbox"/>									
Reading	<input type="checkbox"/>									
Writing	<input type="checkbox"/>									

6. At the moment, how much do you use each language (in any way – speaking, writing, listening or reading)? Please tick one box per language)

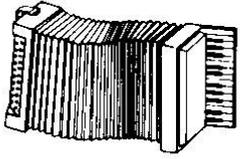
	English	French
Every Day	<input type="checkbox"/>	<input type="checkbox"/>
Two or three times a week	<input type="checkbox"/>	<input type="checkbox"/>
Once a week	<input type="checkbox"/>	<input type="checkbox"/>
Once a month	<input type="checkbox"/>	<input type="checkbox"/>
Less often than once a month	<input type="checkbox"/>	<input type="checkbox"/>

7. Which do you prefer to use for each of the following activities?

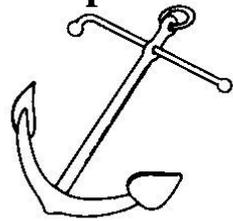
	English	French
Listening	<input type="checkbox"/>	<input type="checkbox"/>
Speaking	<input type="checkbox"/>	<input type="checkbox"/>
Reading	<input type="checkbox"/>	<input type="checkbox"/>
Writing	<input type="checkbox"/>	<input type="checkbox"/>

8. Please list all of the languages that you speak, starting with the language you know the best to the one you know the least.

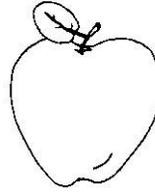
## Appendix two - Stimuli for Experiments 1 and 2



