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Operating in a second language lowers cognitive interference during creative idea generation: Evidence from brain oscillations in bilinguals

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ABSTRACT

Tasks measuring human creativity overwhelmingly rely on both language comprehension and production. Although most of the world's population is bilingual, few studies have investigated the effects of language of operation on creative output. This is surprising given that fluent bilinguals master inhibitory control, a mechanism also at play in creative idea evaluation. Here, we compared creative output in the two languages of Polish (L1)-English(L2) bilinguals engaged in a cyclic adaptation of the Alternative Uses Task increasing the contribution of idea evaluation (convergent thinking). We show that Polish-English bilinguals suffer less cognitive interference when generating unusual uses for common objects in the L2 than the L1, without incurring a significant drop in idea originality. Right posterior alpha oscillation power, known to reflect creative thinking, increased over cycles. This effect paralleled the increase in originality ratings over cycles, and lower alpha power (8–10 Hz) was significantly greater in the L1 than the L2. Unexpectedly, we found greater beta (16.5–28 Hz) desynchronization in the L2 than the L1, suggesting that bilingual participants suffered less interference from competing mental representations when performing the task in the L2. Whereas creative output seems unaffected by language of operation overall, the drop in beta power in the L2 suggests that bilinguals are not subjected to the same level of semantic flooding in the second language as they naturally experience in their native language.

Significance

Creativity, possibly the most critical of human skills, is intimately linked to language. Given the global prevalence of bilingualism and the high likelihood of high-stake creative tasks being undertaken in the second language, we need to know whether creative performance differs between languages in bilinguals. We compared alpha brain rhythms in highly fluent bilinguals whilst they generated creative ideas of alternative uses for everyday objects in their native and second language. Although alpha-band power was slightly higher in the native language, idea originality did not differ between languages. However, creative idea generation was associated with a marked drop in beta-band power in the second language, suggesting that bilinguals experience lower 'cognitive stress' when thinking creatively in the second language.

Creative idea generation (henceforth, *ideation*), the distinctively human capacity to produce novel and context-appropriate ideas, requires both originality and effectiveness (Guilford, 1967; Sternberg, 1998). Measures of ideation often involve language, and linguistic abilities can relate to creativity (Beaty and Kenett, 2023; Holmes et al., 2015, 2019; Kasirer and Mashal, 2018). Studies have shown that bilingual individuals, in particular, have scored higher than monolinguals in a number of creative tasks (for review, see Kharkhurin, 2018), although it is unclear whether such advantage relates to language ability per se or domain-general cognitive traits relating to inhibitory control (Bialystok, 2009; Bialystok et al., 2012a). Nevertheless, studies of creative output in bilinguals' two languages are rare (Jończyk et al., 2024; Storme et al., 2017; Van Dijk et al., 2019), which is surprising given today's worldwide prevalence of bilingualism. Although some studies have looked at differences in creative cognition between languages and cultures in between-subject designs (Van Dijk et al., 2019), to our knowledge only one behavioural study to date has directly compared creative output in

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the two languages of the same bilingual individuals, that is using a within-subject design (Jończyk et al., 2024). English being the lingua franca of decision-making and negotiations in international organisations such as the UN or the EU, as well as science, politics, and business, it seems crucial to characterise the ability of second language speakers of English to generate creative solutions to problems in their L2 as compared to their L1.

Bilinguals are individuals who have the ability to communicate in two languages. They have to manage two sets of more or less intertwined language representations and their activation levels, which has led to the hypothesis that they are particularly apt at managing cognitive resource allocation and inhibitory control (Blom et al., 2014; Rodriguez-Fornells et al., 2006; Ye and Zhou, 2009). The idea that bilingualism may enhance executive control has been a matter of debate for over two decades (Bialystok et al., 2012b; Colzato et al., 2008a) and there is still no consensus regarding cognitive differences between bilinguals and monolinguals, especially when it comes to domain-general executive function (Paap et al., 2015; Poarch and Krott, 2019; Poarch and Van Hell, 2019; Ross and Melinger, 2017). This being said, in a within-subject design, bilinguals have shown a greater ability to cope with non-verbal cognitive interference in a mixed-language as compared to a single language context (Wu and Thierry, 2013).

