Is language control just a form of executive control? Evidence for overlapping processes in language switching and task switching.

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Abstract

Whereas some models claim that language control is part of more general executive control, others have proposed that there is little overlap between these two processes. To shed light on this controversy, we compared switching effects observed in closely matched language switching and task switching tasks. The correlation analyses showed a positive moderate to strong correlation between the two switching variants in all three experiments. The results further showed that language- and task-switch costs differed although the cues, stimuli, response modality, and the number of response alternatives were identical across the two switching variants (Experiments 1), and when additionally the same linguistic tasks (picture naming/category naming) were used in both switching variants (Experiment 3), at least for the error rates. However, similar language- and task-switch costs were obtained when the same non-linguistic tasks (parity/magnitude) were used (Experiment 2). These results point towards overlapping mechanisms for language control and executive control.

Keywords: Language switching; Task switching; Language control; Executive control

It has long been debated whether executive functions that operate during language processing are domain general or language specific. This is also the case for language control (e.g., De Bruin, Roelofs, Dijkstra, & FitzPatrick, 2014; De Baene, Duyck, Brass, & Carreiras, 2015; Dijkstra & van Heuven, 2002; Green, 1998; Weissberger, Gollan, Bondi, Clark, & Wierenga, 2015), which is the process that ensures that bilingual language production occurs in the target language. This claim has mainly been investigated by comparing the effects observed in language switching (LS; for a review, see Declerck & Philipp, 2015), used to measure language control, and task switching (TS; for reviews see Kiesel, Steinhauser, Wendt, Falkenstein, Jost, Philipp, & Koch, 2010; Vandierendonck, Liefooghe, & Verbruggen, 2010), used to measure cognitive ("executive") control. In the present study, we set out to directly compare LS and TS, using a similar setup for both switching variants, to further investigate the relationship between language control and executive control.

According to Meuter and Allport (1999), language control and executive control rely on the same mechanism (see also Dijkstra & van Heuven, 2002). More specifically, they assume that competing languages or tasks are both controlled by inhibitory processes that persist into the following response. In Thomas and Allport (2000), this process was further elaborated by indicating that language control, just like executive control, occurs via task schemas. These task schemas are mental devices that are implemented to achieve task-specific goals, such as speaking a certain language or performing a certain task, and are located outside of language processing. Hence, Allport and colleagues assume that language control is part of the more general executive control process.

Other authors have also proposed that language control is part of executive control (e.g., Green, 1998; Schwieter & Sunderman, 2008). Yet, these accounts additionally introduced a language-specific aspect of language control that is not part of executive control. The inhibitory control model (ICM; Green, 1998), for example, assumes that language control first occurs between task schemas. Similar to the previous account, this is where the ICM assumes language control and executive control to overlap. The language-specific control process occurs between translation-equivalent lemmas (mental representations of words), which are influenced by these task schemas.

There are also language control models that do not assume language control to be operated by task schemas (e.g., Declerck, Koch, & Philipp, 2015; Grainger, Midgley, & Holcomb, 2010). Declerck et al. (2015), for example, proposed a similar structure as the ICM. The major difference is that there is no control process between task schemas, and thus that language control is not part of executive control. In turn, language control occurs between language nodes, which represent language membership, and translation-equivalent lemmas. Hence, these models assume language control and executive control to differ from each other.

The similarity between language control and executive control has, for the most part, been investigated by looking at the overlap between LS and TS. During a typical LS experiment, bilingual participants name a digit or picture in one of two languages, depending on a cue (e.g., blue or green square) that is presented at the same time or prior to the digit/picture. During a typical TS experiment, a cue is also presented, so that participants know which task (e.g., magnitude or parity task for number classification) they have to perform. Since multiple languages are used in LS and multiple tasks are used in TS, a trial is always preceded by either the same language/task or the other language/task. Performance is typically worse when a trial is preceded by a different language/task (switch trial) than when the same language/task is used (repetition trial). This difference in performance is called “switch costs” which is used as a measure for language control when obtained in a LS study (e.g., Declerck & Philipp, 2015), and it is used as a measure for executive control when obtained in a TS study (e.g., Kiesel et al., 2010).

In line with most models, a recent fMRI study found evidence for an overlap between language control and executive control by examining the neural structures involved in LS and TS (De Baene et al., 2015). In this study, Spanish-Basque-English highly proficient trilinguals had to perform a picture naming task with three languages in mixed language blocks (i.e., LS) and a color, gender, or direction decision task in mixed task blocks (i.e., TS). The results of De Baene et al. (2015) showed a large overlap in brain activation for switch costs with these two switching variants (see Weissberger et al., 2015, for similar results).

More evidence for an overlap between language control and executive control was obtained by Prior and Gollan (2011), who investigated language-switch costs (digit naming) and task-switch costs (color/shape decision). Smaller language- and task-switch costs were observed with bilinguals (Spanish-English) who switched often between languages in daily life than with bilinguals who switched less often between languages (Mandarin-English). This was taken as evidence that language control and executive control rely on similar processes, since intensive training in language switching influences control processes during LS, and more importantly also during TS.

