**Language switching during production: The influence of preceding exposure to other bilinguals in different switching contexts**

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**Abstract**

Language control has been argued to adapt dynamically to the language context bilinguals are communicating in (Green & Abutalebi, 2013). Previous research has suggested that the demands of the task and current context itself can influence a bilingual’s language behaviour and potentially also their language control. Here, we examined how the *preceding context*, specifically the switching patterns of another bilingual in that context, can influence a bilingual’s own language control during production. Across two experiments (Experiment 1: Mandarin-English bilinguals; Experiment 2: English-French bilinguals), participants completed a cued switching task preceded by exposure to another bilingual who was switching frequently or rarely. In Experiment 1, switching costs during production were reduced after exposure to a high-switching bilingual. In Experiment 2, switching costs were also reduced compared to exposure to a low-switching bilingual, but only after hearing within-sentence switches (and not after hearing between-sentence switches). This suggests language control can dynamically adapt to the immediately preceding language context, potentially by the linguistic context updating the speaker’s expectations and triggering adaptations in their language control in a top-down manner. However, such adaptations do appear to depend on the nature of the preceding switching context.

Keywords: Bilingualism, Language Control, Language Context

1. **Introduction**

Many bilinguals often find themselves in contexts in which two languages are or can be used. In these contexts, bilinguals can switch languages themselves and are also likely to be exposed to switches produced by the other bilinguals they are interacting with. Producing and processing words in multiple languages involves managing competition between the simultaneously active languages. To do this, bilinguals apply language-control mechanisms to select words in the language they want to/have to use; to avoid interference from the other language; and to switch between languages when appropriate (in switching contexts).

 Following the Adaptive Control Hypothesis (Green & Abutalebi, 2013), this language control is argued to be dynamic and adaptive to the language context a bilingual is in. In particular in dual-language contexts where bilinguals need to select their languages in response to external “cues” (such as specific conversation partners speaking only one of the languages), language-control demands are argued to be high. However, the Adaptive Control Hypothesis also argues that language control differs between language contexts, and adapts based on their varying demands. Indeed, in their daily lives, bilinguals are likely to often find themselves in different types of contexts. Within contexts that allow for or require switching, there is also variation in the type of switches bilinguals are exposed to in interaction with other bilinguals. In the current manuscript, across two experiments, we examine the influence of exposure to these different language-switching contexts on a bilingual’s own language control during language production, to study the adaptation of language control to preceding language contexts.

* 1. **Language control during production**

Language control is argued (Green & Abutalebi, 2013) to be most needed during dual-language contexts in which bilinguals have to use their languages in response to external cues, such as different conversation partners (e.g., using French with one colleague but English with another). In these contexts, bilinguals are argued to require context monitoring to assess language cues and know which language to use when; goal maintenance to ensure the appropriate target language is used; conflict monitoring and interference suppression to avoid interference from the other language; as well as task engagement (target language) and disengagement (switching to another language) in response to the external cues. Both language activation (activating the target language) and inhibition (suppressing the non-target language to avoid interference) have been argued to be key parts of language control during this type of switching (Green, 1998).

 There is a vast literature studying this type of switching in the form of cued picture-naming paradigms. These tasks ask bilinguals to name pictures in response to a cue (for example, a face or country flag associated with a language). In dual-language contexts, both languages have to be used interchangeably, with bilinguals sometimes having to switch languages in response to these cues. This leads to language switch trials (different language on current trial compared to the previous trial) as well as language non-switch trials (same language as on previous trial). Comparing speed of naming onset times between these two trial types typically shows a switching cost: Bilinguals need more time to name a picture when switching languages compared to a non-switch trial. This switching cost has been associated with the control needed to, in response to a switch trial, re-activate a new target language and inhibit the language that can no longer be used (Green, 1998). The control used at the moment of switching (and the associated switching costs) is argued to be reactive in nature and applied in response to the specific utterance that has to be produced. Some studies have found an asymmetry in these switching costs (e.g., Meuter & Allport, but cf. Gade et al., 2021), with larger costs when switching to the first language (L1) than to the second language (L2). These switching costs have often been interpreted through L1 inhibition. When using the L2, stronger inhibition over the L1 might be needed if the L1 is more proficient/dominant and therefore interferes more. When having to switch back to the L1, it might take bilinguals longer to re-activate the L1 and overcome this previously applied inhibition. This could then lead to larger L1 switching costs, compared to the L2 requiring less inhibition (Green, 1998). Although inhibition is the most common interpretation of these findings, they can also be explained through L2 over-activation (e.g., Philipp et al., 2007). Following this interpretation, bilinguals might over-activate their L2 in dual-language contexts to facilitate use of the less proficient language. This over-activation might then spill over into the next trial, therefore slowing down responses when having to switch to the L1.

In addition to switching costs, cued naming tasks have also been associated with relatively slow L1 and relatively fast L2 responses. This has been observed in comparison to single-language contexts (i.e., relatively slow L1 dual-language responses compared to the single-language context, e.g., Christoffels et al., 2007) as well as through “reversed dominance effects”. The latter refers to bilinguals showing faster L2 than L1 responses in dual-language contexts (e.g., Declerck et al., 2020). These patterns, similar to the asymmetry in switching costs, have often been attributed to bilinguals (over-)inhibiting their L1 in dual-language contexts (e.g., Goldrick & Gollan, 2023). While control applied at the moment of switching is argued to be reactive in nature, these reversed dominance effects have been explained through proactive control. This control can be applied proactively (in advance) in anticipation of upcoming language competition, potentially through global L1 (over-)inhibition and/or global L2 over-activation.

Within language production itself, one type of research that supports the adaptive nature of language control is the comparison between these cued switching tasks and voluntary switching tasks. In cued tasks, competitive control is needed to ensure only one language is used at a time while the other language is not. In voluntary tasks, in contrast, bilinguals no longer have to use a specific language in response to external cues but can decide which language they want to use for each picture and therefore when they switch. While switching costs are often still observed in these voluntary tasks too, they tend to be smaller in voluntary than cued tasks (cf. de Bruin & Xu, 2023, Gollan et al., 2014, Jevtović et al., 2019). Exactly how language control is implemented during language production might therefore depend on the type of switching during production (Adaptive Control Hypothesis, Green & Abutalebi, 2013).

While cued switching tasks use competitive control, voluntary switching might be associated with *cooperative* control instead (Control Process Model, CPM; Green & Wei, 2014; Green, 2018). When both languages are understood by the conversation partner, one or multiple words can be inserted (or alternated) within a sentence. The matrix language (e.g., the language a sentence started in) is argued to temporarily hand over control to the other language (to be used for a few words in an insertion or alternation), before the control is given back to the matrix language. This is described to be a gate system, in which the other language gate is always slightly open and can be “pushed open” if words are more appropriate or easier to retrieve in another language. This type of cooperative control is different from the competitive control needed during cued single-word language switching, where a specific language has to be used even if another word in another language is more appropriate or can be retrieved more easily. However, these types of within-sentence switches (insertions and alternations) are still argued to recruit more coupled (cooperative) control than dense code switches. Dense code switches (Green & Wei, 2014; or congruent lexicalisation, Muysken, 2000) refer to utterances in which words/morphemes are used from more than one language, through a shared language structure (e.g., “loopke” using the Dutch lexical item “loop” and the Frisian diminutive “ke”, Muysken, 2000). The CPM argues that in these dense code- switches, the gates are fully open for both languages, with items regardless of the language entering the utterance. How language control is used is thus argued to depend very heavily on the type of switching.

* 1. **The influence of context on language switching**

In the current study, we focused on examining how different types of *preceding* switching contexts influence language-control adaptation during production. We use the production switching tasks that have been argued to recruit the highest degree of language control (the cued switching tasks discussed above). If language control during this type of production adapts to the context, such effects would be expected across a range of temporal distances: in response to the context or demands of the task itself (e.g., how often each language is used or the types of cues present in the task), in response to the immediately preceding context (e.g., the behaviour of another bilingual in that context), and potentially more long-term in response to the language environment a bilingual lives in.

 Starting with the task itself (i.e., the current/immediate context), cued language switching has been found to be affected by the characteristics of the task. Olson (2016) tested Spanish-English bilinguals in “monolingual” (95% of trials named in the L1 or L2) and “bilingual” (50% of trials per language) switching contexts. When bilinguals were asked to use the L1 and L2 equally often (bilingual contexts), they showed symmetrical switching costs (i.e., comparable L1 and L2 switching costs). However, when 95% or 5% of trials had to be named in the L1 (monolingual contexts), the costs were asymmetrical (larger L1 than L2 costs). This suggests the immediate task/language context can influence language switching costs and potentially the control associated with it. However, percentage language use and percentage switching were confounded in these tasks, making it unclear whether switching-cost patterns were specifically related to the switching characteristics of the task or rather related to how often people had to use their L2. Timmer and colleagues (2019) therefore asked Dutch-English bilinguals to complete a cued picture-naming task in which the majority (83%) of trials had to be named in their L1 or in their L2 while keeping switching rates constant. In the L1-dominant context, symmetrical switching costs and slower L1 naming were observed. In the L2-dominant context, larger L2 than L1 switching costs were observed and the L2 was (somewhat) slower than the L1. These patterns were interpreted in light of language activation levels differing between those contexts. When the L2 was used more often, and therefore likely more active, L2 representations perhaps needed to be suppressed more when the L1 occasionally had to be used. The larger L2 than L1 switching costs could therefore reflect the need for more reactive control over the (in this task context) more active L2 when the L1 (occasionally) had to be used, resulting in the L2 requiring more time to be re-activated when having to switch back to that language. In contrast, in L1 contexts, slower overall L1 naming suggested bilinguals relied more on proactive control, potentially by over-inhibiting the L1 in anticipation of upcoming (occasional) language competition.