But does the fact that bilinguals have two sets of mental representations that can be seen as complementary or competing with one another affect their ability to generate ideas in a creative task? It could be that having a second language offers more associations in semantic memory when bilinguals engage in idea generation due to their more extensive vocabulary and cultural references. On the other hand, it could be that having a more extensive network of semantic associations makes it more difficult for bilinguals to identify the most relevant ideas. The requirement of bilinguals to control cognitive interference in everyday language use could mean that they are better in both divergent and convergent thinking aspects of creative tasks (Colzato et al., 2008b; Hommel et al., 2011; Xia et al., 2022). They may have a larger semantic associative network to navigate whilst at the same time having greater potential to prune a set of ideas generated during creative ideation to select the best candidates, whilst suffering less interference from irrelevant concept activation (Kharkhurin, 2011). Indeed, to come up with unusual, unique, and original ideas in a task measuring creativity, one needs to not only extend their search for weaker, more remote associations, but also suppress strong activation of common associations (Benedek and Neubauer, 2013; Mednick, 1962).

Creative ideation can be construed as exploring the semantic association network by alternating between idea generation (divergent thinking) and idea evaluation (convergent thinking). These two processes need not be independent of one another, since evaluation can take place during ideation and further ideas can be generated while the current ones are being evaluated. Alternating between generation and evaluation is reminiscent of the process involved in language-switching when bilinguals have to move from allowing spreading of activation in their semantic memory to inhibiting such mechanisms so that the process can be facilitated in their other language. Relatedly, Russian-English bilinguals have been shown to outperform English monolingual controls on nonverbal measures of the Abbreviated Torrence Test for Adults (ATTA; Goff and Torrance, 2002), a 3-minute verbal and figural creativity task evaluated for fluency, flexibility, elaboration, and originality (Kharkhurin, 2010). In another study, Kharkhurin (2009) showed that Farsi-English bilinguals living in the United Arab Emirates were considered more original than Farsi monolinguals living in Iran, in the absence of fluency or flexibility differences between groups.

A state-of-the-art method to assess neural correlates of creative ideation is the measure of brain oscillation power in the alpha range (8–12 Hz). Alpha band activity has long been associated with creative cognition (Martindale and Hasenfus, 1978; Martindale and Mines, 1975). Increases in alpha power from baseline (alpha synchronisation) have been observed in individuals who obtained a high creativity score compared to low-scoring individuals (Fink et al., 2009; Fink and Neubauer, 2008; Jaušovec, 2000; Martindale and Hasenfus, 1978; Martindale and Mines, 1975). Alpha power also tends to increase with more creative output (Fink and Neubauer, 2006; Grabner et al., 2007) and in tasks that call for more creativity (Jauk et al., 2012; Jausovec, 1997). Unifying theories of alpha have proposed that it reflects inhibitory processing with increase in power relating to attention being focused inwards as external input is suppressed, especially over posterior scalp locations associated with visual input filtering. Alpha synchronisation in creativity tasks is thus argued to reflect an increase in internal attention demands during idea generation (Fink and Benedek, 2014) and inhibition of common associations involved in idea evaluation (Luft et al., 2018). Some studies have attempted to subdivide the alpha power band into lower (8–10 Hz) and upper (10–12 Hz) alpha to specify further the mechanisms at play in each case, but no consensus has yet been reached on what makes the difference (Fink and Benedek, 2014; Jauk et al., 2012; Rataj et al., 2018).

In the current study, we compared creative output in the same Polish-English bilinguals operating either in Polish or English, using an adaptation of the Alternative Uses Task (AUT, Guilford, 1967). In the AUT, participants are asked to generate as many unconventional uses for a familiar item as possible (usually presented as a word; Alhashim et al., 2020; Beaty et al., 2023; Beaty and Silvia, 2012; Benedek, 2018; Gilhooly et al., 2007), within a specified time limit (usually two minutes). Responses are then evaluated for originality, flexibility, and elaboration by a pool of independent raters (Consensual Assessment Technique by Amabile, 1982). The AUT focuses heavily on divergent thinking, i.e., the generative part of the creative process (Guilford, 1956). Here, we adapted the paradigm to increase the contribution of convergent thinking, a key aspect of creative cognition (Benedek et al., 2013; Runco, 2018; Silvia et al., 2008). To increase the contribution of convergent thinking in the AUT, likely affected by inhibitory control mechanisms at play in bilingualism (Hommel et al., 2011; Xia et al., 2022), we used three 30-second cycles of ideation each ending with the selection of the best idea from the current cycle (Witczak et al., 2024). For each object presented as a word-image combination, participants first indicated a common use and then three creative uses, in three successive cycles. The experiment was conducted in two blocks: once through the medium of Polish (preliminary instructions, training, word stimuli, and online instructions) and once through the medium of English.