Yet, not all studies have found evidence for an overlap between language control and executive control. Prior and Gollan (2013) found that short-term practice of LS (digit naming) or TS (color/shape decision) had no effect on task-switch costs or language-switch costs, respectively. Further lack of evidence for an overlap was found with studies that examined the effect of aging on language-switch costs and task-switch costs. Calabria, Branzi, Marne, Hernández, and Costa (2015) examined Catalan-Spanish bilinguals, and found an age-related effect on switch costs in TS (color/shape decision), but not on switch costs in LS (picture naming; see Weissberger, Wierenga, Bondi, & Gollan, 2012, for similar results). Moreover, these and other studies that investigated LS and TS observed little evidence for an overlap using correlation analyses on language- and task-switch costs (Branzi, Calabria, Boscarino, &

Costa, 2016; Calabria et al., 2015; Calabria, Hernández, Branzi, & Costa, 2011; Klecha, 2013; Prior & Gollan, 2013)[1].

Taken together, there appear to be contradictory findings with respect to the overlap between language- and task-switch costs, and thus language control and executive control. However, it should be noted that very different methodologies were implemented in prior studies with respect to LS and TS. Gollan, Kleinman, and Wierenga (2014), for example, argued that prior studies typically implemented different response modalities for LS (vocal) and TS (manual), which leads to an additional difference between LS and TS. Interestingly, Gollan et al. (2014) implemented identical response modalities (vocal) to respond to the naming task for LS and to the read/add or size/parity task for TS, and observed positive weak to moderate correlations (Evans, 1996) between switch cost of the dominant language and task-switch costs with the voluntary switching paradigm. However, when directly comparing the size of switch costs in both LS and TS, they observed that language-switch costs were still significantly different from task-switch costs.

This difference could be due to other methodological differences that were not controlled for. Declerck and Philipp (2015) indicated three other methodological differences across LS and TS in studies that investigated both switching variants, all of which are applicable to the study of Gollan et al. (2014), such as different stimulus types (e.g., digits/pictures vs. colors/shapes), and a different number of response alternatives, with more response alternatives in LS than TS. Another difference includes the implementation of different tasks: LS typically involves digit naming or picture naming, whereas TS generally involves categorization tasks. Hence, it could be that a difference in switch costs was obtained across LS and TS in Gollan et al. (2014), and other prior studies, due to substantial methodological differences.

In the current study we compared switch costs in LS and TS with similar methodologies over three experiments (see Table 1 for an overview of the similarities and differences between LS and TS across the three experiments). This allowed us to investigate the overlap between language control and executive control, without any major methodological differences between LS and TS. To investigate this, we looked at a direct comparison of the size of switch costs in LS and TS, and correlations of switch costs between LS and TS.

—Table 1—

Experiment 1

To investigate the overlap between LS and TS, and thus between language control and executive control, we used LS and TS blocks with similar methodology in Experiment 1. To keep the LS and TS blocks as similar as possible, the same cues and stimuli were used in LS and TS. Furthermore, an identical number of response alternatives were used, and the same response modality (i.e., vocal responses) was used in LS and TS.

Method

Participants. 24 native German speakers who spoke English as their second language took part in the experiment (21 female, mean age = 20.5). Prior to the experiment they were asked to fill in a questionnaire about their English age-of-acquisition, how many years of formal English education they had, and how high they rated their own level of spoken English and reading English (see Table 2).

—Table 2—

Apparatus and concepts. During the LS and TS blocks, the participants were required to respond to two digits, 1 vs. 8. We chose to use only two digits to keep the number of response alternatives identical across LS and TS (i.e., four response alternatives). The digits were 300 x 300 pixels in size. The language/task cues, which indicate the language or task the participant had to perform in each trial, were green or blue squares of 160 x 106 pixels. The cue color-to-language/task was counterbalanced across participants, but stayed the same for each participant during the experiment.[2] The experiment was presented using E-prime, while errors were coded online by the experimenter.

Procedure. The study consisted of two parts, a LS part during which participants had to name the digits in German or English, and a TS part during which the participants had to perform a magnitude task, in which they had to indicate whether the digit was smaller or larger than five by vocally responding with "kleiner" (smaller) or "größer" (larger), or a parity task, for which they had to vocally respond with "gerade" (even) or "ungerade" (odd).

Both the LS and TS part started with instructions that were followed by two practice blocks, both consisting of 10 trials. Next, there were two experimental blocks, both consisting of 108 trials. The LS and TS parts were counterbalanced and there were an equal number of switch and repetition trials for both languages/tasks in each block.

Each trial started with a language/task cue that was visible for 300 ms or 1000 ms[3], followed by a digit, which would not disappear before a response was registered. Finally a pause of 400 ms would occur immediately after speech onset.

Design. The independent variables were switching variant (LS vs. TS) and transition (switch vs. repetition). The dependent variables were reaction time (RT) and error rate.

Results

The first trial of each block and the error trials were excluded from RT analyses, as were trials following an error trial. Furthermore, RTs that were larger or smaller than two standard deviations from the mean (per participant) were discarded as outliers. Taking these criteria into account, a total of 8.4% of the LS RT data was excluded and 11.0% of the TS RT data.