 Apart from language use and/or switching frequency within a task, the presence of contextual cues within a task can also modulate language-switching costs. For example, Liu et al. (2019) compared language switching without faces to different conditions with faces matching a language (e.g., Asian face presented with trials that had to be named in Mandarin) or mismatching a language (e.g., Asian face presented with trials that had to be named in English). When asymmetries were found, these were in the direction of larger L1 than L2 costs in the baseline and incongruent conditions, but larger L2 costs for the congruent trials. The authors interpret this as contextual cues facilitating language activation in congruent conditions and therefore potentially reducing the need for L1 language control. This appeared to affect reactive control as only the switching costs were influenced by the cues. These findings are in line with various other studies (e.g., Roychoudhuri et al., 2016; Zhang et al., 2013) suggesting that the presentation of cultural cues associated with the L1 can influence a bilingual’s L2 production. Together, these studies suggest the exact demands of the task context (frequency of language use and switching, cues present in the context, etcetera) can influence language activation, competition, and potentially reactive control.

 This suggests bilingual language control is dynamic, but also raises the question whether this flexible nature and potential adaptation extends beyond purely adapting to the task context/demands itself. Adaptation beyond the immediate/current context has mostly been studied on a longer-term scale, often by comparing language groups that differ in their daily-life language backgrounds. For example, various studies have shown that both language production (e.g., Beatty-Martinez et al., 2020; Bonfieni et al., 2019) and language comprehension (e.g., Gosselin & Sabourin, 2021; Kaan et al., 2020) can differ depending on the bilingual groups tested, and in particular their daily-life language switching exposure and behaviours. Studies that have looked at more long-term changes in language control *within* bilinguals in response to real-life language environment changes, rather than comparing groups, have found mixed results. Liu et al. (2021) showed a reduction in language switching costs in L2 learners after a year of classroom L2 learning. However, Coumel et al. (submitted) showed no changes in language control during cued switching tasks in a longitudinal study testing bilinguals immediately after they moved to a new language environment and seven months later. This suggested long-term (across months) adaptation to the general language environment might be limited or restricted to certain types of language learners or users.

 However, bilinguals vary constantly in the language context they are in and the language contexts they are exposed to. For example, a Mandarin-English bilingual might within the span of one hour go from listening to an English monolingual friend in class, to switching languages with another Mandarin-English bilingual, to making a phone call with a friend who mostly uses Mandarin but occasionally inserts an English word. A key missing step, therefore, to better understand language-control adaptation to context is to study changes in language control in response to the immediately preceding language context. In daily-life conversations, a core component of immediately preceding contexts is the conversation partner.

 Focusing on *comprehension*, Kaan and colleagues’ (2020) work suggests that language control adapts to the language behaviour of the conversation partner present, even when that partner’s language behaviour is not immediately relevant to the task (i.e., it is not part of the task demands). They asked Spanish-English bilinguals to read sentences with another person who was introduced as an English monolingual speaker or a Spanish-English bilingual (cf. also Tomić & Kaan, 2022). ERP data were collected, showing switching costs as switch words elicited a larger early frontal positivity and LPC (late positive component) than non-switch trials. These ERP effects differed depending on whether the task was completed with another bilingual or monolingual. The LPC switch cost was smaller with a bilingual than monolingual partner, but only when participants thought the monolingual partner did not understand the switched Spanish sentences. These findings were interpreted as supporting dynamic language control. In line with Green and Wei’s Control Process Model (CPM, Green & Wei, 2014; Green, 2018), the linguistic and non-linguistic context a bilingual is in might influence the bilingual’s expectations and intentions. In Kaan et al.’s research, the presence of another bilingual was therefore argued to alter the participant’s expectations about language use and switching, thereby shaping the language control used at the moment of switching (see further discussion below).

 During production too, the conversation partner’s (switching) behaviour has been found to influence a bilingual’s own production. Kapiley and Mishra (2019) asked Telugu-English bilinguals to name pictures to a virtual character that was introduced has having a high or low L2 proficiency. Participants switching rate and language choice was influenced by the cartoon’s proficiency (see also Kapiley & Mishra, 2024). While these studies manipulated language proficiency of the conversation partner, de Bruin and Shiron (2024) examined influences of the interlocutor’s switching patterns and found that bilinguals’ voluntary language switching was influenced by the conversation partner’s switching (cf. Kootstra et al., 2020, for similar findings). However, only Kapiley and Mishra (2024) showed an influence of the conversation partner’s behaviour on the bilingual’s own switching costs during production. The other two studies showed the conversation partner influenced *when* bilinguals switched, but not the cost (and therefore potentially language control) associated with it. However, these studies focused on *voluntary* language switching, which has been argued to recruit less language control than during contexts in which bilinguals have to switch in response to external cues. (cf. de Bruin et al., 2018; Green & Abutalebi, 2013).

A recent study focusing on language control during single-language contexts suggested that the immediately preceding context can influence language control during production too. Degani et al. (2024) asked Hebrew-English bilinguals to name pictures in Hebrew before and after completing an English “exposure” block, in which participants had to read English words out loud or judge whether English words were animals or not. Participants showed more filled pauses (hesitations to fill a gap before speaking) when producing the picture names in Hebrew after the English exposure block, compared to before English exposure. This L2 exposure effect was comparable regardless of whether the type of exposure included production (reading words out loud) or not (animacy judgements). This suggests that exposure to L2 words in the immediately preceding language context can influence L1 production (cf. also Elston-Güttler et al., 2005, for effects of preceding language exposure on language co-activation during single-language comprehension). This may be due to L2 exposure increasing L1 inhibition, meaning more time is needed to recover the L1 in the next block, or due to L2 (over-)activation increasing interference with the L1 after L2 exposure. Their study, however, assessed proactive control during single-language contexts and did not look at reactive control during language switching.

 Thus, beyond the actual task demands and task context itself, the immediately preceding context and/or the language behaviours of a conversation partner can influence language production and comprehension. However, production studies so far have focused on single-language contexts or voluntary switching and did not assess reactive control during language switching when demands on language control are highest. Therefore, to study the dynamic nature of reactive control during language-switching production and the adaptation to other bilinguals’ language behaviours in the immediately preceding context, we examined how exposure to another bilingual’s switching behaviour can influence language control during cued language production.

* 1. **Why might language control adapt to other bilinguals’ behaviour in the preceding context?**

An influence of the preceding context on the bilingual’s own switching costs would suggest language control is dynamic and can adapt to the context. Such adaptation could operate in (at least) two ways. First, exposure to a switching context could prepare bilinguals for the need for language control during their own production. Bilinguals could proactively take the socio-linguistic context into consideration, including its language demands and possibilities (i.e., which language(s) can be used), in advance of their own production. Exposure to another bilingual who is frequently switching languages could therefore prepare a bilingual for switching in their own production too, and hence optimise their language-control mechanisms in advance for such switching during production. This could help bilinguals, for example, to proactively activate and/or inhibit their two languages for easier use in a dual-language context. It could also optimise the more reactive control mechanisms that are argued to be used at the moment of switching (Green, 1998). This potential mechanism aligns with the interpretation Kaan et al. (2020) provide for their bilingual participants showing reduced switching costs during comprehension in the presence of another bilingual. In their study, earlier ERP effects (frontal negative effects) were interpreted to reflect top-down modulation of language activation and control by the non-linguistic context (i.e., the conversation partner). Later LPC effects were interpreted to reflect later-stage dynamic adaptation, including potential adaptation in response to social norms and in response to anticipating more switches when a bilingual is present. This interpretation was further supported by the LPC effects depending on the participants’ expectations or awareness of their conversation partner’s Spanish understanding. This is in line with other studies showing LPC effects to be related to socially unexpected stimuli (e.g., Lattner & Friederici, 2003).

 Dynamic top-down modulation of language control could also align with several models of language comprehension and production. In terms of language production, they align with the Adaptive Control Hypothesis (Green & Abutalebi, 2013) relating to the dynamic context-dependent nature of language control, as well as the CPM (Wei & Green, 2014; Green, 2018) regarding language control proactively adapting based on the information present in the (non-)linguistic context. Although models of language comprehension do not directly apply to language production (as studied here), the BIA model of comprehension (Dijkstra & Van Heuven, 1998) includes language nodes that can top-down modulate language activation in the lexicon. These language nodes can be updated depending on various sources of information, including the (non-)linguistic context. Later models include a task/decision schema that can be influenced by external contextual factors (e.g., the BIA+ model, Dijkstra & Van Heuven, 2002; MultiLink model, Dijkstra et al., 2019). Although this task schema is argued in the BIA+ to not directly influence the lexicon and activation levels during comprehension, such schema could be incorporated to influence language-control and language activation levels during subsequent production.