We hypothesised that (i) Idea originality should increase over ideation cycles along with alpha-band power; (ii) Participants would be more creative in their L2 than their L1 given their ability to apply inhibitory control when operating in L2. Alpha-band power should reflect the same difference. We also conducted an exploratory analysis of (iii) potential differences in beta-band power between cycles and language contexts.

1. Results

Inter-rater agreement based on intra-class coefficients was 95.1 % (See Methods).

1.1. Creativity ratings

As expected, average creativity ratings increased over ideation cycles, $b = -0.11$, 95 % CI [−0.18,−0.04], $p = .003$, $\eta^2 = 0.012$, such that creativity scores in cycles 2 and 3 were significantly higher than in cycle 1 (cycle 2 – cycle 1: $t(1636.63) = 3.35$, $p = .002$; cycle 3 – cycle 1: $t(1637.25) = 4.25$, $p = < 0.001$; Fig. 1). We did not find significant differences in creativity scores between languages ($b = -0.05$, 95 % CI [−0.10 – 0.01], $p = 0.109$).

1.2. Event-related spectral power changes

We found increasing event-related synchronization (ERS) in the

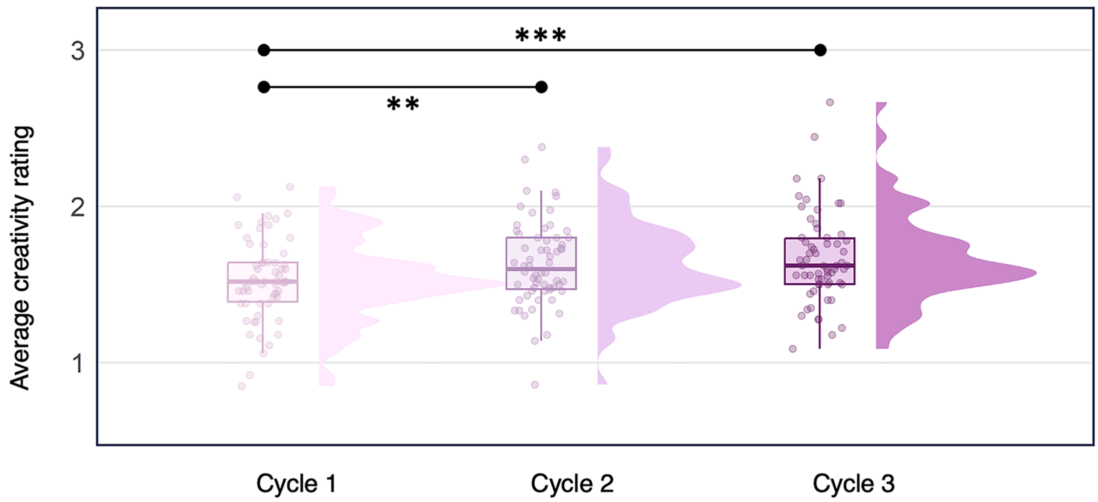

Fig. 1. Change in mean creativity ratings over cycles averaged across languages.

lower alpha band (8 – 10 Hz) over successive ideation cycles, F(2, 60)= 10.23, $p < .001$, $\eta^2 = 0.25$, such that cycle 2 and cycle 3 elicited greater ERS than cycle 1 (for post hoc contrasts, see Supporting Information). Also, ERS in the lower alpha range was more pronounced over the right than left hemisphere at electrodes of interests selected predictively (see Methods), F(1, 30)= 26.09, $p < .001$, $\eta^2 = 0.47$ (Fig. 2).

In addition, we found decreased lower alpha power in English (L2) as compared to Polish (L1), F(1, 30)= 4.88, $p = .035$, η2= 0.14 (Fig. 3).

In the upper alpha range (10 – 12 Hz), power increased over cycles as in the case of lower alpha, F(2, 60)= 18.06, $p < .001$, $\eta^2 = 0.38$, and was also greater over the right than the left hemisphere, F(1, 30)= 27.86, $p <$ .001, $\eta^2 = 0.48$ (Fig. 2). However, there was no difference between languages in the upper alpha range.

In the low-beta range (12.5 – 16.5 Hz), consistent with the difference found in the lower alpha range, we observed relatively greater event-related desynchronization (ERD) in L2 than L1, F(1, 30)= 4.55, $p =$ .041, $\eta^2 = 0.13$ (Fig. 3). This effect was greater in the left than the right region of interest, F(1, 30)= 24.53, $p < .001$, $\eta^2 = 0.45$ (Fig. 2).