—Table 3—

—Table 4—

Reaction times. As can be seen in the ANOVA outcomes in Table 3, the RT data revealed a main effect of switching variant, with faster responses during LS (556 ms; see Table 4) than during TS (680 ms), and of transition, with repetition-trial responses (576 ms) being faster than switch-trial responses (660 ms), amounting to switch costs of 84 ms. Importantly, the interaction between switching variant and transition was significant, with smaller switch costs for LS (49 ms) than TS (119 ms).

Since the overall difference between LS and TS was significant, we examined whether proportional switch costs would show the same pattern. Hence, we calculated proportional switch costs for both LS and TS by dividing the mean RT switch cost by mean repetition trial RT. The results showed that language-switch costs (performance is decreased by 9.0% in switch trials relative to repetition trials) were still significantly smaller than task-switch costs (18.8% performance decrease), $t(23) = 6.52$, $p < .001$.

To have a sense of the degree of overlap, we also examined the correlation of the average language- and task-switch costs per participant. The results additionally showed a significant positive relation in RT, $r(24) = .438$; $p < .05$, between language- and task-switch costs (see Figure 1 for a scatter plot).

—Figure 1—

Error rates. The error data revealed a significant main effect of switching variant, with less errors during LS (2.5%) than during TS (3.4%), and of transition, with a smaller error rate during repetition trials (2.1%) than during switch trials (3.8%), indicating switch costs of 1.6%. The interaction between switching variant and transition was not significant.

Taken together, while the correlation coefficient indicates that the LS and TS task are similar to a certain degree, we found significantly smaller language-switch costs than task-switch costs.

Experiment 2

Some differences (i.e., size of switch costs across LS and TS) and similarities (i.e., positive correlation of language- and task-switch costs) have been observed between LS and TS in Experiment 1, while the methodology of LS and TS were kept very similar. However, it could be that language- and task-switch costs differed in Experiment 1 because there was still a considerable methodological difference between LS and TS: bilinguals had to name digits in the LS blocks and categorize numbers in the TS blocks. In Experiment 2, this difference between LS and TS was removed by having bilinguals perform two categorization tasks in two languages in both the LS and TS part. The only difference between LS and TS would then consist of whether they switch between languages in the LS part while consistently performing the same categorization task within a block (i.e., LS in a block where they perform a magnitude task and LS in a block where they perform a parity task), whereas in the TS part they would switch between the two categorization tasks while consistently producing in the same language within a block (i.e., TS in a block while responding in German and TS in a block while responding in English).

Method

Participants. 24 native German speakers that spoke English as their second language took part in the experiment (19 female, mean age = 24.1). They had not participated in Experiment 1. Similar to Experiment 1, they were asked to fill in a questionnaire (see Table 2).

Apparatus and concepts. The apparatus was identical to those implemented in Experiment 1. Unlike Experiment 1, however, the participants were required to respond to digits 1-9, excluding 5.

Procedure. Identical to Experiment 1, there was a LS part during which participants had to respond to the digits in German or English, and a TS part during which the participants had to perform a magnitude task, in which they had to indicate whether the digit was smaller or larger than five, or a parity task, in which they had to indicate whether the digit was even or odd. The difference with Experiment 1 is that in the LS part the bilinguals had to perform a magnitude task for one block and a parity task in the other block while switching languages, by vocally responding with “kleiner”/”smaller” or “größer”/” larger” and “gerade”/“even” or “ungerade”/“odd”, respectively. In the TS part, they had to switch tasks (i.e., magnitude and parity) while vocally producing the response in German for one block (i.e., “kleiner”, “größer”, “gerade” or “ungerade”) and in English in the other block (”smaller”, ”larger”, ”even”, or “odd”).

Prior to each of these four experimental blocks, consisting of 108 trials, a practice block of 8 trials was presented to the bilinguals. Similar to Experiment 1, the LS and TS parts were counterbalanced. Furthermore, the two blocks within each of these parts were also counterbalanced. There was an equal number of English and German trials in the LS blocks and an equal number of magnitude and parity trials in the TS blocks, combined with an equal number of switch and repetition trials for both languages/tasks in each block.

Each trial started with a language/task cue (160 x106 pixels) that was visible for 300 ms, followed by a digit (300 x 300 pixels), which would not disappear before a response was registered. Finally a pause of 400 ms would occur immediately after speech onset.

Design. The independent variables were switching variant (LS vs. TS) and transition (switch vs. repetition). The dependent variables were RT and error rate.

Results

We used identical outlier criteria and error definitions as in Experiment 1, which resulted in the exclusion of 10.6% of the LS RT data and 15.6% of the TS RT data.

—Table 5—

Reaction times. As can be seen in Table 3, the ANOVA of the RT data revealed a main effect of switching variant, with faster responses during LS (771 ms; see Table 5) than during TS (826 ms), and of transition, with repetition-trial responses (738 ms) being faster than switch-trial responses (859 ms), amounting to switch costs of 121 ms. Unlike Experiment 1, the interaction between switching variant and transition was not significant.