Finally, dynamic language control would align with conflict adaptation observed in the non-linguistic control literature (e.g., Botvinick et al., 2001). Tasks such as Stroop and flanker tasks have frequently shown faster responses to incongruent conflict trials (e.g., the word “red” in green ink) after another incongruent trial, compared to after a congruent trial (e.g., the word “red” in red ink; congruency sequence effect, e.g., Botvinick et al., 1999). Furthermore, conflict costs (i.e., the RT difference between congruent and incongruent trials) are often reduced in conditions that include a large percentage of incongruent trials, compared to tasks using mostly congruent trials (e.g., Logan & Zbrodoff, 1979). Although the exact mechanisms and modulating factors are debated (with further review being beyond the scope of this manuscript, but see e.g., Botvinick et al., 2001; Schmidt, 2019), one proposed mechanism is that incongruent trials signal the presence of conflict in the presented information, and thereby trigger the control system to prevent or more efficiently manage conflict. Such adaptation could take place by directing attention more strongly towards the target stimulus and/or by moving such attention away from the distractor stimulus. Although others have proposed other explanations for the effects observed during e.g., Stroop or flanker tasks (e.g., Schmidt, 2019), the mechanisms described above could apply to language control. Exposure to another switching bilingual could prepare the bilingual for upcoming language competition and switching during their own production, and therefore optimise the system by directing attention more strongly towards the target language/word (while potentially moving attention away from the non-target language/word and/or inhibiting the non-target language/word more strongly).

A potential second mechanism relies on shared control mechanisms being involved in comprehension and production. Having to process another bilingual’s language switches can recruit language control, potentially similarly to production by having to inhibit one language while processing the other language (e.g., Coumel et al., 2024; Litcofsky & Van Hell, 2017). If comprehension uses the same language-control mechanisms as the ones used during production, this previous use of language control could optimise language control when it is subsequently used in another task. This would depend on comprehension and production at least partly sharing language-control mechanisms. Studies looking at bilinguals alternating between (written) comprehension and spoken production have suggested comprehension trials can influence word production and might indeed recruit similar control mechanisms (e.g., Peeters et al., 2014). However, this might be modulated (or even explained) by task demands, with comprehension potentially only influencing production when task demands are high (cf. Li & Gollan, 2022; Li et al., 2024). Furthermore, while mechanisms might partly overlap, studies have also highlighted that language-control mechanisms differ between comprehension and production, with language inhibition proposed to be more important during production than comprehension (e.g., Li et al., 2024). Indeed, switching costs in comprehension and production might not necessarily correlate with each other (e.g., Ahn et al., 2020). This also aligns with recent research not finding any switching costs during comprehension (e.g., Declerck et al., 2019) or, when these are found, finding switching costs that are much smaller than those typically observed during production (e.g., Coumel et al., 2024). Thus, while shared control mechanisms between comprehension and production could explain potential changes in production after comprehension, previous studies suggest overlap is only partial at best and language comprehension recruits less language control than production. This makes the potential contributions of shared comprehension-production control mechanisms a less likely, or less powerful, mechanism to drive any language-control adaptations in response to preceding contexts.

1. **Study 1**
	1. **Introduction**

Aiming to study when and how language control during production adapts to other bilinguals’ switching behaviours in the preceding context, our first experiment examined how bilinguals switched languages during production in a cued switching task after exposure to another bilingual who switched frequently versus very rarely. We asked Mandarin-English bilinguals to complete a cued language-switching task twice after watching one of two videos of another Mandarin-English bilingual telling a short story. In both exposure contexts, each language was used approximately half of the time to keep L1/L2 exposure consistent. The two contexts only differed in the switching frequency being high or low (i.e., switching once, to go from the L1 to L2, or vice versa, in the middle of the story). If language control is dynamic and adaptive to the (preceding) language context, we expected performance during the cued production task to differ depending on whether participants had just watched the low- or high-switching video. Specifically, if bilinguals’ language control *during switching* (i.e., when conflict is highest) adapts after exposure to another bilingual switching frequently, we expected smaller cued switching costs after watching the high-switching video compared to the low-switching video.

This reduction in switching costs would be predicted by both mechanisms proposed above. Firstly, if the linguistic context alters the speaker’s expectations (including the expectation of upcoming switching and potential language competition), this could trigger the language-control system (mechanism 1), potentially increasing attention to/activation of the target language during switching and/or moving attention away from the non-target language. Both increased (target) activation and moving attention away from the non-target language would be expected to reduce switching costs. Moreover, if this (also) triggers increased inhibition of the non-target language, we expected to see a larger asymmetry in switching costs after exposure to a high-switching bilingual, with a larger L1 switching cost (due to more L1 non-target inhibition and therefore more time needed to switch back to the L1).

Second, if comprehension and production recruit the same language-control mechanisms, using them during comprehension could optimise them for subsequent use during production (mechanism 2), and thus would also be expected to result in reduced switching costs.

 Exposure to another bilingual could also affect dual-language production more globally, beyond the switching cost. If exposure to another switching bilingual increases a bilingual’s overall attention and motivation (because they are expecting a more difficult task during their own production), we would expect overall faster production RTs across switch and non-switch trials after watching another switching bilingual. If exposure to another switching bilingual proactively changes the activation levels of the L1 and L2, we might expect faster L2 responses (more activation) and/or slower L1 responses (more inhibition) across both switch and non-switch trials after watching another high-switching bilingual, compared to the low-switching bilingual. Given that both the low- and high-switching bilingual contexts included equal use of the L1 and L2, such interaction between Language and Context would only be expected to occur if language control is adjusted proactively in preparation for a dual-language context *with many* *switches.*

* 1. **Methods**
		1. ***Participants***

Experiment 1 was completed by 30 participants (*M*age = 23.1 years, *SD* = 3.0; 7 female, 23 male). One additional participant completed the study but their recordings were empty and could not be scored. The sample size for Experiment 1 was based on feasibility for a student project. For Experiment 1, we did not have an effect size from previous literature to base a power analysis on, but we used Experiment 1’s data to conduct a power analysis for Experiment 2. Both experiments received ethics approval from the Ethics Committee in the Department of Psychology (approval numbers 2224 and 2273), University of York, and were conducted in line with the principles of the 1964 Declaration of Helsinki.

 All participants reported being native speakers of Mandarin Chinese. The mean reported age of starting English acquisition was 6.2 years old (*SD* = 2.8). Participants self-reported their proficiency on a scale from 1 (no proficiency) to 10 (what could be considered an L1 speaker’s proficiency) in both languages (see Table 1). Participants were unbalanced bilinguals with, on average, a higher proficiency in and use of their L1 than their L2. However, participants varied in their reported language use in the past year, with some participants reporting more frequent L2 than L1 use (N = 4) and others reporting relatively balanced use (40-60% each language; N = 10).

Table 1. *Language proficiency of the participants in Experiment 1.*

|  |  |  |
| --- | --- | --- |
| *Question* | **Mandarin (L1)** | **English (L2)** |
| **Self-rated proficiency (1-10)**Speaking Understanding speechReading Writing | 9.8 (0.6)9.6 (0.8)9.7 (0.7)9.4 (1.1) | 6.0 (1.9)6.3 (1.9)6.7 (1.8)5.9 (1.7) |
| **% time use (0-100%)** | 68.4 (19.6) | 33.8 (19.1) |

* + 1. ***Design***

Participants completed a cued switching task, with reaction times (RTs) as the main dependent variable (DV). Reaction times were defined as the onset of naming relative to the onset of picture presentation. The three independent variables (IVs) were Trial type (language switch or non-switch), Context (preceding context being high-switch or low-switch), and Language (picture named in Mandarin or English, in response to the cue).

* + 1. ***Materials***

We used two sets of twenty pictures, also used in de Bruin and Xu (2023) with Mandarin-English bilinguals (see Supplementary Materials Appendix A). Participants always saw both the high- and low-switch contexts. Half of the participants named Set A after the preceding low-switch context and set B after the high-switch context; the other half named Set A after the preceding high-switch context and set B after the low-switch context. In both sets, frequency was matched between the two languages (Set 1: Mandarin *M* = 4.5, *SD* = 0.6; English *M* = 4.6, *SD* = 0.5; *t*(19) = -0.585, *p* = .565; Set 2: Mandarin *M* = 4.6, *SD* = 0.7; English *M =* 4.6, *SD* = 0.5; *t*(19) = -0.004, *p* = .997). This was based on ZIPF log frequency (SUBTLEX-CH, Cai & Brysbaert, 2010; SUBTLEX-UK, Van Heuven et al., 2014). The pictures were taken from the MultiPic database (Duñabeitia et al., 2018) and were selected to be easy-to-name objects, with a high frequency and short picture names (English words were one to three syllables and one to nine phonemes long; Mandarin words were all one or two characters). An additional four pictures were used in the practice phases and not repeated in the experimental tasks. Two of the picture names also occurred in the videos; removing these two items did not influence the result patterns.

 For the videos, we chose two short stories about the effects of music on emotions and the urban life of animals. These topics were chosen because they were informative and interesting but also easy to follow. They were presented to the participants in the way a friend could share an interesting piece of news they had recently read about. The texts were created based on Frontiers for Young Minds articles (based on Magle et al., 2021 and Park et al., 2022). The music text included 371 words in English and the urban life one 379 words. For each text, we created two low-switch versions and one high-switch version. In the low-switch videos, approximately half of the words were in English and the other half in Mandarin. The first part of the low-switch condition was spoken in English only *or* in Mandarin only, while the second part exclusively used the other language. This ensured there was only one language switch in the middle of the video. In the high-switch version, both languages were again used approximately equally often. These videos included frequent language switches. The music text included fifteen switches to Mandarin and fourteen switches to English (29 in total, around 8% of words, based on the English word count). The urban life text included eleven switches to Mandarin and ten switches to English (21 in total, around 6% of words). These switches occurred between sentences and within sentences and the switching rate was chosen in line with switching rates observed in corpus data (Fricke & Kootstra, 2016). The videos were between 2.15 and 2.31 minutes long. The full texts are provided in the Supplementary Materials.