Accordion  
Accordéon



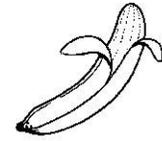
Anchor  
Ancre



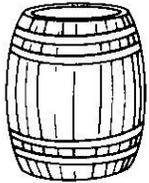
Apple  
Pomme



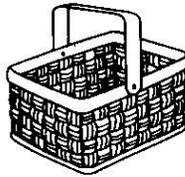
Ball  
Boule



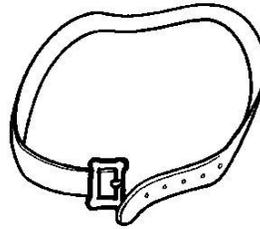
Banana  
Banane



Barrel  
Baril Tonneau



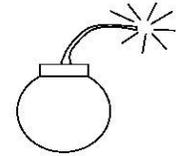
Basket  
Panier



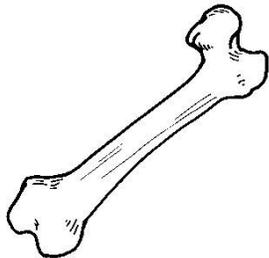
Belt  
Ceinture



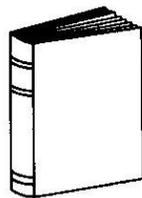
Bird  
Oiseau



Bomb  
Bombe



Bone  
Os



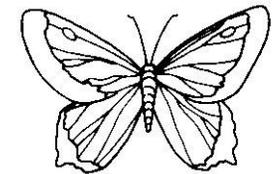
Book  
Livre



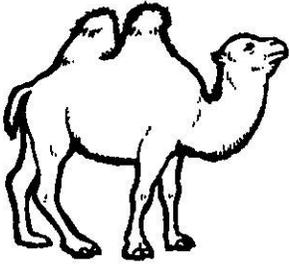
Boy  
Garçon



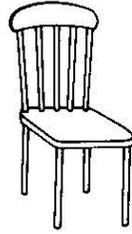
Bridge  
Pont



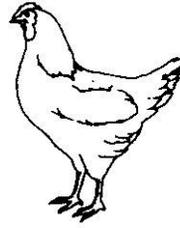
Butterfly  
Papillon



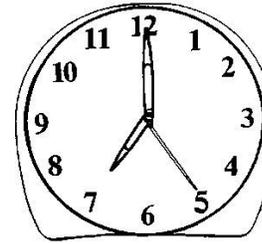
Camel  
Chameau



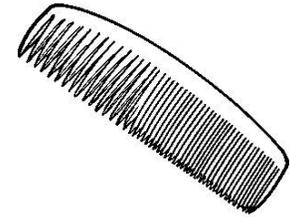
Chair  
Chaise



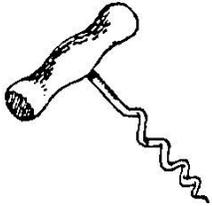
Chicken  
Poulet



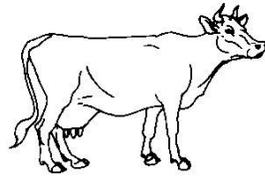
Clock  
Horloge



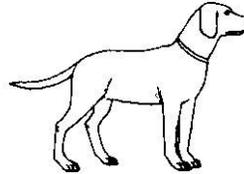
Comb  
Peigne



Corkscrew  
Tire-Bouchon



Cow  
Vache



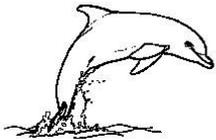
Dog  
Chien



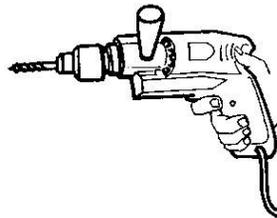
Doll  
Poupée



Arrow  
Flèche



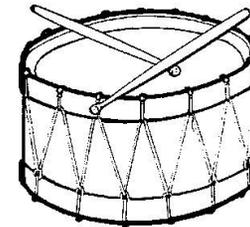
Dolphin  
Dauphin



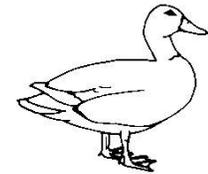
Drill  
Foreuse



Dress  
Robe



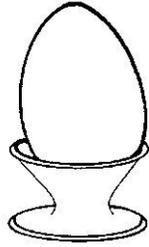
Drum  
Tambour



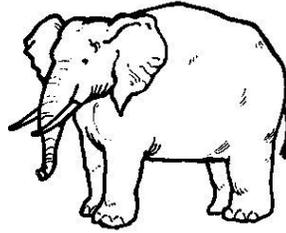
Duck  
Canard



Ear  
Oreille



Egg  
Oeuf



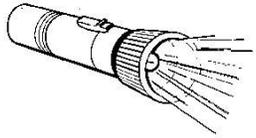
Elephant  
Eléphant



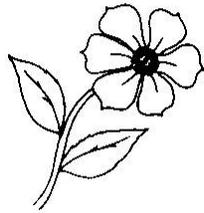
Feather  
Plume



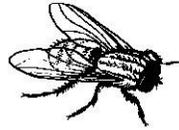
Fire  
Feu



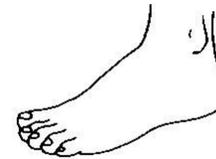
Torch  
Lampe de poche



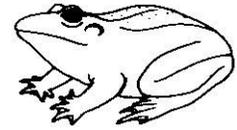
Flower  
Fleur



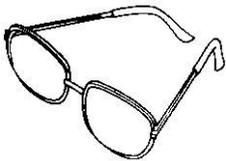
Fly  
Mouche



Foot  
Pied



Frog  
Grenouille



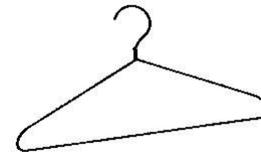
Glasses  
Lunettes



Guitar  
Guitare



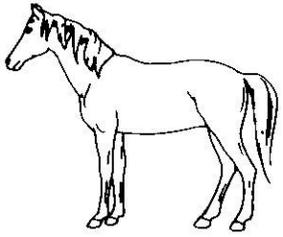
Brush  
Brosse a cheveux



Hanger  
Cintre



Highchair  
Chaise haute



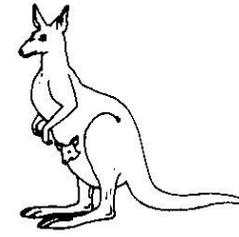
Horse  
Cheval



Igloo  
Igloo



Ironing board  
Planche à repasser



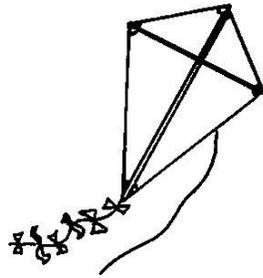
Kangaroo  
Kangourou



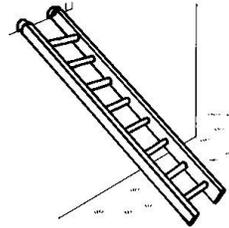
Key  
Clé



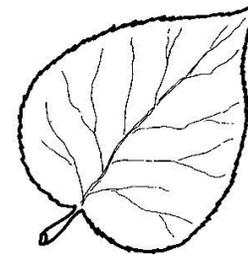
King  
Roi



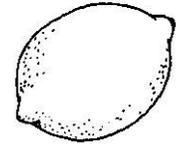
Kite  
Cerf-volant



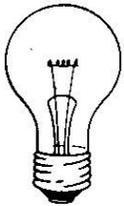
Ladder  
Echelle



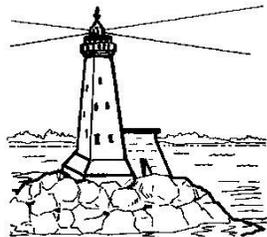
Leaf  
Feuille



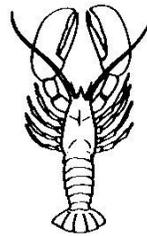
Lemon  
Citron



Lightbulb  
Ampoule



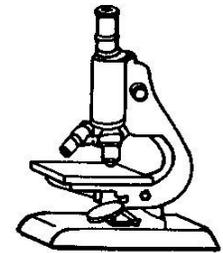
Lighthouse  