Since the overall difference between LS and TS was significant, we examined whether proportional switch costs would show the same pattern. The results showed that language-switch costs (performance is decreased by 15.5% in switch trials relative to repetition trials) were not significantly different from task-switch costs (17.5% performance decrease), $t(23) = 1.07$, ns.

The results additionally showed a significant positive relation in RT, $r(24) = .572$; $p < .01$, between language- and task-switch costs (see Figure 2 for a scatter plot).

—Figure 2—

Error rates. The error data revealed no significant effect of switching variant, but there was a significant main effect of transition, with a smaller amount of errors during repetition trials (1.7%) than during switch trials (3.1%), indicating switch costs of 1.5%. The interaction between switching variant and transition was not significant.

Taken together, with an even more similar set-up between LS and TS than in Experiment 1, the positive correlation observed in Experiment 1 was replicated. Furthermore, we observed no significant difference between language-switch costs and task-switch costs in Experiment 2.

Experiment 3

Experiment 2 indicates that switch costs can be similar across LS and TS when the tasks, cues, stimuli, response modality, and the number of response alternatives are identical across the two switching variants. However, it should be noted that the tasks in Experiment 2 did not allow for typical production-based LS. In a typical LS task, bilinguals get to see a language cue prior or during stimulus presentation. This stimulus, usually a digit or picture, should then be named in one of two languages. However, there is an additional processing stage in Experiment 2: deciding whether the number that is represented by the digit is larger or smaller than five, or whether the number is odd or even. Hence, it could be that different control processes were at work during this stage, compared with those that would normally occur during production-based LS.

In Experiment 3, we set out to circumvent this issue by using two tasks that are more language-specific than those used in Experiment 2. More specifically, participants had to either name the picture or name the category of the picture in this experiment. To further generalize the obtained data pattern, we conducted Experiment 3 with a different group of bilinguals, namely French-English bilinguals instead of German-English bilinguals.

Participants. 24 native French speakers that spoke English as their second language took part in the experiment (15 female, mean age = 22.4). Similar to Experiments 1 and 2, they were asked to fill in a questionnaire (see Table 2).

Apparatus and concepts. The apparatus were identical to those implemented in Experiments 1 and 2. Unlike the two prior experiments though, the participants were required to respond to four pictures representing a chair, a dress, a hammer, and a shark.

Procedure. The procedure was identical to Experiment 2, with the only difference being that instead of the magnitude and the parity task, the participants had to either name the pictures (“chaise”/“chair”, “robe”/“dress”, “marteau”/“hammer”, and “requin”/“shark”) or name the category of the pictures (“meuble”/“furniture”, “vêtement”/“clothing”, “outil”/“tool”, and “poisson”/ “fish”)

Design. The independent variables were switching variant (LS vs. TS) and transition (switch vs. repetition). The dependent variables were RT and error rate.

Results

We used identical outlier criteria and error definitions as in Experiments 1 and 2, which resulted in the exclusion of 16.0% of the LS RT data and 16.2% of the TS RT data.

—Table 6—

Reaction times. As can be seen in Table 3, the ANOVA of the RT data only revealed a main effect of transition, with repetition-trial responses (1228 ms) being faster than switch-trial responses (1324 ms; see Table 6), amounting to switch costs of 96 ms. Similar to Experiment 2, the interaction between switching variant and transition was not significant.

The results additionally showed a significant positive relation, $r(24) = .639$; $p < .01$, between language- and task-switch costs (see Figure 3 for a scatter plot).

—Figure 3—

Error rates. The error data also revealed no significant effect of switching variant, but there was a significant main effect of transition, with a smaller amount of errors during repetition trials (3.0%) than during switch trials (4.8%), indicating switch costs of 1.8%. The interaction between switching variant and transition was also significant, with smaller task-switch costs (0.5%) than language-switch costs (3.0%).

Taken together, using a similar setup as in Experiment 2, but with more linguistic tasks, we observed no significant difference in RT between language-switch costs and task-switch costs and found a positive correlation between language-switch costs and task-switch costs. This is a similar pattern as we observed in Experiment 2. However, unlike in Experiment 2, a significant difference was observed in the error rates between language-switch costs and task-switch costs.

General Discussion

In the present study, we investigated the comparability of LS and TS. To this end, German-English bilinguals and French-English bilinguals were presented LS and TS blocks that were methodologically very similar. The results indicated significantly different language- and task-switch costs when the cues, stimuli, response modality, and the number of response alternatives were the same in a cued switching paradigm (Experiment 1). However, the correlation analysis showed a positive relation between language- and task-switch costs in Experiment 1. When the tasks were the same, as well as the cues, stimuli, response modality, and the number of response alternatives, language-switch costs were not different from task-switch costs in a cued switching paradigm, and correlations between language- and task-switch costs were also significant (Experiment 2). Yet, this was only the case when non-linguistic tasks were used (magnitude/parity). When linguistic tasks were used (picture naming/category naming), a positive correlation was observed, but language- and task-switch costs were significantly different in the error rates (Experiment 3).