* + 1. ***Procedure***

Participants completed the study online using Gorilla.sc (Anwyl-Irvine et al., 2020). After providing informed consent, participants were first asked to check their microphone was recording their responses audibly. After this check, participants saw the pictures in a familiarisation phase (see Figure 1). This phase was included to ensure participants could easily recognise the pictures. Each picture was presented on the screen with the corresponding English and Mandarin words and participants were asked to press SPACE to see the next picture-words set once they had looked at the picture and words. After this familiarisation, participants named each picture once in L1-Mandarin and once in L2-English in two single-language blocks. Participants always did this practice in their L1 first. These single-language blocks were only included so that participants could practice each picture name once in response to the language cue before the switching task and were not included to compute mixing effects. Next, participants completed four practice trials in which we asked them to switch languages in response to the cue.

 After these practice blocks, the real experiment started. Each participant watched two videos of a Mandarin-English bilingual. After each video, they completed a switching task, using one set of 20 pictures in one of the tasks and the other set of 20 in the other task (counterbalanced across participants). In each switching task, they named eighty trials. This included an equal number of L1 switch, L1 non-switch, L2 switch, and L2 non-switch trials. Each picture was presented once in each condition. Trials were presented in an unpredictable order but pseudo-randomised so that there were no more than three trials of the same type (e.g., switch or non-switch) in a row and no repetition of pictures on two subsequent trials. Each trial started with a fixation cross for 500 ms, followed by the cue being shown on its own for 300 ms. Afterwards, the cue and picture were shown together for 2500 ms, regardless of when the response was given. The cue was always shown above the picture. Participants were instructed to name the picture in the language indicated by the cue. The instructions were always shown in English only. Two cues were used per language to avoid confounds between language and cue switching costs (Heikoop et al., 2016). We used faces (taken from the Chicago Face Database, Ma et al., 2015) as language cues and asked participants to use Mandarin in response to Asian faces and English in response to White faces. We opted for face cues as faces are often a strong indication of the language that has to be used in real-life interactions.

 Prior to each switching task, participants watched a short video in which a Mandarin-English speaker talked about the effect of music on emotions or the urban life of animals. Half of the participants saw the high-switch video first (half about music and half about urban life) and the other half saw the low-switch video first (half about music and half about urban life). The language order in the low-switch video (first half in English or Mandarin) was also counterbalanced across participants.

 At the end of the switching task, participants first completed one comprehension question per video, to make sure they paid attention and listened to them carefully. These questions and answer options were presented in both languages. All participants answered correctly on both multiple-choice questions. After this, they completed a short language-background questionnaire (see Table 1).



*Figure 1.* Overview of the task phases in Experiments 1 and 2.

* + 1. ***Data analysis***

The data and analysis script are available here: https://osf.io/83nqm/

Accuracy was coded by the bilingual Mandarin-English author (JW). Answers were scored as being incorrect if no (audible) response was given or if the response used the wrong word or language. RTs were determined from the recordings using CheckFile in Checkvocal (Protopapas, 2007). For the RT analysis, we removed incorrect responses, the very first trial and trials preceded by no response or the wrong language (as trial type could not be determined), and RT outliers (2.5*SD* above/below mean per participant and condition, using *trimr,* Grange, 2015; 1.0% of correct switch/no-switch trials). Accuracy was high in both video conditions (low-switch: *M* = 96.5%, *SD* = 4.2; high-switch: *M* = 95.5%, *SD* = 7.3) and not analysed further. The data were analysed through linear mixed-effects analyses using lme4 package version 1.1-36 and lmerTest version 3.1-3.

RTs were log-transformed for the analysis to improve normality of the distribution (but means of untransformed RTs are reported in the text and figures). The analysis included the fixed effects Trial Type (non-switch = -0.5; switch = 0.5), Language (Mandarin = -0.5; English = 0.5), and preceding Context (LowSwitch = -0.5; HighSwitch = 0.5). Analyses started with a maximal structure including participants’ and items’ intercepts and slopes. When models did not converge, we removed correlations between intercepts and slopes and then the by-item slopes explaining the least variance until convergence was reached. The final model converged with participant slopes for Trial Type, Language, and preceding Context, and item slopes for preceding Context, Trial Type x Language, Trial Type x preceding Context, Language x preceding Context, and Language x Trial Type x preceding Context.

* 1. **Results**

There was a significant effect of trial type (β = 0.054, *SE* = 0.008, *t* = 6.864, *p* < .001), indicating a switching cost. Responses on non-switch trials (*M* = 1103ms, *SD* = 137) were faster than on switch trials (*M* = 1169ms, *SD* = 155, see Figure 2 and Table 2). This switching cost differed between the two contexts (β = -0.028, *SE* = 0.013, *t* = -2.071, *p* = .045). It was smaller after exposure to a high-switching (*M*cost = 51ms, *SD* = 58) than a low-switching bilingual (*M*cost = 83ms, *SD* = 66). This was driven by the switch trials (high-switch condition: *M* = 1156ms, *SD* = 165; low-switch condition: *M* = 1184, *SD* = 162, although the effect of Context did not reach significance in the switch trials only: β = -0.020, *SE* = 0.014, *t* = -1.438, *p* = .160). The no-switch trials were similar in both contexts (high-switch condition: *M* = 1105ms, *SD* = 147; low-switch condition: *M* = 1101ms, *SD* = 141; β = 0.006, *SE* = 0.016, *t* = 0.358, *p* = .723). There was no main effect of video context on overall RTs (β = -0.008, *SE* = 0.018, *t* = -0.421, *p* = .676).

 There was a main effect of language (β = -0.078, *SE* = 0.015, *t* = -5.053, *p* <.001). Responses were faster in English (*M* = 1089ms, *SD* = 147) than in Mandarin (*M* = 1183, *SD* = 152). The switching cost was larger when switching to English (*M*cost = 100ms, *SD* = 71) than to Mandarin (*M*cost = 27ms, *SD* = 53; β = 0.061, *SE* = 0.014, *t* = 4.501, *p* < .001). Language did not interact with Context (β = 0.008, *SE* = 0.022, *t* = 0.348, *p* = .730) or with Context and Trial Type (β = 0.030, *SE* = 0.027, *t* = 1.082, *p* = .286).

Table 2. *Mean RTs (and switching costs, difference between switch and non-switch trials) per preceding context (low switch and high switch) and per language (Mandarin and English) and trial type (non-switch and switch trials) during the cued production task.*

|  |  |  |
| --- | --- | --- |
| Preceding context | Low-switch | High-switch |
| **Mandarin**Non-switchSwitch*Switching cost* | 1162 (159)1220 (168)58 (92) | 1175 (171)1173 (162)-2 (82) |
| **English**Non-switchSwitch*Switching cost* | 1040 (147)1145 (166)105 (79) | 1042 (153)1136 (179)94 (80) |
|  |  |  |



*Figure 2.* Switching costs (RT difference switch minus non-switch trials) in Experiment 1 per language (left: Mandarin, right: English) and by preceding switching context (left box plot per panel: after exposure to a low-switching bilingual; right box plot per panel: after exposure to a high-switching bilingual). Individual points reflect individual participant means (jittered). The horizontal line shows the median and the centre of the triangle the mean across participants.

* 1. **Discussion**

Experiment 1 examined whether language control is dynamic in response to exposure to different types of switching patterns produced by other bilinguals. Mandarin-English bilinguals therefore completed a cued switching task preceded by another bilingual switching regularly or rarely. Cued switching costs during production were reduced after exposure to the high-switching bilingual.

 This reduction in switching costs was driven by a decrease in RTs in response to switch trials, with no change in non-switch trials. This suggests a difference in language-control mechanisms *at the moment of switching.* One possible underlying mechanism is that exposure to a high-switching bilingual updated bilinguals’ expectations about their own language production requiring language switches too, and in turn triggered their language-control mechanisms. These findings and interpretation align with Kaan and colleagues (2020) showing a reduction in switching costs during language comprehension in the presence of another bilingual. In line with Kaan et al’s data, the preceding context could change people’s expectations about the (non-)linguistic environment they are in.

 Responses to switch trials specifically are often linked to reactive control applied at the moment of switching, in response to the stimulus that has to be named at that point (cf. Green, 1998). The change in switch trials suggests this reactive control was affected in particular, potentially through more attention being directed to activating the new target language at the moment of switching. This impact did not differ between the two languages (i.e., the asymmetry in switching costs was not affected). The asymmetry in switching costs has often (although not always) been linked to reflecting (differences in) inhibition over the non-target language (Green, 1998). The finding that the asymmetry was not modulated by context in the current study suggests the preceding context did not influence the inhibition of the non-target language, but rather facilitated switching by directing attention to the new target language.

The finding that non-switch trials were not affected by the preceding context suggests that bilinguals did not alter their attention, engagement, or motivation more generally after exposure to another switching bilingual. This further confirms any adaptation was more reactive rather than proactive in nature, as also supported by the absence of an effect of preceding context on language. This suggests bilinguals did not proactively update the general activation levels of the two languages (either through L1 inhibition or L2 activation) in preparation for a dual-language context with frequent switching. We will further discuss these underlying mechanisms, and the potential role of shared control mechanisms between comprehension and production, in the General Discussion.

We did observe some general effects of language, not significantly influenced by the preceding context. Bilinguals were overall faster in English (the L2 for most participants) than Mandarin (the L1). In previous cued switching tasks, these findings have often been interpreted as reflecting reversed dominance effects (e.g., Declerck et al., 2020), with bilinguals showing relatively faster L2 than L1 performance. This could potentially reflect (over-)inhibition of the L1 to allow for easier L2 use in these dual-language contexts. However, in the absence of baseline single-language blocks, we cannot be sure if this pattern truly reflected a change in inhibition or language control in response to the dual-language context. Participants furthermore varied in their profile, with some participants using the L2 frequently in their daily lives (likely because they were living in an L2-dominant country or environment).