Phare



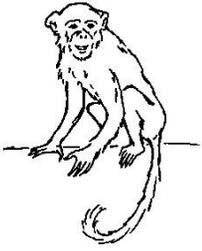
Lobster  
Homard



Log  
Rondin



Microscope  
Microscope



Monkey  
Singe



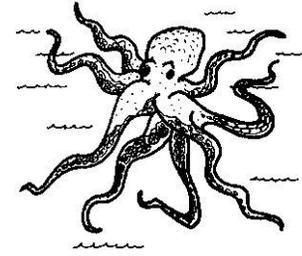
Mouse  
Souris



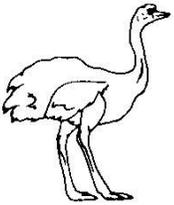
Mushroom  
Champignon



Nail  
Ongle



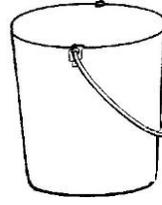
Octopus  
Pieuvre



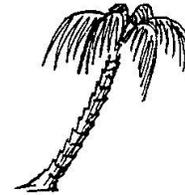
Ostrich  
Autruche



Owl  
Hibou



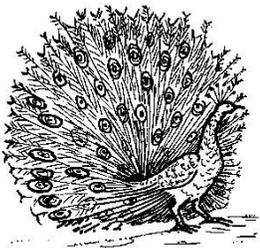
Bucket  
Seau



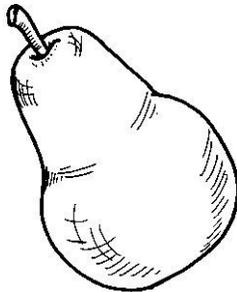
Palm tree  
Palmier



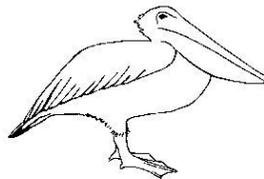
Parrot  
Perroquet



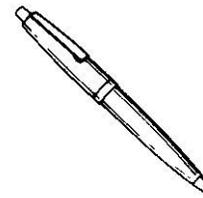
Peacock  
Paon



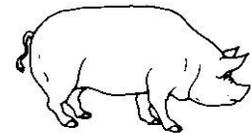
Pear  
Poire



Pelican  
Pélican



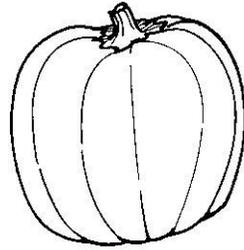
Pen  
Stylo



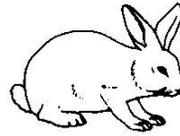
Pig  
Couchon



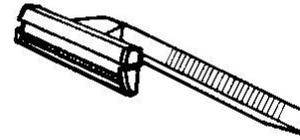
Pirate  
Pirate



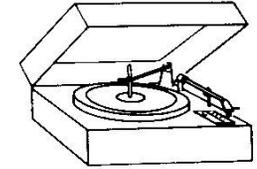
Pumpkin  
Citrouille



Rabbit  
Lapin



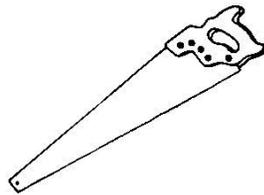
Razor



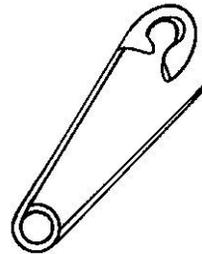
Record player  
Tourne disque



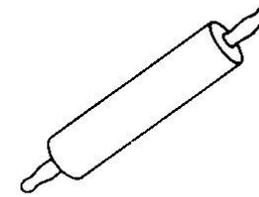
Rocking chair  
Fauteuil à bascule



Saw  
Scie



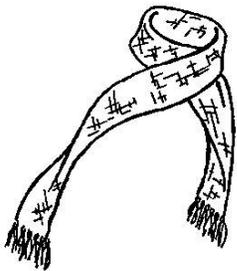
Safety pin  
épinge de sûreté



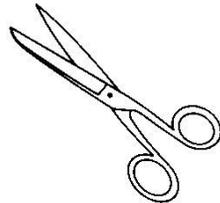
Rolling pin  
Rouleau à pâtisserie



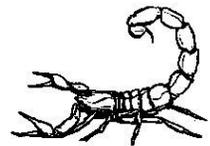
Saxophone  
Saxophone



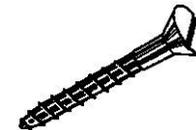
Scarf  
Esharepe



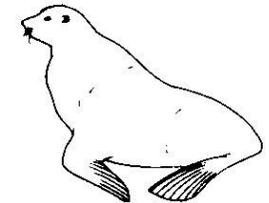
Scissors  
Ciseaux



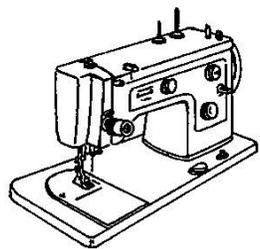
Scorpion  
Scorpion



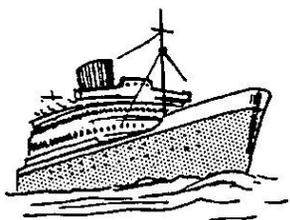
Screw  
Vis



Seal  
Sceau



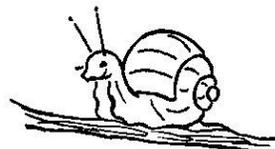
Sewing machine  
Machine à coudre



Boat  
Bateau



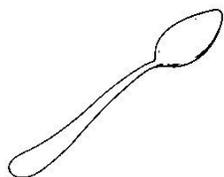
Shoe  
Chaussure



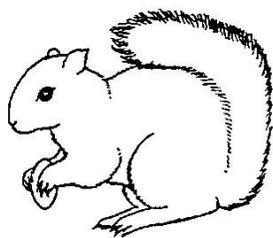
Snail  
Escargot



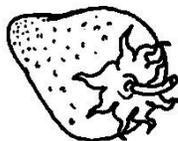
Snowman  
Bonhomme de nige



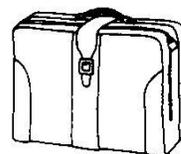
Spoon  
Cuillere



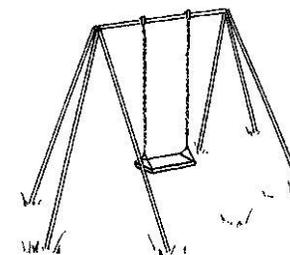
Squirrel  
Ecureuil



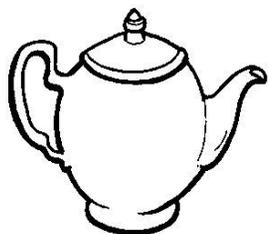
Strawberry  
Fraise



Suitcase  
Valise



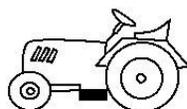
Swing  
Balancoire



Teapot  
Théière



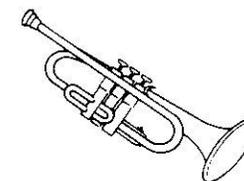
Toothbrush  
Brosse de dent



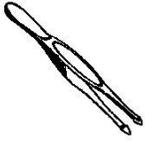
Tractor  
Traktor



Tree  
Ambre



Trumpet  
Trompete



Tweezers  
Pince à épiler



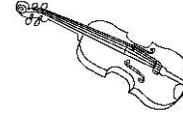
Typewriter  
Machine à écrire



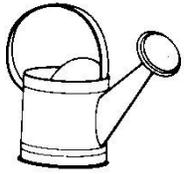
Umbrella  
Parapluie



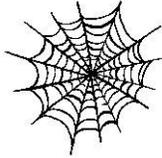
Unicorn  
Licorne



violin  