The observed pattern in the correlation analyses indicate that LS and TS involve shared mechanisms to a certain degree. More specifically, the correlation coefficients (Experiment 1: .438; Experiment 2: .572; Experiment 3: .639) show a moderate to strong relation between LS and TS (Evans, 1996). Moreover, the split-half correlation coefficients (odd vs. even trials) of the separate language-switch costs and task-switch costs are similar or markedly smaller than the correlation coefficients between language-switch costs and task-switch costs (see Table 7), indicating that the correlation coefficients obtained between language-switch costs and task-switch costs are a valid reflection of the relation between these two types of switch cost. Since language-switch costs and task-switch costs are measures of language control and executive control respectively (e.g., Declerck & Philipp, 2015; Kiesel et al., 2010; Vandierendonck et al., 2010), the positive correlation between language- and task-switch costs would mean that language control and executive control overlap to a certain extent. More generally, this provides evidence that executive functions can be implemented during language processing.

—Table 7—

However, part of this overlap could be due to cue-switch costs, which reflect worse performance due to switching of cues relative to perceiving the same cue across trials (e.g., Heikoop et al., 2016; Schneider & Logan, 2005; for a review of cue-switch costs in TS, see Jost et al., 2013). Yet, the fact that other studies that used a cued switching paradigm to examine the overlap between LS and TS found no significant correlation between the two switching variants (Branzi et al., 2016; Calabria et al., 2011, 2015; Klecha, 2013; Prior & Gollan, 2013), indicates that only a small proportion of the positive correlations observed in the current study can be attributed to cue-switch costs in both LS and TS. Moreover, Gollan et al. (2015) observed a positive correlation between switch costs in the dominant language and task-switch costs with a switching paradigm that did not require cues (i.e., voluntary switching paradigm), thus providing further evidence that control processes during cue processing in LS and TS contribute little to the positive correlations observed in the present study.

The difference in language- and task-switch costs in Experiment 1 indicates that language control and executive control do not entirely overlap. However, this switch-cost difference could be due to the different tasks that were used in the LS part (digit naming) and the TS part (magnitude/parity). Hence, we additionally used the same tasks in both switching variants in Experiment 2 with nonlinguistic tasks and in Experiment 3 with linguistic tasks. Next to the similar correlation coefficients in Experiment 2 and 3, the results showed no difference in language- and task-switch costs with non-linguistic tasks, but there was a difference in error switch costs when linguistic tasks were used.

While we should be careful interpreting the overlap between language-switch costs and task-switch costs on the basis of relatively small error rates, we can tentatively propose some possible explanations for the evidence for more similar control processes seen in

Experiment 2 compared with Experiment 3. This might, for example, be due to the different languages of the bilingual participants that were tested in these two experiments (i.e., German-English vs. French-English). Martin et al. (2013) investigated the effect of different language combinations during language switching. In this study, Spanish-Catalan bilinguals that spoke English as a third language were compared to Spanish-English bilinguals that spoke Catalan as a third language. By switching between Spanish and their third language (i.e., Spanish-English vs. Spanish-Catalan), no difference was observed between the two language groups in overall language-switch costs.[4] From this study we could deduce that language control, and possibly also its overlap with executive control, should be similar for different language combinations. However, since the effect of different language combinations on the overlap between language control and executive control was not explicitly investigated, we cannot completely exclude different language combinations as a possible cause for the different patterns observed in Experiments 2 and 3.

Alternatively, it might be that the use of digits (Experiment 2) and pictures (Experiment 3) caused the different patterns. Prior research has indicated that larger language-switch costs are elicited with pictures than with digits (Declerck, Koch, & Philipp, 2012), and thus more language control processes might be implemented during picture naming than during digit naming. The smaller language-switch costs observed in digit naming was explained by assuming that phonological co-activation, caused by the high number of numbers being cognates, resulted in a higher activation of the non-target language, which would make it easier to language switch into cognates than into non-cognates. Since this would be specific to language switching, relatively larger language-switch costs than task-switch costs should be found with pictures than with digits, which is exactly what our data shows.

A final possibility is that language control and executive control were more similar with non-linguistic tasks due to the fact that the bilinguals required an additional processing stage in this case (i.e., deciding whether the digit represented a number larger or smaller than five or whether it represented an odd or even number), which does not typically occur during a LS experiment. Because of this additional processing stage, the focus might have been put more on the non-linguistic aspects of the tasks, thus engaging more executive control than language-specific control processes (cf. Green, 1998).

The results obtained in this study could, at least partially, be explained with the assumptions of Meuter and Allport (1999), who proposed that language control and executive control rely on the same mechanism. More specifically, if both control processes would rely on the same mechanism, then we would expect a positive correlation to occur between language- and task-switch costs, which was the case. Moreover, we would have expected to find similar language- and task-switch costs in both Experiments 2 and 3, since the only difference between LS and TS in these experiments was that bilinguals had to switch either between different languages that relied on both tasks across blocks (LS) or had to switch between different tasks in both languages across blocks (TS). Hence, the control processes should have been the same according to Meuter and Allport (1999), and accordingly the switch costs should be similar. Such a pattern was observed with non-linguistic tasks, but not with linguistic tasks. However, as we indicated above, this could be due to the difference in stimuli (digits vs. pictures).