Switching costs were also larger to the L2 than to the L1. This is a pattern that has been observed previously when the L2 is the faster and potentially more active language (e.g., Bonfieni et al., 2019; Coumel et al., submitted). One possible interpretation is that the L2 was the more active language for participants, either because it is a language they use relatively frequently or because they over-activated the L2 for easier use in a dual-language context. At the moment of switching, if more inhibition is needed over the more active language, it might be the L2 that needs to be suppressed more, resulting in relatively larger costs when switching back to the L2 (see Coumel et al., submitted, for similar findings; cf. Timmer et al.,2019, for similar findings in L2-dominant task contexts). However, for the current study, the key finding is that these potential language effects did not significantly interact with the preceding context.

Experiment 1 was a first examination to test whether language control during switching can adapt to the preceding context, and specifically the language behaviour of another bilingual. In Experiment 2, we firstly aimed to replicate the findings observed in Experiment 1, with a larger sample size and a different group of bilinguals who overall are more balanced in their proficiency in and use of both languages. This way, we aimed to work with bilinguals who switch more often themselves and are also more likely to find themselves in real-life contexts that include exposure to switches produced by other bilinguals. Although we did not measure daily-life switching frequency in the bilinguals tested in Experiment 1, it is likely many participants spent relatively little time in switching contexts in their daily-life interactions. Therefore, it is possible that exposure to another high-switching bilingual stood out substantially to these participants and triggered changes in their language switching for that reason. We therefore aimed to replicate the Experiment 1 findings with another group of bilinguals who are more likely to encounter language switching more regularly in their daily lives. Furthermore, as developed further below, we compared two types of switching conditions in the preceding contexts (between- and within- sentence switching), to further examine the exact influence of preceding switching contexts.

1. **Experiment 2**
	1. **Introduction**

As discussed above, one mechanism potentially underlying the effects observed in Experiment 1 is that exposure to another switching bilingual updates the speaker’s expectations about their own upcoming production, and therefore their intention to switch (e.g., Green, 2018). If exposure to switching in general is sufficient to trigger language control through this updating of expectations, exposure to any type of switching should reduce switching costs. In Experiment 2, we therefore compared two types of preceding switching contexts: One with within-sentence switches and one with between-sentence switches. We hypothesised that if exposure to switching in general is sufficient to update speakers’ expectations about the (non-)linguistic context they are in, both types of contexts should be followed by reduced switching costs in the cued production task, relative to exposure to a low-switch context.

 However, effects might also be modulated by the type of switching bilinguals are exposed to. If the reduction in switching cost during production is related to the similarity of language control during comprehension and production (proposed mechanism 2 in the Introduction), the reduction would be expected to be largest for the comprehension condition most strongly recruiting language-control mechanisms also involved in production. Furthermore, if bilinguals form specific expectations about the *type* of switching context they are in (as opposed to general expectations about being in a switching context, mechanism 1), the context with the most similar type of switching as the production task should influence the production switching costs most.

As discussed in the Introduction, the Control Process Model (CPM, Green & Wei, 2014; Green, 2018) distinguishes between control involved in different types of switching. Single-language contexts and dual-language contexts without within-sentential switching (where only one language is used at a time and the other language is not used within the same utterance) are linked to competitive control (cf. also Green & Abutalebi, 2013). This is the type of control that is argued to be the most necessary during cued single-word switching, the type used in the production tasks here, where individual “units” (in this case words) can be produced in one language only, without the other language being allowed. An equivalent during sentence comprehension would be between-sentence switching, where individual “units” (sentences) are produced in only one language at a time, without the other language being allowed within that sentence.

In contrast, the CPM argues that within-sentence (intra-sentential) switches, in particular alternations and insertions, are associated with cooperative, rather than competitive, control. This suggests that the type of language control used in cued language switching (competitive control) is more similar to the type of control used during between-sentence switching (in both cases, switches only take place between “units”, with no use of the other language within that unit) than to within-sentence switching (where both languages can be used freely within the utterance, using cooperative rather than competitive control). This is in line with Han et al. (2023), showing a reduction in RTs on a flanker task after bilinguals were exposed to between-sentence switches compared to after exposure to within-sentence switches. This study suggests between-sentence switches required a larger involvement of competitive control than processing of within-sentence switching, with only the former showing an impact on control processes used in a subsequent task (in their case, a non-linguistic flanker task).

If shared production-comprehension control mechanisms drive the reduction in switching costs observed in Experiment 1, and if between-sentence switching comprehension recruits more competitive control than within-sentence switching comprehension, we would therefore expect a stronger reduction in production switching costs after exposure to between-sentence switching than after exposure to within-sentence switching. Furthermore, if a speaker’s contextual expectations trigger the language-control system differently depending on the type of switching they hear or expect, such reduction in production switching costs should again be most pronounced for the switching context that recruits competitive rather than cooperative control. Thus, if expected control difficulty and/or control similarity between comprehension and production play a role, we hypothesised that cued production switching costs should be smaller after exposure to between-sentence switching, but not (or less so) after exposure to within-sentence switching, compared to exposure to a low-switching bilingual.

However, the model we based our hypotheses on (CPM) focuses on language production and it is unclear whether similar arguments around cooperative versus competitive control also apply to the *processing* of between- or within-sentence switches. The hypotheses above thus only apply if between-sentence switching comprehension indeed recruits more competitive control than within-sentence switching comprehension. There is not much research directly comparing comprehension of within- versus between-sentential switches. When studied individually, both between- and within-sentence switching are sometimes linked to switching costs (e.g., Litcofsky & Van Hell, 2017; Pérez & Duñabeitia, 2019; Philipp & Huestegge, 2015) and in other cases not linked to switching costs (e.g., Gullifer et al., 2013), making it less clear how the *comprehension* of different types of switching is linked to competitive versus cooperative control.

* 1. **Methods**

Experiment 2 was pre-registered and the data are available on https://osf.io/83nqm/

* + 1. ***Participants***

Experiment 2 was completed by 90 participants (*M*age = 24.9 years, *SD* = 3.2; 61 female, 25 male, 4 chose one of the other answer options). Ten participants were left-handed, three ambidextrous, and the others right-handed. Participants reported not having any neurological, language, communication, or reading difficulties or any hearing or vision difficulties that could have affected task performance. None were colour blind. Fifteen additional participants took part but were excluded and replaced following our pre-registered criteria of not correctly answering enough comprehension/attention check questions (N=7), reporting having neurological or language difficulties (N=1), not having audible audio in their recordings (N=6), or having a LexTALE score below the pre-registered cut off (N=1). A few of these already excluded participants also did not meet the pre-registered language-profile criteria.

 The sample size was determined based on a power analysis using the effects reported in Experiment 1 for the interaction between preceding context and trial type, but running simulations to now include context as a three-level variable. The sample size provided over 80% power to detect an interaction between switching costs and preceding context.

 All participants were English-French or French-English bilinguals, with 20 reporting acquiring only English from birth, 65 only French, and five both. Mean age of acquisition for English was 5.6 years old (*SD* = 4.4, 0-20 years) and 1.8 years old for French (*SD* = 3.6, 0-14 years). Participants reported high proficiency in both languages (see Table 3). Most participants reported using French more than English during childhood (*M* = 2.3, *SD* = 1.2; scale 1 = all French to 5 = all English, based on the LSBQ, Anderson et al., 2018). In terms of current language use, most participants reported using both regularly (*M* = 3.0, *SD* = 0.9). Following our pre-registered criteria, none of the participants predominantly used French or English only (all included participants scored mean scores between 1.5 and 4.7 in terms of current language use measured through the LSBQ) and all scored at least 50% on both LexTALES.

At the group level, participants also indicated regular to frequent language switching on a daily basis (scale 1 = never – 7 = very frequently, *M* = 4.9, *SD* = 1.8), within a conversation while talking with another French-English bilingual (*M* = 4.7, *SD* = 2.1), and within a sentence while talking with another French-English bilingual (*M* = 3.4, *SD* = 2.1).

Table 3. *Language proficiency of the participants in Experiment 2.*

|  |  |  |
| --- | --- | --- |
| *Question* | **French** | **English** |
| **Self-rated proficiency (1-10)**Speaking Understanding speechReading Writing | 9.3 (1.4)9.5 (1.1)9.6 (0.8)9.2 (1.4) | 8.5 (1.5)9.1 (1.2)9.3 (1.1)8.6 (1.5) |
| **LexTALE (0-100%)** | 78.8 (14.2) | 87.6 (8.7) |

* + 1. ***Design***

The design was the same as in Experiment 1, but Context was now a three-level variable (low-switch, between-sentence switch, and within-sentence switch). The levels of the variable Language were now French and English.

* + 1. ***Materials***

We used three sets of twenty pictures, which again reflected easy-to-name objects with a high frequency and relatively short picture names. Three sets were created so that participants always saw a different set of pictures per preceding context, with the set-context combination counterbalanced across participants. In all sets, frequency and length were matched between the two languages (see Supplementary Materials Appendix B for details). Thirteen of the sixty picture names used in the cued production tasks also occurred across the three videos (due to counterbalancing, these were often not used in the video preceding the stimulus set used in the immediately following picture-naming task). The data patterns reported below stayed the same when these items were excluded. Ten separate items (with the exception of one repeated picture) were always used in the baseline task at the very beginning.