Violon



Wateringcan  
Arrosoir



Spiders web  
Toile d'araignée



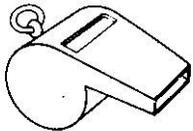
Well  
Puits



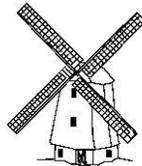
Wheelbarrow  
Brouette de roue



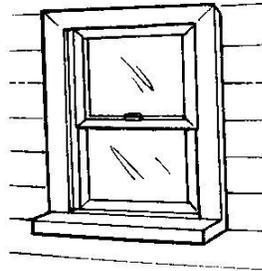
Wheelchair  
Fauteuil roulant



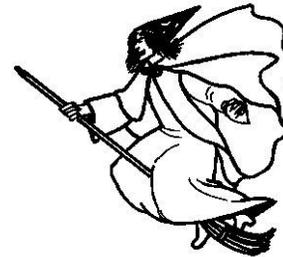
Whistle  
Snifflet



Windmill  
Moulin à vent



Window  
Fenêtre



Witch  
Sorcière



Penguin  
Pinguin

# Appendix Three

## Second Language Experience Questionnaire

I am investigating how bilingual speakers process different languages. It is important that I know how much experience you have had with each of your languages. Please answer each of the following questions carefully. For some, you can write your answer directly after the question (click once in the grey box and start typing), for multiple choice questions use your mouse to click in the box next to the relevant answer.

1. What is your name?

2. What is your age?

- 17 – 20
- 21 – 24
- 25 – 30
- 31 – 34
- 35 – 40
- 40 +

3. How old were you when you started to learn English?

4. How many years have you lived in countries where German/English is the main language that is spoken?

English speaking countries          years

German speaking countries          years

6. Please rate your current fluency in German for each of these skills from one to ten; 1 being not fluent, 10 being very fluent, (please only tick one box per line)

	Not Fluent							Very fluent		
	1	2	3	4	5	6	7	8	9	10
Listening	<input type="checkbox"/>									
Speaking	<input type="checkbox"/>									
Reading	<input type="checkbox"/>									
Writing	<input type="checkbox"/>									

6. At the moment, how much do you use each language (in any way – speaking, writing, listening or reading? Please tick one box per language)

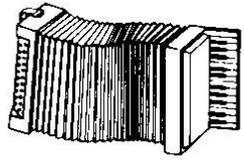
	German	English
Every Day	<input type="checkbox"/>	<input type="checkbox"/>
Two or three times a week	<input type="checkbox"/>	<input type="checkbox"/>
Once a week	<input type="checkbox"/>	<input type="checkbox"/>
Once a month	<input type="checkbox"/>	<input type="checkbox"/>
Less often than once a month	<input type="checkbox"/>	<input type="checkbox"/>

7. Which do you prefer to use for each of the following activities?

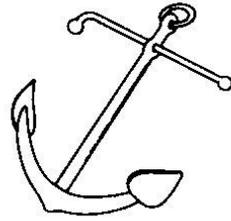
	German	English
Listening	<input type="checkbox"/>	<input type="checkbox"/>
Speaking	<input type="checkbox"/>	<input type="checkbox"/>
Reading	<input type="checkbox"/>	<input type="checkbox"/>
Writing	<input type="checkbox"/>	<input type="checkbox"/>

8. Please list all of the languages that you speak, starting with the language you know the best to the one you know the least.