In the mid-beta range (16.5 – 20 Hz), we found lower power in L2 than L1, F(1, 30)= 9.22, $p = .005$, $\eta^2 = 0.24$ (Fig. 3), and over the left than right hemisphere, F(1, 30)= 7.22, $p = .012$, $\eta^2 = 0.19$ (Fig. 2). We also found an interaction between Language and Cycle, F(2, 60)= 3.34, $p = .042$, $\eta^2 = 0.10$, such that mid-beta power was greater in cycle 3 than cycle 2 in L1 Polish, and in English than in Polish in cycle 1, cycle 2, and marginally in cycle 3 ($p = .070$; Fig. 4).

In the high-beta range (20 – 28 Hz) we found an interaction between Language and Cycle, F(2, 60)= 3.75, $p = .029$, $\eta^2 = 0.11$, with greater ERD in cycle 2 than cycle 1 in English, and greater ERD in English than Polish in cycle 2, $b = 1.93$, SE= 0.76, t(30)= 2.561, $p = .016$ (Fig. 4).

We also ran two supplementary analyses. First, we included block order as a between-subject factor to exclude the possibility of language order effects. This analysis revealed no significant block order effect. Second, we separately analysed the 5-second window preceding the idea reporting prompt to determine whether frequency power would differ in pattern from the rest of the 30-second window since idea evaluation was more likely to take place just before the prompt than at the beginning of each cycle. This analysis, however, replicated the findings reported for the whole 30-second windows. The results of both supplementary analyses can be found on the Open Science Framework (https://osf.io/9cxh6/).[1]

[1] We would like to thank an anonymous reviewer for prompting us to run both these analyses

2. Discussion

Our results show an increase in alpha power in Polish-English bilinguals engaged in a modified alternative uses task. Alpha power was particularly enhanced at parietooccipital sites and more so in the right than the left hemisphere in both languages. Power in the alpha band (lower and upper) also increased over cycles in both languages, following the same pattern as that of originality ratings. Contrary to our prediction, however, lower alpha power was reduced in L2 English as compared to L1 Polish, and, surprisingly, power also decreased in the beta band in L2 relative to L1.

2.1. Strengths

The increase in originality and alpha power over cycles observed here is consistent with the serial order effect often reported in the literature (Beaty and Silvia, 2012; Benedek and Neubauer, 2013; Wang et al., 2017). As people produce ideas in divergent thinking tasks, a predominant finding is that response rates decrease while response originality increases, resulting in a productivity-originality trade-off. It takes more 'effort-time' to come up with an uncommon idea than a common one (Acar and Runco, 2014; Beaty and Silvia, 2012; Wang et al., 2017). However, here, we did not measure fluency (i.e., the number of ideas produced) and we increased the contribution of convergent thinking. This aimed to reduce interference from the monitoring and reporting of ideas as they are being produced and capitalise on the differential involvement of inhibitory control in bilinguals. Our results thus corroborate a functional association between creative ideation and alpha brain power since we found that originality and alpha power go hand-in-hand and increase over ideation cycles (Fink and Benedek, 2014; Klimesch et al., 2007).

Our main goal was to test for differences between languages when bilinguals engage in an ideation task. We found no difference in idea originality between languages and, instead of the anticipated increase in alpha power in L2, lower alpha power was stronger in L1. Increase in alpha power has long been hypothesised to relate to inhibitory control and top-down modulation (Fink and Benedek, 2014; Jensen and Mazaheri, 2010; Klimesch, 2012; Klimesch et al., 2007; Sauseng et al., 2005). Such top-down modulation may thus apply to ideation in L1 to a greater extent than L2 given the likelihood of interference stemming from access to irrelevant conceptual links and representations more prone to happen in the native language (Borodkin et al., 2016; Fernández-Fontecha and Kenett, 2022; Jończyk et al., 2024). Indeed, studies comparing L1 and L2 organization in bilinguals have suggested that L1 semantic networks are denser (i.e., more complex) and that they bring to play more associative