Experiment 2 used three texts related to animals, one about animals living in cities (based on Magle et al., 2021), one on animals and emotions (based on Krause & Nawroth, 2021), and one on protecting wild animals (based on Marques et al., 2022). The texts were altered to be used in French and English and made longer compared to Experiment 1 (between 489 and 507 words in English). For each version of the text, we created two low-switch versions (starting in French or starting in English, with just one switch in the middle), one between-sentence switching version, and one within-sentence switching version. Similar to Experiment 1, approximately half of the words in each text were in French while the other half were in English. The number of switches within each text was 28-32 in the between-sentence switching condition and 31-34 in the within-sentence switching condition, distributed comparably across switches to French or English. The switching rate (relative to the number of English words per text) therefore was around 6% in all combinations (between 5.5% and 6.8% across texts). Switches in the within-sentence story mostly included multi-word insertions and alternations (these two types have been suggested to be comparable in processing effort, Johns & Dussias, 2022), with no dense code switches. The recordings were between 2.41 and 3.29 minutes long.

* + 1. ***Procedure***

The procedure was very similar to Experiment 1 (see Figure 1). Participants were first familiarised with all pictures, followed by English and French single-language practice blocks (counterbalanced across participants) that included all seventy pictures (sixty experimental pictures plus ten pictures for the baseline task). Participants then first completed a baseline switching task consisting of forty trials. This was followed by the three cued-switching tasks preceded by the low-switch, within-sentence, or between-sentence switching exposure contexts. In addition to the baseline, participants therefore completed the cued language switching task three times, with each part including 80 trials. The order of contexts, text topics, and context-topic pairs was counterbalanced across participants. Instructions were provided in French and English, with the order on the screen (French or English text at the top part of the screen) counterbalanced. We used two cues per language: one being the French or British flag and one being the shape of France or the UK. We opted for these cues as they could easily be connected to one specific language (more easily so than faces of unfamiliar people in the case of French-English bilinguals). After the cued switching task, participants first completed the French and English LexTALEs (order of language counterbalanced). Finally, they completed the questionnaire including short comprehension questions about the stories they heard (multiple-choice questions presented in both languages) and questions about their language background (see “Participants”).

* + 1. ***Data analysis***

Data pre-processing followed the same procedure as in Experiment 1, with 0.9% of correct trials removed as RT outliers. Accuracy was scored by two of the authors (RD and AdB). Accuracy was high but just below 95% and therefore analysed further.

RTs were log-transformed to improve normality of the distribution (means of untransformed RTs are reported below). The analysis included the two-level fixed effects Trial Type (non-switch = -0.5; switch = 0.5) and Language (French = -0.5; English = 0.5). Participants varied in their age of acquisition (AoA), proficiency in, and use of English and French, with many participants not having a clear L1 or L2 across AoA, proficiency, and use measures. Language therefore did not correspond directly to participants’ first or second language. The three-level variable Context was Helmert coded to compare the two switching conditions to the low-switch condition and the two switching conditions to each other. As an additional (not pre-registered) check, we also re-ran the analyses with Context sum coded to compare the between- and within-switching contexts individually to the low-switch condition. Analyses started with a maximal structure including participants’ and items’ intercepts and slopes. When models did not converge, we removed correlations between intercepts and slopes and then the by-item slopes explaining the least variance until convergence was reached. The final RT model converged with participant and item intercepts, the language x context slopes for participants, and the context x switch x language slope for items. The final accuracy model converged with intercepts only.

* 1. **Results**
		1. ***Accuracy***

In terms of accuracy, there was a significant effect of Language (β = 0.574, *SE* = 0.058, *z* = 9.830, *p* < .001), reflecting higher accuracy on English trials (*M* = 95.0%, *SD* = 5.2) than on French trials (*M* = 91.7%, *SD* = 7.4). There was also a significant effect of trial type (β = -0.374, *SE* = 0.058, *z* = -6.396, *p* < .001), reflecting higher performance on non-switch (*M* = 94.4%, *SD* = 5.6) than switch trials (*M* = 92.3%, *SD* = 6.1). Context interacted with the switch cost, but only in the comparison between the low-switch and two high-switch conditions (β = -0.307, *SE* = 0.125, *z* = -2.455, *p* = .014), reflecting a larger accuracy switch cost after the low-switch condition (*Mcost* = 3.2%, *SD* = 5.3) than after the between-switch (*Mcost* = 1.8%, *SD* = 5.3) or within-switch contexts (*Mcost* = 1.4%, *SD* = 5.0). There was no further switching cost difference after exposure to within- versus between-sentence switching conditions (β = 0.084, *SE* = 0.141, *z* = 0.592, *p* = .554). There was no main effect of preceding switching context either (low-switch versus high-switch contexts: β = 0.052, *SE* = 0.063, *z* = 0.828, *p* = .408; between- versus within-sentence switching contexts: β = -0.117, *SE* = 0.071, *z* = -1.654, *p* = .098), with accuracy in all three conditions between 93.1% and 93.6%. There were no interactions between any of the predictors and Language (all *p*s > .45).

* + 1. ***Reaction Times***

In terms of reaction times, there was a significant effect of trial type (β = 0.048, *SE* = 0.003, *t* = 15.282, *p* < .001), reflecting a switching cost with slower responses to switch (*M* = 1107, *SD* = 168) than non-switch trials (*M* = 1054, *SD* = 159).

 The switching cost differed significantly between the between- and within-sentence switching contexts (β = -0.018, *SE* = 0.008, *t* = -2.319, *p* =.020), reflecting smaller switching costs after exposure to a within-switching context (*M*cost = 40ms, *SD* = 60) than the between-switching context (*M* cost = 62ms, *SD* = 61; see Figure 3 and Table 4). There was no significant difference when comparing the two switching contexts together to the low-switch context (*M* cost = 58ms, *SD* = 70; β = 0.006, *SE* = 0.007, *t* = 0.949, *p* = .343). However, comparing the within-sentence switching context to the low-switching context confirmed there was indeed a significant reduction in switching costs compared to the low-switching context too (β = -0.015, *SE* = 0.008, *t* = -1.978, *p* = .048). No main effect of context was observed on overall RTs when comparing switch versus low-switch contexts: β = 0.003, *SE* = 0.003, *t* = 0.938, *p* = .348. The comparison of between- versus within-sentence switching contexts showed significantly faster responses in the within-sentence condition (β = -0.009, *SE* = 0.004, *t* = -2.356, *p* = .019).

 To follow-up on the interaction between Context and the switching cost, we examined whether this reduction in switching costs (and overall RTs) was specifically driven by faster switch RTs. This was indeed the case, with the switch trials being significantly faster after exposure to the within-sentence switching context (compared to the between-sentence switching context: β = -0.018, *SE* = 0.006, *t* = -3.246, *p* = .001; compared to the low-switch context: β = -0.015, *SE* = 0.006, *t* = -2.716, *p* = .007), while non-switch trials were not influenced (compared to the between-sentence switching context: β = -0.001, *SE* = 0.005, *t* = -0.107, *p* = .915; compared to the low-switch context: β = 0.0003, *SE* = 0.005, *t* = 0.047, *p* = .962; see Table 4).

 There was a significant main effect of Language (β = -0.025, *SE* = 0.008, *t* = -3.210, *p* = .002), reflecting faster English (*M* = 1065ms, *SD* = 159) than French responses (*M* = 1096ms, *SD* = 176). There was also a slightly larger English switching cost (*M*cost = 62ms, *SD* = 59) than French cost (*M*cost = 45, *SD* = 66), although this did not reach significance (β = 0.017, *SE* = 0.009, *t* = 1.829, *p* = .073). Language did not interact with Context (switch versus low-switch contexts: β = -0.008, *SE* = 0.007, *t* = -1.099, *p* = .275; between- versus within-sentence switching contexts: β = 0.002, *SE* = 0.009, *t* = 0.272, *p* = .786). The interaction between Language, Trial Type, and switch contexts were not significant (switch versus low-switch contexts: β = 0.028, *SE* = 0.014, *t* = 1.970, *p* = .053; comparing between- and within-sentence switching contexts: β = 0.009, *SE* = 0.016, *t* = 0.557, *p* = .578).



*Figure 3.* Switching costs (RT difference switch minus non-switch trials) in Experiment 2 per language (left: English, right: French) and by preceding switching context (from left to right: after exposure to a low-switching bilingual, a between-sentence switching bilingual, and a within-sentence switching bilingual). Individual points reflect individual participant means (jittered). The horizontal line shows the median and the centre of the triangle the mean across participants.