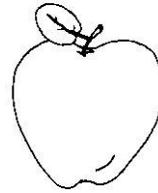
## Appendix Four - Stimuli for Experiments 3 and 4



Accordion  
Akkordeon



Anchor  
Anker



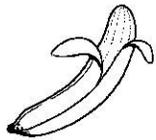
Apple  
Apfel



Arrow  
Pfeil



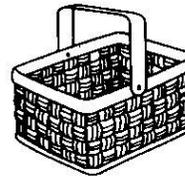
Ball  
Ball



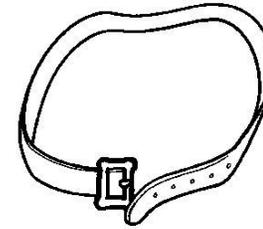
Banana  
Banane



Barrel  
Fass



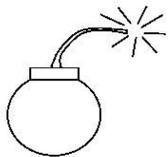
Basket  
Korb



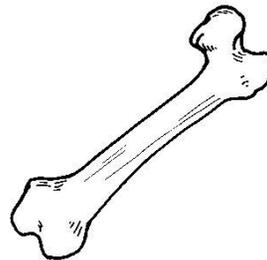
Belt  
Gürtel



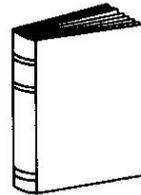
Bird  
Vogel



Bomb  
Bombe



Bone  
Knochen



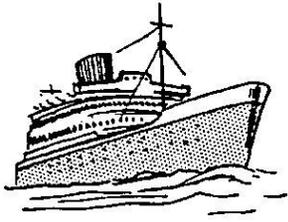
Book  
Buch



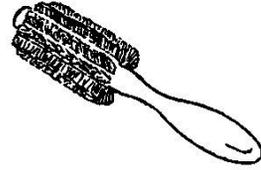
Boy  
Junge



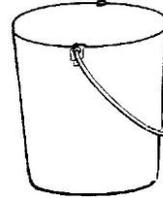
Bridge  
Brücke



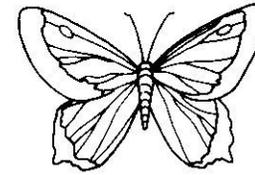
Boat  
Boot



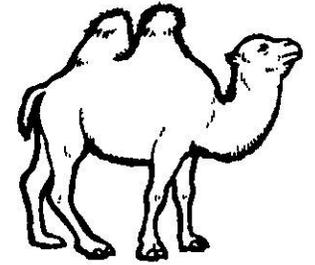
Brush  
Pinsel



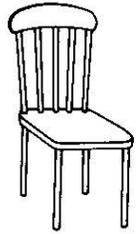
Bucket  
Eimer



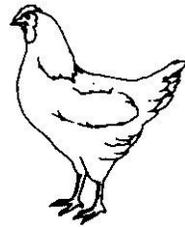
Butterfly  
Schmetterling



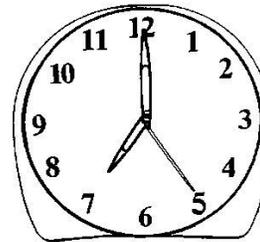
Camel  
Kamel



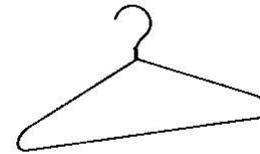
Chair  
Stuhl



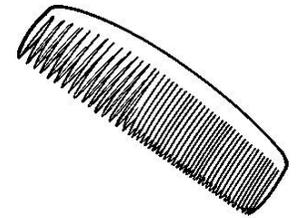
Chicken  
Huhn



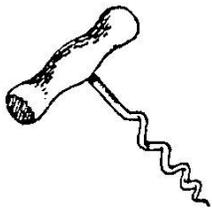
Clock  
Uhr



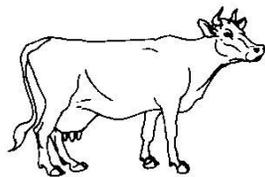
Coat Hanger  
Kleiderbügel



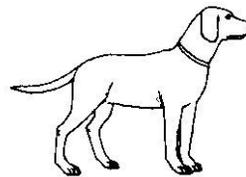
Comb  
Kamm



Corkscrew  
Korkenzieher



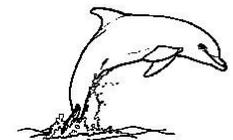
Cow  
Kuh



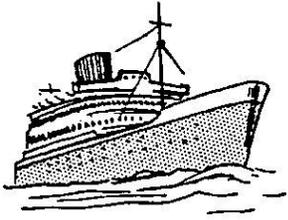
Dog  
Hund



Doll  
Puppe

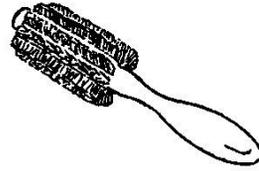


Dolphin  
Dolphin



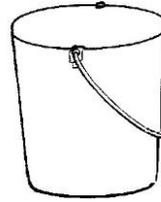
Boat

Boot



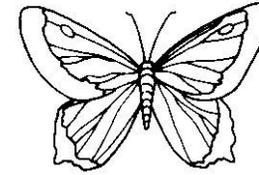
Brush

Pinsel



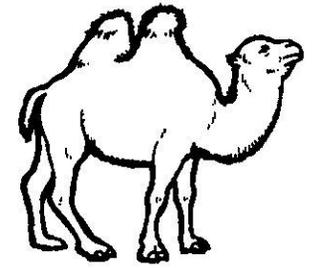
Bucket

Eimer



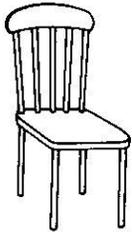
Butterfly

Schmetterling



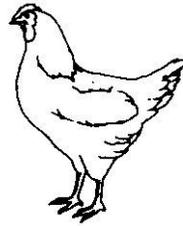
Camel

Kamel