Models such as the ICM (Green, 1998; see also Schwieter & Sunderman, 2008) can explain the observed data pattern, since they assume that language control and executive control are shared to a certain degree, with some language control processes being language specific. Thus, a similar pattern observed in LS and TS could have been observed due to the shared control process. The idea of language-specific control processes could also explain the differences in language- and task-switch costs in Experiment 3, as we argued that the focus would be more on linguistic aspects of processing with linguistic tasks such as in Experiment 3 (see above), and thus engage more language-specific control processes during language control.

The present results are not in line with accounts of language control which assume that language control and executive control do not rely on shared mechanisms (Declerck et al., 2015; Grainger et al., 2010). According to these accounts, language control is not part of executive control, and mainly occurs between language nodes and/or translation-equivalent lemmas. Hence, no positive correlation should have been observed between language- and task-switch costs, according to these models, and no similarity in switch costs across LS and TS. Yet, a positive correlation was found in all three experiments, and while Experiment 1 and 3 found differences in language- and task-switch costs, Experiment 2 did not.

In the present study, we set out to investigate whether evidence for an overlap between language control and executive control could be observed by investigating methodologically very similar LS and TS tasks. Unlike prior research that analyzed correlations between LS and TS (Branzi et al., 2016; Calabria et al., 2011, 2015; Gollan et al., 2014; Klecha, 2013; Prior & Gollan, 2013), a positive correlation between language- and task-switch costs was observed consistently across three experiments. From this finding we can deduce that methodological differences between LS and TS in prior research might have obscured their overlap, and thus that the overlap between language control and executive control might have been underestimated so far. Hence, based on the current results, we would encourage future research to implement a similar methodology for both switching variants when investigating LS and TS.

Taken together, examining language- and task-switch costs, with a similar methodology for both switching variants, led to moderate to strong positive correlations and similar language- and task-switch costs when both tasks were non-linguistic, but significantly different language- and task-switch costs when both tasks were linguistic or different between LS and TS. These findings demonstrate the importance of task-specific influences in switching experiments, but more importantly also provide evidence for an overlap in the mechanisms underlying language control and executive control.

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Footnotes

[1] It should be noted that a positive correlation has been observed between language- and task-mixing costs, which is the performance deterioration in mixed language blocks relative to single language blocks, for bilinguals, but not for monolinguals (Prior & Gollan, 2013).

[2] Prior research has indicated that cue switching can instigate an additional cost (Heikoop, Declerck, Los, & Koch, 2016; for a review, see Jost, De Baene, Koch, & Brass, 2013). Yet, we did not include a 2:1 cue-to-language/task mapping, which would have allowed for us to measure this additional cue-switch cost, because this additional cost should have been similar for LS and TS.

[3] For exploratory reasons, we used two cue-to-stimulus intervals. However, the interaction of language-switch costs and cue-to-stimulus interval did not differ significantly from the interaction of task-switch costs and cue-to-stimulus interval, Fs < 1 for RT and error rate.

[4] There was a difference in asymmetrical switch costs between the two groups of bilinguals, with late bilinguals (Spanish-English-Catalan) showing asymmetrical switch costs and early bilinguals (Spanish-Catalan-English) showing symmetrical switch costs. However, this has been attributed to the bilinguals being late or early bilinguals with respect to L1 and L2 (cf. Costa & Santesteban, 2004).

Table 1. Overview of the similarities and differences between language switching (LS) and task switching (TS) across Experiments 1-3.

	LS	TS
Experiment 1		
Stimuli	Digits	Digits
No. response alternatives	4	4
Tasks	Name digits in L1 or L2	Categorize digits based on magnitude or parity
Experiment 2		
Stimuli	Digits	Digits
No. response alternatives	16	16
Tasks	Categorize digits based on magnitude or parity (between blocks) in L1 or L2 (within blocks)	Categorize digits based on magnitude or parity (within block) in L1 or L2 (between blocks)
Experiment 3		
Stimuli	Pictures	Pictures
No. response alternatives	8	8
Tasks	Name the picture or the category (between blocks) in L1 or L2 (within block)	Name the picture or the category (within block) in L1 or L2 (between blocks)

Note that all stimuli were presented visually and all responses were given vocally.

Table 2. Overview of demographic information of the participants of Experiments 1-3 (standard deviations between brackets). The information consists of the average of English age of acquisition, the average years of formal English education, a self-rated score of spoken English and reading English from 1-7, with 1 being very bad and 7 being very good.

Experiment	Age of acquisition	Formal English education	Self-rated score of spoken English	Self-rated score of reading English
Experiment 1	9.8 (1.2)	8.8 (1.0)	5.3 (0.9)	5.8 (1.0)
Experiment 2	9.6 (1.3)	9.2 (1.4)	4.9 (1.0)	5.5 (1.0)
Experiment 3	9.3 (3.7)	8.9 (3.3)	3.9 (1.3)	4.5 (1.1)

Table 3. *F*-values, along η_p^2 between brackets, of the language-switching (LS) and task-switching (TS) data (both RT and error rate) in Experiments 1-3, with independent variables: switching variant (LS vs. TS) and transition (switch vs. repetition).