Table 4. *Mean RTs (and switching costs, difference between switch and non-switch trials) per preceding context (low switch, between-sentence switch, and within-sentence switch) and per language (French and English) and trial type (non-switch and switch trials) during the cued production task.*

|  |  |  |  |
| --- | --- | --- | --- |
| Preceding context | Low-switch | Between-sentence switch | Within-sentence switch |
| **French**Non-switchSwitch*Switching cost* | 1080 (190)1120 (202)40 (103) | 1070 (192)1130 (188)60 (96) | 1073 (198)1103 (189)30 (91) |
| **English**Non-switchSwitch*Switching cost* | 1027 (175)1104 (183)77 (85) | 1039 (163)1102 (177)63 (90) | 1038 (179)1084 (171)46 (96) |
|  |  |  |  |

* + 1. ***Exploratory analyses on the within-sentence switch context reduction***

Finally, we conducted a few exploratory analyses focusing on the comparison between the within-sentence switch and low-switch exposure contexts, to further examine the observed reduction in switching costs after the within-sentence switch context. Firstly, we examined whether there was a relationship with individual differences in daily-life language experiences. Here, we included both LexTales as predictors to reflect vocabulary knowledge in each language, participants’ daily-life language use (as reported in the LSBQ), and their self-reported daily-life switching within sentences. The four predictors were z-scored and allowed to interact with Language and Context (low-switch versus within-sentence switch exposure). This analysis showed no main effects of either LexTale, language use, or daily-life switching within sentences (all *p*s > .05). French LexTale (β = -0.020, *SE* = 0.009, *t* = -2.273, *p* = .026) and language use (β = 0.021, *SE* = 0.010, *t* = 2.217, *p* = .029) interacted with Language. Analysing the relationships per language separately showed that neither French nor English RTs were significantly related to the French LexTale or language use (*p*s > .05). The interaction, however, reflected that participants with a higher French LexTale score showed a relatively larger RT difference between English and French (i.e., relatively slower French RTs). Participants who reported using French more often in their daily lives also showed a relatively larger RT difference between the languages (i.e., relatively slower French RTs). There were no significant interactions between the Switch x Context interaction and any of the four predictors (all *p*s > .05), suggesting the reduction in switching cost was not significantly related to the four language-profile predictors.

 A second set of analyses examined whether the reduction in switch costs after exposure to the within-sentence switching context took time to build up, or was already present from the start. It should be pointed out here that all participants completed a baseline switching task at the very beginning, so that they knew before the start of each context what type of production task they had to complete themselves. This was included to minimise any practice effects in the tasks after the three context conditions. Indeed, the baseline showed a numerically larger switching cost (*M* cost = 77ms, *SD* = 85) than after each of the three contexts, suggesting participants benefited from this practice, which in turn likely reduced any further practice or task order effects within the three context-tasks of interest. Including trial number within each context task as a predictor showed no significant main effect of trial number across the within-sentence switching and low-switching contexts tasks (β = -0.001, *SE* = 0.002, *t* = -0.461, *p* = .645), no interaction with the switching cost (β = 0.0002, *SE* = 0.004, *t* = 0.052, *p* = .959), no interaction with Context (β = -0.001, *SE* = 0.004, *t* = -0.242, *p* = .809), and crucially no interaction with Context and the switching cost (β = 0.003, *SE* = 0.008, *t* = 0.344, *p* = .731). This strongly suggests the reduction in switching costs after exposure to within-sentence switching did not build up over time. Indeed, only looking at trials two to ten showed switching costs were already smaller after the within-sentence context (*Mcost* = 38ms, *SD* = 208) than after the low-switch context (*Mcost* = 82ms, *SD* = 197).

We also checked whether the smaller switching costs after within-sentence switching contexts were driven by participants completing that task last in the order of the three tasks. Participants who completed a task last showed smaller costs than participants who completed that task first. However, that pattern was present for both the low-switch context (Task first: *M* = 85ms, *SD* = 80; Task last: *M* = 36ms, *SD* = 46) and the within-sentence switching context (Task first: *M* = 49ms, *SD* = 55; Task last: *M* = 23ms, *SD* = 52). The smaller switching costs in the within-sentence switching context were present both in participants completing that task first and in participants completing that task last (with these being different groups of participants), with both tasks showing a reduction of approximately 55% when doing the task last versus first. This again suggests that the smaller switching costs after within-sentence exposure were stable in terms of trial order within the block as well as in terms of the order of tasks across the study.

The only significant effects observed for trial number were small changes in the switching costs per language (interaction Language x Switching x Trial Number: β = 0.019, *SE* = 0.008, *t* = 2.380, *p* = .017), further modulated by Context (β = 0.041, *SE* = 0.015, *t* = 2.634, *p* = .008). This reflected an increase in English switching costs with time, after the low-switch context (interaction Switching x Context x Trial Number: β = 0.024, *SE* = 0.011, *t* = 2.275, *p* = .023). In contrast, French switching costs did not change significantly with time (three-way interaction: β = -0.018, *SE* = 0.011, *t* = -1.638, *p* = .102, and if anything, they decreased).

* 1. **Discussion**

Experiment 2 aimed to firstly replicate the findings observed in Experiment 1, now using a larger sample of French-English bilinguals. As intended, these bilinguals (at the group level) reported switching languages relatively frequently, allowing us to study the research questions in a group of bilinguals who are indeed exposed to and produce switches in their daily lives. We furthermore included two types of preceding switching contexts, in the form of within- and between-sentence switching. These were included to examine whether any adaptation was generalisable across preceding switching contexts or dependent on a specific type of switching during preceding comprehension. We found a partial replication of Experiment 1, with switching costs being reduced after exposure to a within-sentence switching context compared to the low-switch context. However, there was no reduction in switching costs after exposure to a between-sentence switching context. This suggests that merely being exposed to any type of switching context is not sufficient to influence language control during production. Rather, this seems to depend on the type of switching, as we will discuss further in the General Discussion.

 In Experiment 1 an effect was found for a context including both between- and within-sentence switches. It is possible that effect was driven by the presence of within-sentence switches in that context, as we will discuss further below. However, an alternative interpretation is that the two participant groups tested differed from each other in various ways. Bilinguals in Experiment 2 had a higher and more balanced proficiency in and use of both languages. They reported regular daily-life switching, something which was not assessed in Experiment 1 but likely lower given the socio-linguistic context and proficiency and use levels reported. Furthermore, bilinguals in Experiment 2 spoke two relatively similar languages (French and English) while Mandarin and English (Experiment 1) are more distinct in terms of phonology, lexicon, and syntax. Although we cannot rule out the differences being driven by these language-group differences, analyses looking at individual differences in terms of proficiency, use, and daily-life switching within Experiment 2 showed no significant relationships with the reduction in switching costs after within-sentence switching exposure. This suggests any adaptations in terms of language control during switching (and the observed reductions at the group level after within-sentence exposure) were not explained by individual differences in daily-life switching frequency. It strongly suggests the differences between the two experiments are unlikely to be explained by differences between the groups in terms of language proficiency, use, or switching. It furthermore suggests that the effects observed in Experiment 1 were not due to these switching patterns standing out only to bilinguals who perhaps do not switch often themselves.

 Participants responded faster overall in English, which was also the language showing the largest switching cost numerically. In this Experiment, it was difficult to identify a clear L1 or L2 for many participants (or at the group level). While many participants reported French being their L1 in terms of age of acquisition, their proficiency and/or use were comparable for the two languages or did not align across age of acquisition, use, and proficiency. Interestingly, the RT difference between languages was related to French vocabulary scores and language use. Participants with a higher French vocabulary and who used French more often showed a relatively larger difference between English and French RTs (i.e., the relatively slower French RTs versus English RTs were more pronounced for these participants). If overall RTs purely reflect ease/speed of lexical selection (without any language control), this pattern should have been reversed. Rather, it suggests that participants with a higher proficiency in and/or use of French used language control more strongly in the form of English (over-)activation (leading to relatively faster English responses) and/or French inhibition (leading to relatively slower French responses). Given this relationship was only found for the difference between the languages, and not for each of the languages individually, it is possible both mechanisms play a role.

Similar to Experiment 1, the largest (numerical) switching cost was observed for the language that was the fastest/most active during the task, again suggesting more reactive control might be used over that language at the moment of switching. These larger English switching costs increased with time within the task (significant interaction Language x Switching x Trial Number), suggesting bilinguals might have applied more reactive control as they were using English more often throughout the task.

1. **General Discussion**

Across two experiments, this research aimed to examine the dynamic and adaptive nature of language control, in response to different switching patterns of another bilingual prior to a bilingual’s own production. Both experiments showed adaptation, in the form of smaller switching costs after exposure to another switching bilingual. However, Experiment 2 showed that this adaptation is not observed after exposure to just any type of switching, but rather that adaptation depends on the features of the preceding switching context.

Together the two experiments show that, in some circumstances, language control when switching languages during production adapts to the preceding context. Previous literature has focused on examining changes in language control in response to the task context itself and demands within the current context. Our findings showing adaptation to *preceding* contexts, aligning with those studies, including with previous research showing that language control and switching costs differ depending on the type of switching that is required during production (e.g., de Bruin et al., 2018; Gollan et al., 2014); the percentage of L1 and L2 use within the task (e.g., Olson, 2016; Timmer et al., 2019); and the type of cues or faces present within the context (e.g., Liu et al., 2019).

Our findings also are compatible with the alignment literature showing that bilinguals adjust their language behaviour (including when and how often they switch) to that of the conversation partner (e.g., de Bruin & Shiron, 2024; Kootstra et al., 2020). Previous voluntary language-switching studies have not always shown an influence of exposure to another bilingual’s switching patterns on *language control* in the form of switching costs (e.g., de Bruin & Shiron, 2024; Kapiley & Mishra, 2019; but cf. Kapiley & Mishra, 2024). However, language control is generally argued to be less recruited during voluntary language switching. Any (noticeable) language-control adaptations during production in response to different preceding contexts might therefore predominantly or only emerge during contexts posing higher control demands on production (such as the cued switching tasks used here).

Finally, our findings align with comprehension studies (e.g., Kaan et al., 2020) showing that switching costs during *comprehension* are influenced by the other person present in the room during a switching task. Crucially, in the current study, however, the manipulation of the other bilingual’s language behaviour (in the recorded video or audio) concerned the preceding context rather than any manipulation of task demand or conversation partners within the bilingual’s own switching task itself. This suggests adaptation does not just occur to the demands and characteristics of the task or current context itself but also to the immediately preceding context.