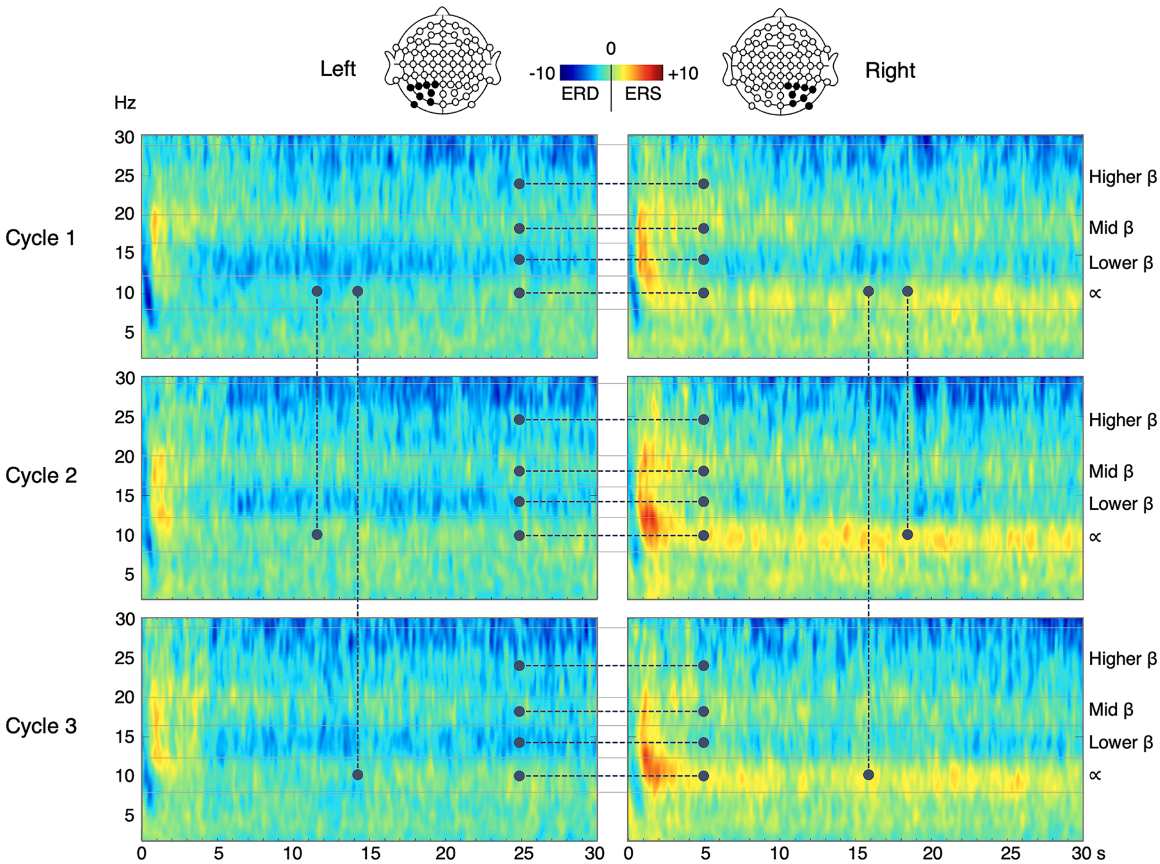

Fig. 2. Event-related spectral power elicited over three consecutive 30-second cycles averaged across participants and languages, to illustrate main effects of Cycle and Hemisphere. Significant differences are highlighted by connectors (vertical connectors highlight differences between cycles and horizontal connectors, differences between hemispheres).

connections (Wilks et al., 2005; Wilks and Meara, 2002, 2007) than their L2 counterpart which has been shown to be more 'fuzzy' (Bordag et al., 2022). Fernandez-Fontecha and Kenett (2022) proposed that the L2 semantic memory network has a less flexible, less clustered, and less random structure than the L1 network. This is consistent with our findings, because the more random and flexible structure in L1 is prone to activate representations that are not relevant for the task at hand, which in turn requires more inhibitory control to subdue such activations (see also Broersma, 2012). Increase in lower alpha power in our experiment may thus reflect increased inhibitory control (Klimesch, 2012; Klimesch et al., 2007) in L1 as compared to L2 rather than the expected reverse pattern, due to the nature of the task employed.

Our finding of greater beta ERD in L2 is also compatible with a less interconnected and more rigid semantic network in L2 relative to L1, since beta band ERD is associated with reduced cognitive interference and domain-general inhibitory control underpinned by the fronto-subthalamic circuit (Wessel and Anderson, 2023). The idea of weaker connectivity between lexical representations and concepts in L2 has been around for a long time in bilingualism research (Kroll and Stewart, 1994). However, this proposal concerned mostly late, unbalanced bilinguals, and it is commonly accepted that more balanced, fluent bilinguals of the kind tested here, also enjoy high levels of connectivity between lexical and conceptual representations in their L2 (Dijkstra et al., 2019; Kroll et al., 2010; Ning et al., 2020). It would thus be of high interest in future studies to test unbalanced bilinguals using a similar experimental design. Overall, whilst fluent bilinguals are better equipped for ideation in L1 owing to a more robust associative network, they may suffer more interference in L1 from irrelevant lexical-conceptual associations, which are likely to impede efficacy during idea evaluation.