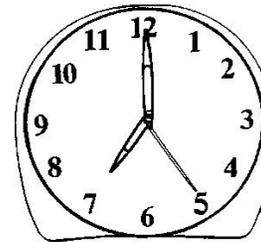
Chair

Stuhl



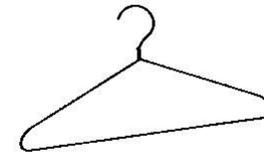
Chicken

Huhn



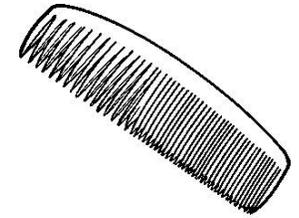
Clock

Uhr



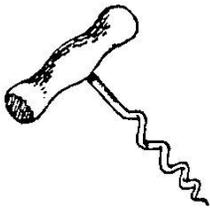
Coat Hanger

Kleiderbügel



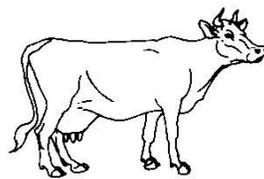
Comb

Kamm



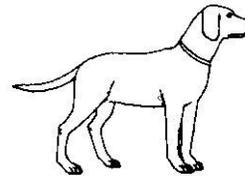
Corkscrew

Korkenzieher



Cow

Kuh



Dog

Hund



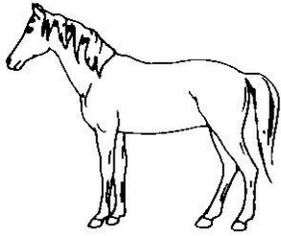
Doll

Puppe



Dolphin

Dephin



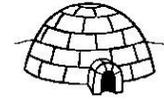
Horse/ Pony  
Pony



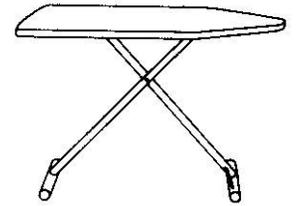
Guitar  
Gitarre



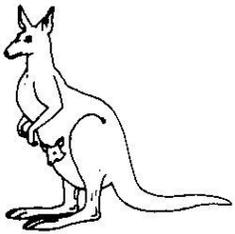
Highchair  
Hochstuhl



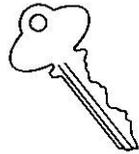
Igloo  
Iglu



Ironing board  
Bügelbrett



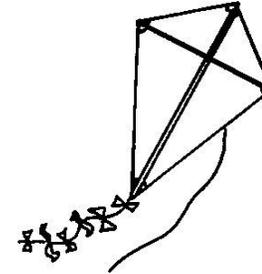
Kangaroo  
Känguruh



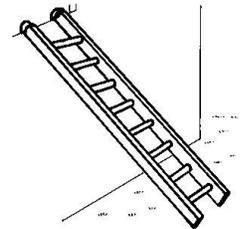
Key  
Schlüssel



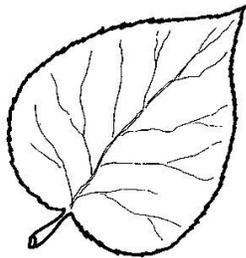
King  
König



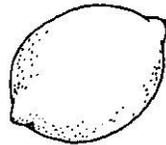
Kite  
Drachen



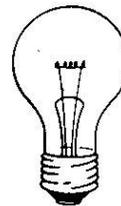
Ladder  
Leiter



Leaf  
Blatt



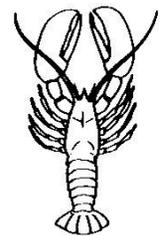
Lemon  
Zitrone



Lightbulb  
Glühbirne  
165



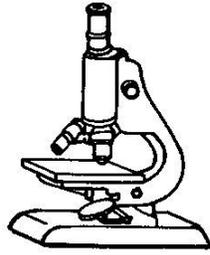
Lighthouse  
Leuchtturm



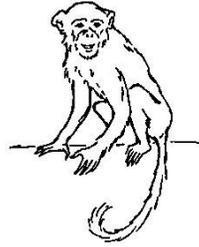
Lobster  
Hummer



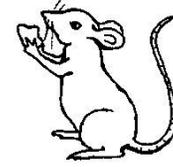
Log  
Protokoll



Microscope  
Mikroskop



Monkey  
Affe



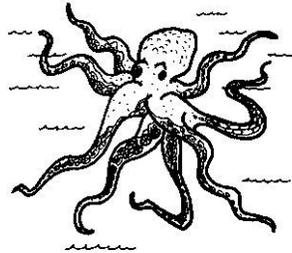
Mouse  
Maus



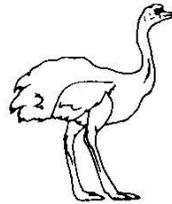
Mushroom  
Pilz



Nail  
Nagel



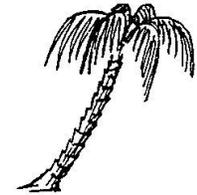
Octopus  
Krake



Ostrich  
Strauss



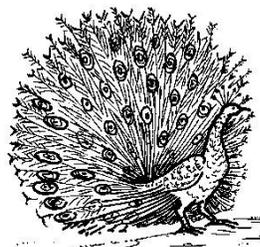
Owl  
Eule



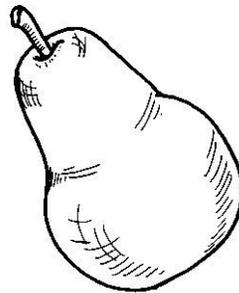
Palm tree  
Palme



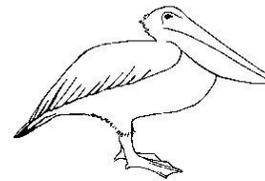
Parrott  
Papagei



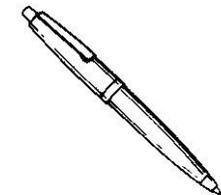
Peacock  
Pfau



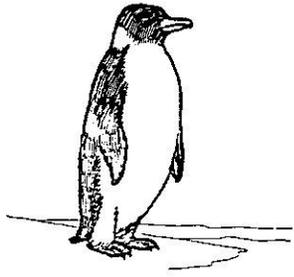