 These changes in production switching cost can occur because of various underlying mechanisms. One potential key mechanism is that other bilingual speakers are part of the larger (non-)linguistic context that can shape a speaker’s expectations about the language context (such as which languages are to be used, whether switching is likely to occur, etcetera). Language switching is not possible in all contexts. In monolingual contexts, where conversation partners only know one language, switching is unlikely to be an efficient way of communication. Similarly, considering the stigmas that still surround language switching in some contexts (e.g., Mata, 2023), bilinguals might not always know whether language switching is deemed socially appropriate in a given context. Bilinguals might therefore constantly monitor the surroundings to adjust their expectations about their upcoming production, including when they can switch languages. This in turn can influence the language control used for language switching (Green, 2018). These changes in language control at the moment of switching could be in the form of increasing attention to the target language while potentially also moving attention away from the non-target language, as also proposed in the conflict monitoring literature (e.g., Botvinick et al., 2001). The overall patterns across experiments showed context affected switching costs in both languages, without significant differences between the two. This suggests adaptation concerned attention to the target/away from the non-target language more strongly than changes in the inhibition of the non-target language (or over-activation of one specific language).

In the non-linguistic control literature, several other explanations have been proposed to explain changes in conflict costs without the need for adaptation (cf. Schmidt, 2019). Many of these arguments centre around item-specific effects and/or learning/memory effects due to the frequent repetition of a small set of stimuli and responses. Crucially, in the current study, the context triggering adaptation (exposure to another bilingual) was separate from the task itself and included different stimuli (i.e., a different topic, sentence context, and different words), rather than the same small set of stimuli (e.g., *green* presented in red) often used in flanker or Stroop studies looking at adaptation.

In both of our studies, the switch trials in particular were affected by task context, suggesting top-down influences of the linguistic context most strongly affected language control at the moment of switching. The finding that the reduction in switching costs in Experiment 2 was observed from the very beginning of the task, and did not build up with time, furthermore suggests this top-down modulation happened immediately. The preceding context did not influence overall RTs on non-switch trials, nor the RTs per language. This suggests the contexts did not necessarily influence proactive control, in the form of potentially over-activating the L2 or inhibiting the L1 for use in a dual-language context. It is possible that proactive language control over the L1 and L2 was not affected because the bilinguals in the preceding contexts always used both languages equally often. Bilinguals in our study perhaps therefore always proactively adjusted their L1 and L2 activation levels to efficiently use both languages, in response to the preceding context involving a bilingual using both languages (regardless of the presence of switching). Overall language activation levels could be influenced more strongly when the actual exposure to an L1 or L2 differs between contexts (cf. e.g., Timmer et al., 2019, for a study showing effects of percentage L1 or L2 use within a task).

The absence of RT changes during non-switch trials also rules out that switching costs were reduced after exposure to certain contexts because bilinguals found the task easier, focused more, or were more motivated or engaged. It also suggests any changes in switching costs were not because bilinguals experienced less language competition (and therefore needed less language control in general) – an explanation that is also unlikely because the amount of L1 and L2 use in the preceding contexts was always the same.

 The finding that this reduction in switching costs was only observed after exposure to a *within-switching* context suggests that bilinguals might not use just any type of switching context to update their expectations. One possibility is that the within-switching context stood out more than the between-switching context. The switching pattern in the between-switching context was relatively predictable, with the switches always happening between sentences and usually after one or two sentences. In contrast, while the within-switching task was relatively predictable in terms of the type of switches (multi-word insertions and alternations), the position of these switches varied more. These types of switches might therefore have stood out more to participants, creating a stronger impression of a switching context. It might only be when contexts stand out as being substantially different from the expectations or preceding contexts that these contexts can update a speaker’s expectations and trigger top-down language control adaptations. This would be in line with Kaan et al’s (2020) findings showing changes in the LPC component depended on expectations about the other speaker present, an ERP component also associated with the processing of unexpected information (e.g., Lattner & Friederici, 2003).

An alternative, not mutually exclusive, mechanism explaining these findings could be related to shared control mechanisms during production and comprehension. If bilinguals apply language control during comprehension, and then again have to apply the same control mechanisms during production, previous use of this control could facilitate applying it again during production. This could be similar to training studies showing a reduction in language-switching costs after receiving language-switching practice (e.g., Kang et al., 2018; Wu et al., 2018). We expected within-sentence switching to be *less* similar to the type of competitive control used during cued language production tasks than between-sentence switching, as within-sentence switching of this type is argued to rely more on cooperative than competitive control during production (Green, 2018). However, contrary to these predictions, we observed a smaller switching cost after within-sentence switching contexts only. Our predictions were based on a production model (Green & Wei, 2014; Green, 2018). It is possible that the actual comprehension of between-sentence switches requires less language control than the comprehension of within-sentence switches (especially when considering alternations, Jiang et al., 2023; cf. also Byers-Heinlein et al., 2017). Thus, shared overlap in production and comprehension control mechanisms (but only in terms of within-sentence switching processing versus controlled single-word production) cannot be excluded as the mechanism underlying the observed switch-cost reduction. This would assume that the comprehension of between-sentence switches does not rely on competitive control, or at least not to the same extent as within-sentence switch processing.

However, this interpretation would rely on at least partially shared control mechanisms between comprehension and production. While there is some research suggesting these mechanisms are at least partly shared (e.g., Peeters et al., 2014), there is also ample research suggesting the mechanisms differ substantially between comprehension and production (e.g., Ahn et al., 2020). In addition to mechanisms being argued to differ, research has found that language competition and control during comprehension might be reduced compared to production. For instance, Declerck et al. (2019) did not observe switching costs during a series of language switching tasks (see also Gullifer et al., 2013, for not showing switching costs in a sentence reading task).

Furthermore, our comprehension and production tasks differed in many ways. One of the key differences was that only the comprehension task included sentences, which could have introduced many other demands on control, including at the syntactic level. Therefore, the combination of studies showing relatively low competition and language control during comprehension; studies highlighting differences in control between comprehension and production; and the task and possible control demand differences between comprehension and production suggest that the overlap in control mechanisms is less likely to explain the observed context effects.

In this study, we manipulated the preceding language context in the form of short videos or audio recordings presenting information on a topic chosen to be of general interest. However, the bilinguals in these recordings were reading a text, with the main aim of presenting that information to an audience. In daily life interactions, preceding language contexts are more likely to be interactions between multiple other people and on a range of (often more informal) topics. It is possible that in the recordings and texts used here, the general switching frequency (based on a conversation corpus, Fricke & Kootstra, 2016) captured the participants’ attention as being more frequent than might usually be the case in more “formal” presentations. It is furthermore possible that within-sentence switching stands out more than between-sentence switching in the type of context used here. Previous corpus research examining switching in more formal “monologue” type settings as used here (e.g., parliamentary speeches and Tedx talks) suggest both between- and within-sentence switching can occur frequently in those types of contexts too (e.g., Mohamad Khalil et al., 2018; Refendi et al., 2019). However, those patterns (based on e.g., Malay-English speakers) might not necessarily hold true for the multilinguals tested here. Future research therefore needs to address adaptation to different types of switching patterns across more formal and informal contexts.

In the current study, we kept language exposure in the preceding contexts constant, with each context using half of the words in Language A and the other half in Language B. The consequence was that none of the contexts used a true default language. This way we avoided influences of language exposure on the production task. The absence of one default language in the contexts is also in line with the production task not having one default language, as both languages had to be used equally often there too. However, bilinguals do often use a default language in their daily-life conversations (cf. Matrix Language Framework; Myers-Scotton, 1993). Language control has been found to relate to (violations) of default language switches (cf e.g., Li & Gollan, 2021). Between- and within-language switching contexts might furthermore differ in the extent to which they use one default language in daily life conversations, which in turn might impact how these switching contexts can influence language control. Studying contexts varying in their use of a default language in future research could therefore help to better understand the multi-faceted nature of daily-life switching contexts and their impact on language control.

In conclusion, the current study shows that language control can be dynamic and adapt to the immediately preceding context. While studies have not always shown long-term effects of language environment on language control (e.g., Coumel et al., submitted), bilinguals frequently alternate between different language contexts in their daily lives. Their language control might therefore need to constantly adjust and adapt flexibly. While we showed some evidence for language adaptation across two very different language groups (in terms of language proficiency, use, likely daily-life switching frequency, and languages spoken), our data also strongly suggest that the exact adaptation might be context dependent. The linguistic context can update a speaker’s expectations and consequently trigger top-down language control adjustments, but this might only happen when the context provides sufficiently unpredictable or outstanding information.

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***Consent:*** All participants provided informed consent for study participation before starting the study.

***Consent for publication:*** No personal data are included in this manuscript and participants cannot be identified from this manuscript or the data shared. Participants gave consent for their data to be used for the research described in this manuscript and for their anonymous data to be shared publicly.

***Open practices statement and Data/code availability:*** Experiment 2 was pre-registered. The data and analysis code for both experiments are available on https://osf.io/83nqm/

***Author contributions:***

AdB: Conceptualisation, Data curation, Resources, Formal Analysis, Supervision, Funding Acquisition, Validation, Investigation, Methodology, Visualisation, Writing-original draft, Project administration.

JW: Conceptualisation, Data curation (Exp 1), Resources (Exp 1) Formal Analysis (Exp 1), Investigation (Exp 1), Methodology (Exp 1), Writing – review & editing.

RD: Data curation (Exp 2), Investigation (Exp 2), Writing – review & editing.

MC: Conceptualisation, Data curation, Resources, Supervision, Investigation, Methodology, Writing – review & editing, Project administration.

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