Another convergent explanation, which is slightly different from weaker connectivity in L2, is the well-evidenced greater ability of bilinguals to apply inhibitory control in L2 (Borragan et al., 2018; Misra et al., 2012; Wu and Thierry, 2017). Indeed, it is widely accepted that bilinguals apply greater inhibition to L1 whilst operating in L2 than the reverse, and this might translate as relative increase in ERD in the higher beta range. Greater beta ERD may also result from participants being more satisfied and less self-critical when operating in L2. The idea is that bilinguals are likely to have higher expectations regarding creative output when doing the task in L1 (Jończyk et al., 2024), increasing the likelihood of monitoring and dismissal of ideas. Self-criticism has long been identified as a counter-productive force in creative ideation (Osborn, 1942). Interestingly, a recent study showed that criticism may have a lower impact in the second language (Gao et al., 2020). If a similar mechanism applies to self-judgment, one expects bilinguals to be less critical of their ideas during creative ideation in L2, thus lowering the threshold of inhibition, and in turn resulting in beta desynchronisation.

2.2. Weaknesses

First, we found differences in originality ratings between both cycles 3 and cycle 2 as compared to cycle 1 in the current study, whereas in our previous behavioural study (Witczak et al., 2024), we only found a significant difference between cycle 3 and cycle 1. This slight inconsistency between studies is likely driven by statistical power, since within-subject comparisons in the study by Witczak et al. were based on five items per condition (comparing the more common list procedure of AUT with the ideation cycles implemented within one language) whereas here participants ideated on ten items per language. Thus, the current results can still be considered a replication of our previous

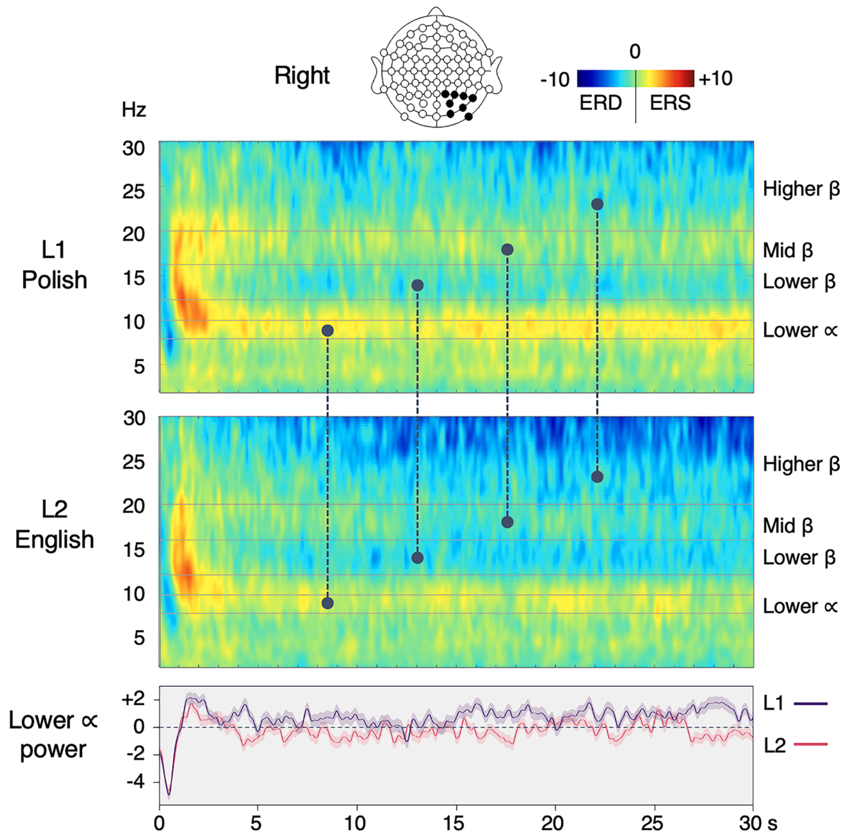

Fig. 3. Event-related spectral power averaged across participants and cycles in each of the two language contexts, to illustrate main effects of language. Significant differences are highlighted by connectors. Bottom panel depicts average lower alpha power over time in L1 Polish and L2 English. Shading depicts 95 % confidence intervals around the mean.