Effects	F (η_p^2) RT	F (η_p^2) Error rate
Experiment 1		
Switching variant	36.45 (.613)***	4.28 (.107)*
Transition	127.39 (.847)***	22.01 (.490)***
Switching variant x transition	51.04 (.689)***	1.31 (.054)
Experiment 2		
Switching variant	9.54 (.293)**	0.02 (.001)
Transition	99.48 (.812)***	20.68 (.473)***
Switching variant x transition	1.86 (.075)	1.57 (.064)
Experiment 3		
Switching variant	0.05 (.002)	0.07 (.003)
Transition	15.53 (.403)**	13.97 (.378)**
Switching variant x transition	0.26 (.011)	9.02 (.282)**

* $p < .05$; ** $p < .01$; *** $p < .001$

Table 4. Overall reaction time (RT) in ms and percentage of errors (PE) (SD in parentheses) of Experiment 1 as a function of switching variant (language switching [LS] vs. task switching [TS]), and transition (switch vs. repetition).

	Switching variant	Switch	Repetition	Switch costs
RT	LS	581 (81)	532 (59)	49 (34)
	TS	739 (135)	620 (97)	119 (51)
PE	LS	3.4 (3.4)	1.5 (2.5)	1.9 (2.8)
	TS	4.1 (2.9)	2.7 (1.8)	1.4 (3.2)

Table 5. Overall reaction time (RT) in ms and percentage of errors (PE) (SD in parentheses) of Experiment 2 as a function of switching variant (language switching [LS] vs. task switching [TS]), and transition (switch vs. repetition).

	Switching variant	Switch	Repetition	Switch costs
RT	LS	827 (159)	715 (129)	112 (51)
	TS	891 (167)	761 (138)	130 (82)
PE	LS	3.2 (2.70)	1.5 (1.36)	1.7 (2.2)
	TS	3.0 (2.05)	1.9 (2.04)	1.1 (1.6)

Table 6. Overall reaction time (RT) in ms and percentage of errors (PE) (SD in parentheses) of Experiment 3 as a function of switching variant (language switching [LS] vs. task switching [TS]), and transition (switch vs. repetition).

	Switching variant	Switch	Repetition	Switch costs
RT	LS	1323 (315)	1220 (285)	103 (162)
	TS	1325 (216)	1235 (214)	90 (101)
PE	LS	5.3 (3.8)	2.3 (2.2)	3.0 (3.7)
	TS	4.2 (3.9)	3.7 (3.3)	0.5 (2.4)

Table 7. Split-half correlation coefficients for the language-switch costs and the task-switch costs, and the correlation coefficients between language- and task-switch costs.