Pear  
Birne



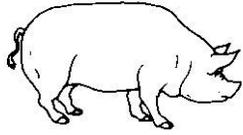
Pelican  
Pelikan



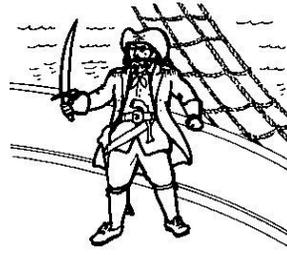
Pen  
Stift



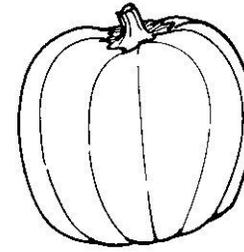
Penguin  
Pinguin



Pig  
Schwein



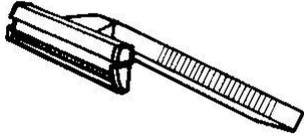
Pirate  
Pirat



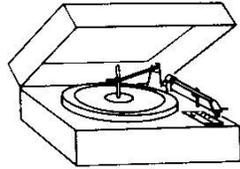
Pumpkin  
Kürbis



Rabbit  
Kaninchen



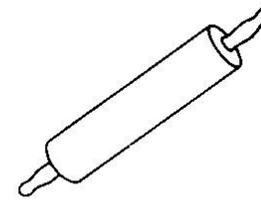
Razor  
Rasierapparat



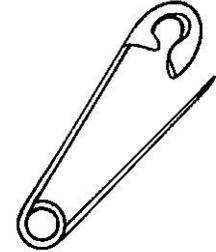
Record Player  
Plattenspieler



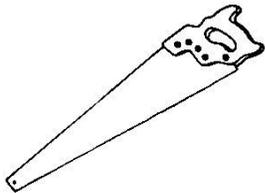
Rocking chair  
Schaukelstuhl



Rolling pin  
Nudelholz



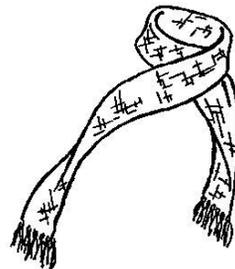
Safety Pin  
Sicherheitsnadel



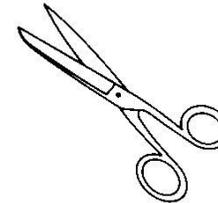
Saw  
Säge



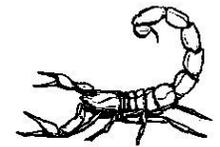
Saxophone  
Saxophon



Scarf  
Schal



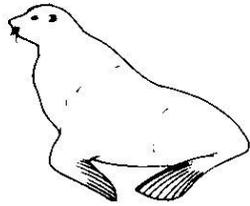
Scissors  
Schere



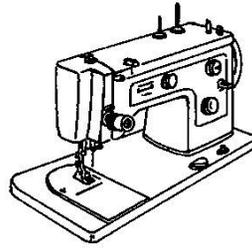
Scorpion  
Skorpion



Screw  
Schraube



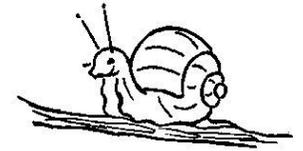
Seal  
Siegel



Sewing machine  
Nähmaschine



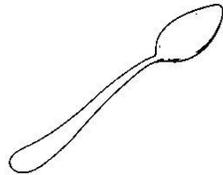
Shoe  
Schuh



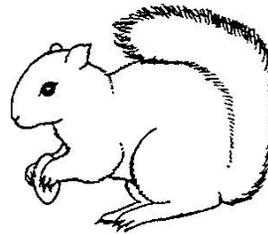
Snail  
Schnecke



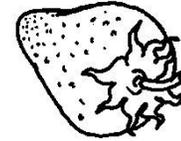
Snowman  
Schneemann



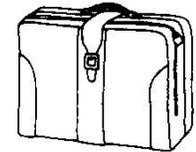
Spoon  
Löffel



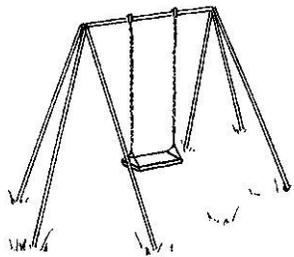
Squirrel  
Eichhoernchen



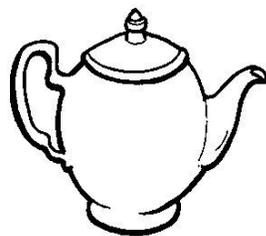
Strawberry  
Erdbeere



Suitcase  
Koffer



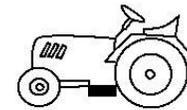
Swing  
Schaukel



Teapot  
Teekanne



Toothbrush  
Zahnbürste



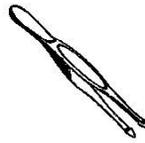
Tractor  
Traktor



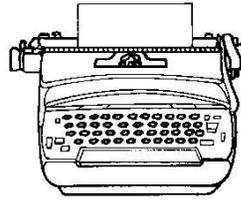
Tree  
Baum



Trumpet  
Trompete



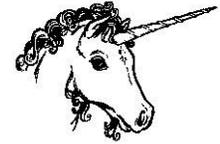
Tweezers  
Pinzette



Typewriter  
Schreibmaschine



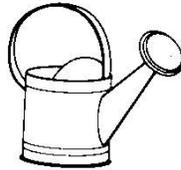