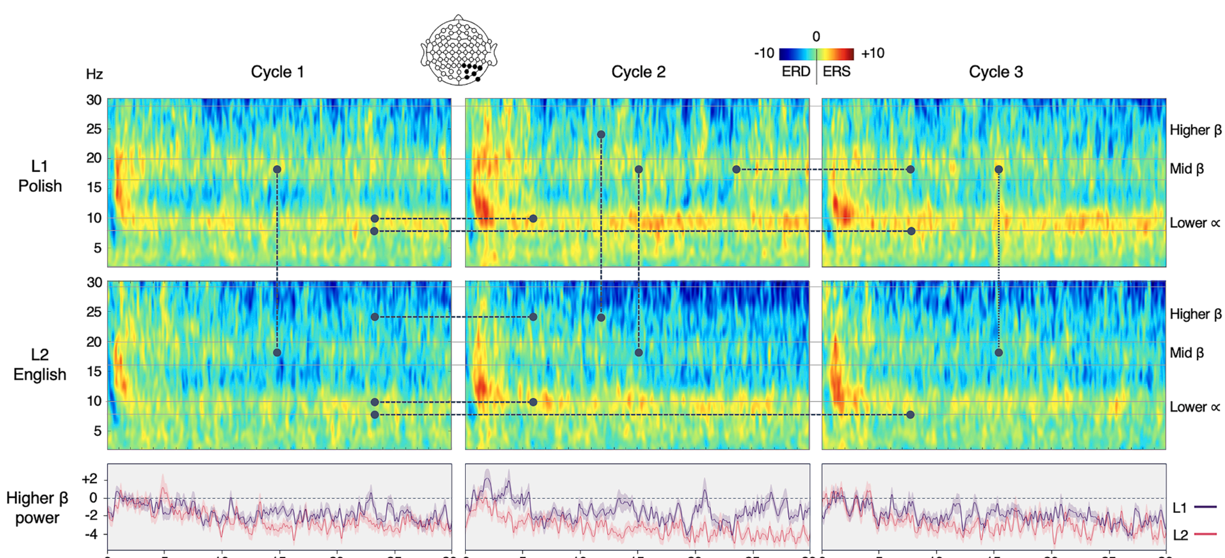

Fig. 4. Event-related spectral power averaged across participants in each cycle and in the two language contexts from the right parietal ROI, to illustrate interactions between cycles and languages. Significant differences are highlighted by connectors (the dotted connector denotes marginal significance). Bottom panel depicts average higher beta power over time in the L1 Polish and the L2 English. Shading depicts 95 % confidence intervals around the mean.

behavioural study.

Second, as in our previous study, the use of word+image prompts may have reduced originality at the ideation outset. Whilst this is discussed elsewhere (Witczak et al., 2024), it is worth noting that originality outputs may have been more diverse if we had only used word prompts as is common in creativity investigations using the AUT. At the same time, using word+image prompts provides a better ideation baseline and greater control over inter-individual variability (Witczak et al., 2024).

We also acknowledge that this first study of EEG power elicited by a creativity task in bilinguals has limitations. For instance, we did not implement a measure of idea fluency, which could have provided additional insights regarding the creative ideation process and another measure by which to compare ideation across language contexts. This was a choice guided by our goal to increase the involvement of convergent thinking in the task. However, it must be noted that in our previous study comparing the more classic list format of idea reporting and the cycle format implemented here, we did not find any significant difference in originality between testing contexts. In any event, we should expect higher originality in the cycle than the list format, given the greater involvement of convergent thinking. Also, we note that we constrained our stimuli to everyday objects, which may have artificially decreased differences between language contexts, while such differences could have been stronger for more unfamiliar objects.

2.3. Future directions

Our study is the first to establish a difference in bilinguals during creative ideation in L1 and L2. Although the difference was not observed in the originality of the ideas produced, we found a striking difference in background activity underpinning the creative ideation process. In the native language, bilinguals likely engage in more top-down inhibitory control to deal with multiple sources of cognitive interference and wide-scale spreading activation in the semantic system. Whilst this could give ideation in L1 an advantage, we found no behavioural difference between languages, presumably because the wider field of semantic associations to explore in L1 means also having to deal with 'creative noise', ideas that are too remotely connected or unsuitable for the task at hand. This, we suggest, results in both greater alpha and beta power. One possible future direction from this research is to test creativity in more demanding conditions, requiring problem solving or using objects that have rich as compared to low semantic associations (Beaty et al., 2023). Maybe this is where differences between L1 and L2 will become marked enough to translate into behavioural differences. Other fascinating avenues of research involve looking to differences driven by proficiency and language use, as well as participants engaging in activities that tend to increase alpha power, such as boredom (Mann and Cadman, 2014), meditation, and contemplative states, and whether they can boost creativity differently in the two languages.