Experiment	LS	TS	LS vs. TS
1	.500	.520	.438
2	.475	.574	.572
3	.673	.063	.639

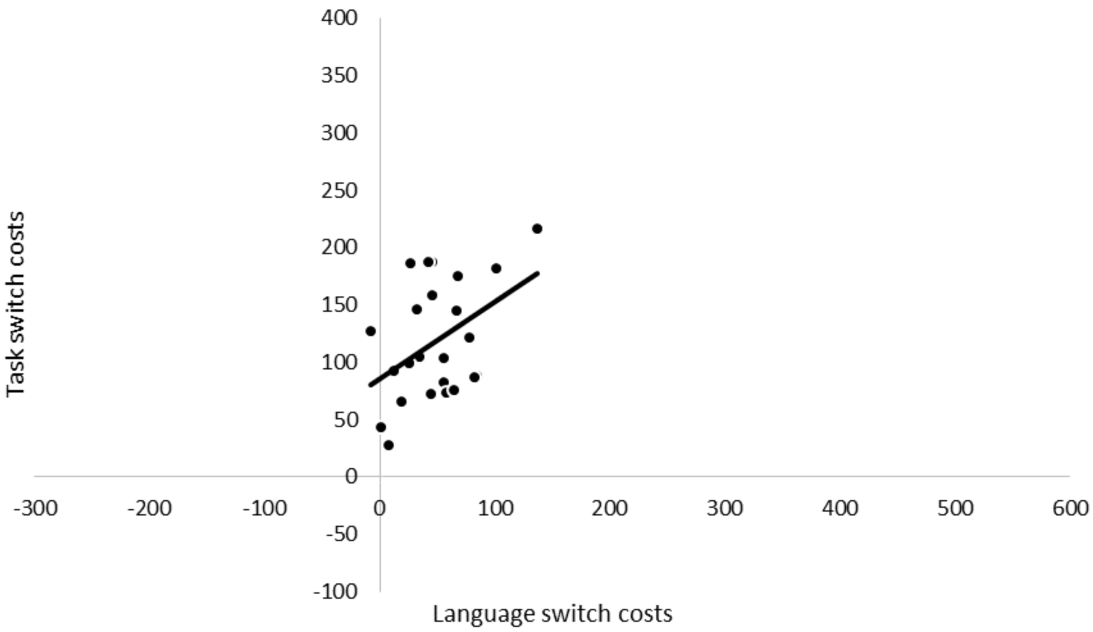

Figure 1. Scatter plot of Experiment 1

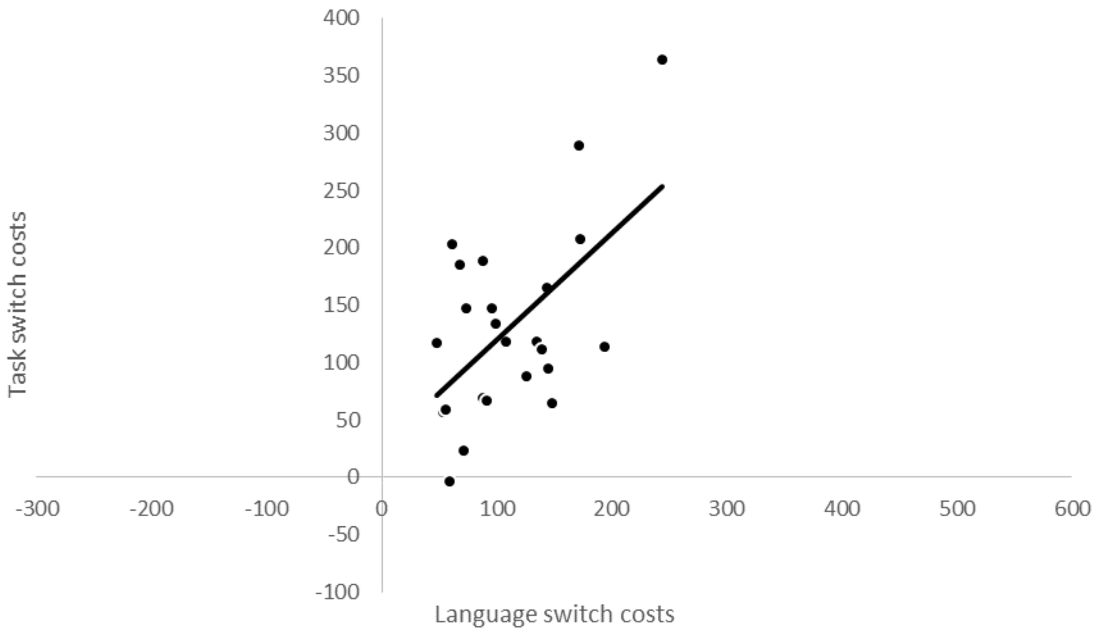

Figure 2. Scatter plot of Experiment 2

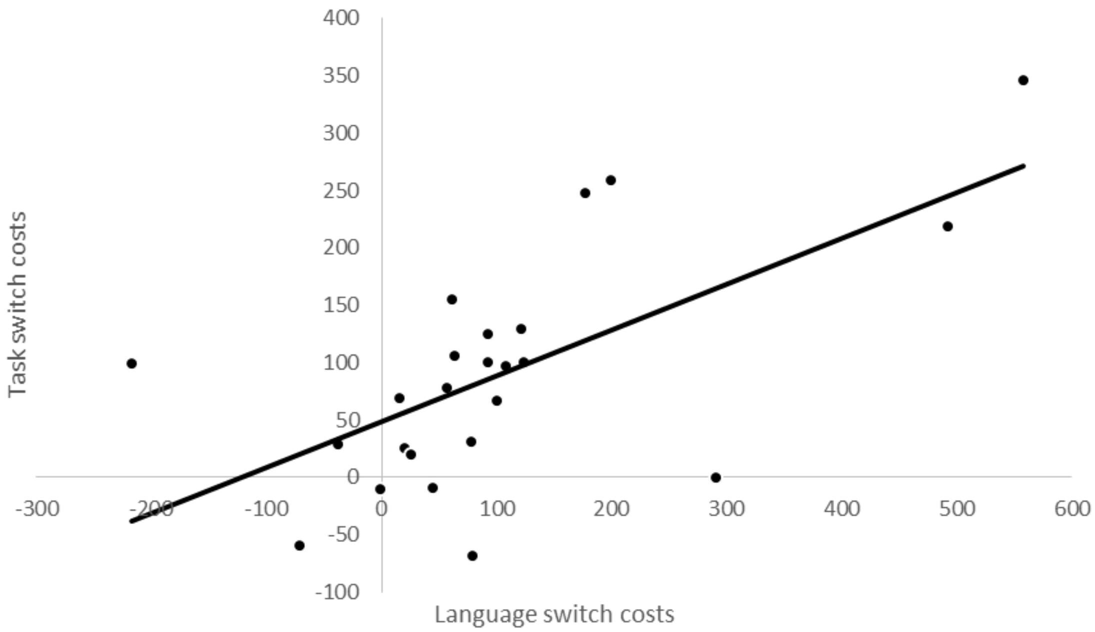

Figure 3. Scatter plot of Experiment 3