Umbrella  
Regenschirm



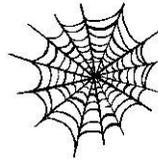
Unicorn  
Einhorn



Violin  
Geige



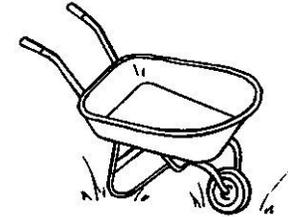
Watering Can  
Gieskanne



Web  
Spinnennetz



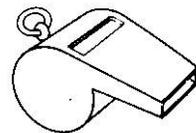
Well  
Brunnen



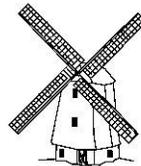
Wheelbarrow  
Schubkarre



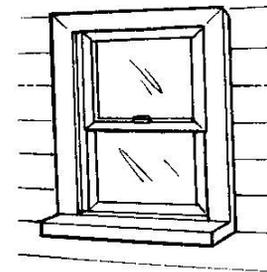
Wheelchair  
Rollstuhl



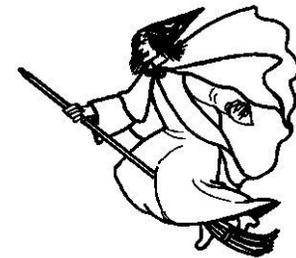
Whistle  
Pfiff



Windmill  
Windmühle



Window  
Fenster



Witch  
Hexe

## Appendix Five - Auditory Probes For Experiment Five

<b>English</b>	<b>French</b>	<b>English</b>	<b>French</b>
boat	bateau	apple	pomme
boy	garcon	bee	abeille
camel	chameau	butterfly	papillon
car	voiture	comb	peigne
Chair	chaise	ear	oreille
cow	vache	fly	mouche
horse	cheval	frog	grenouille
house	maison	glasses	lunettes
ladder	échelle	key	clé
lighthouse	phare	leaf	feuille
lorry	camion	lemon	citron
moon	lune	pear	poire
mountain	montagne	screw	vis
ostrich	autruche	snail	escargot
pig	cochon	spoon	cuillère
shark	requin	stamp	timbre
suitcase	valise	strawberry	fraise
swing	balancoire	tea cup	tasse
tree	arbre	tooth	dent
witch	sorcière	whistle	sifflet

## Appendix Six - Auditory Probes For Experiment Six

<b>English</b>	<b>German</b>	<b>English</b>	<b>German</b>
barn	Scheune	ant	Ameise
church	Kirche	apple	Apfel
cow	Kuh	bee	Biene
donkey	Esel	carrot	Möhre
farmer	Bauer	cherry	Kirsche
giraffe	Giraffe	coin	Münze
helicopter	Hubschrauber	earring	Ohrring
horse	Pferd	frog	Frosch
lion	Löwe	glove	Handschuh
moon	Mond	handkerchief	Taschentuch
mountain	Berg	lipstick	Lippenstift
piano	Klavier	mushroom	Pilz
pig	Schwein	needle	Nadel
pram	Kinderwagen	onion	Zwiebel
scarecrow	Vogelscheuche	pear	Birne
ship	Schiff	plum	Pflaume
soldier	Soldat	potato	Kartoffel
suitcase	Koffer	raspberry	Himbeere
tree	Baum	scissors	Schere
wardrobe	Schrank	screw	Schraube