3. Methods

3.1. Participants

Thirty-one participants gave informed consent to take part in the study and were included in the final analysis (M_{age}= 26, SD_{age}= 6.15, min_{age}= 21, max_{age}= 44; 21 women, 9 men, 1 nonbinary person). The target number of participants was determined based on previous creativity studies using time-frequency analysis (Benedek et al., 2011; Jauk et al., 2012; Jończyk et al., 2022; Stevens and Zabelina, 2020). They were late sequential bilinguals, native speakers of Polish (L1) and advanced learners of English (L2). Proficiency in L2 was assessed using the Lexical Test for Advanced Learners of English (LexTALE; Lemhöfer and Broersma, 2012) and language use was measured using the Language History Questionnaire (LHQ; Li et al., 2020). Mean L2 proficiency score corresponded to C1–C2 on the Common European Framework of Reference for Languages scale (M = 89.6 %, SD= 9.16, min= 66 %, max= 100 %). Participants reported balanced use of their L1 and L2 in various contexts (M = 0.94, SD= 0.13, min= 0.70, max= 1.24).[2] They were significantly more immersed in their L1 (Mdn= 0.93, SD= 0.09) than L2 (Mdn= 0.72, SD= 0.11), $U = 31$, $p < .001$. All participants had normal or corrected-to-normal vision and hearing, and no neurological or language-related disorders. Handedness was assessed through self-report ($N_{right} = 29$; $N_{left}= 2$). Participants received compensation for their time (PLN 100).

3.2. Stimuli

We selected 20 objects of everyday use (ten per language) to be presented as a word and image combination (greyscale picture overlaid with a word, see Fig. 5). Stimuli were normed and tested thoroughly in a previous behavioural study (Witczak et al., 2024). Words overlaying images were presented in white Arial font, size 15 and 0.7-point expanded character spacing, outlined in black. Text outlining improved legibility by detaching the word from the picture background. The stimuli can be found on the Open Science Framework (https://osf.io/9cxh6/).

3.3. Procedure

The procedures followed in the study were approved by the Ethics Committee for Research Involving Human Participants at Adam Mickiewicz University in Poznań, Poland (Resolution no. 23/2021/2022). Participants were seated 55 cm away from a 24-inch LCD monitor in a quiet and dimly lit testing booth. After EEG cap preparation, participants completed the questionnaires. First, two 1-min resting-state EEG sequences were recorded, the first with eyes open, the second with eyes closed. Next, participants received instructions to the modified alternative uses task and engaged in practice trials. They were asked to generate one typical and three unusual but plausible uses for an everyday object presented on the screen. Each trial started with a display of a white cross for a mean of 5 s (random jitter between 4950 and 5050 in steps of 10) which served as a pre-stimulus baseline for time-frequency analysis. Then, an everyday object was displayed for 1.5 s (random jitter between 1450 and 1550 in steps of 10). Participants had 15 s to type the common use of the object. Following this, participants generated unusual but plausible uses of the presented object over three 30-second ideation cycles. At the end of each cycle, participants had 15 s to type their single best idea from that cycle (Fig. 6). Responses were collected at the end of each cycle, and not during ideation, to avoid muscle artefacts on the EEG and to allow for uninterrupted influx of ideas during each cycle. Our previous behavioural study also showed that the modified cyclic procedure was effective in increasing the contribution of idea evaluation, allowing to measure creativity as opposed to merely idea originality (Witczak et al. 2024). Participants completed 20 trials –10 in Polish and 10 in English– in separate language blocks. Object presentation was randomised, and block order was counterbalanced across participants. Each object appeared in both language contexts but was never repeated for an individual participant. After completing the experiment, two 1-min resting-state EEG sequences were recorded (eyes open, eyes closed).

3.4. Ratings

As in Witczak et al. (2024), the rating procedure followed the Consensual Assessment Technique (Amabile, 1982). Five raters assessed the creativity of participants' ideas on a 5-point scale (0 – common, unoriginal use, 1 – not very original but a bit uncommon, 2 – quite original and quite uncommon, 3 – original, uncommon, 4 – highly original, rare). To be considered creative, an idea had to be novel, unique, and plausible. Implausible ideas received a score of 10 and were excluded from analysis. Interrater reliability was 95.1 %. Scores were averaged across raters, yielding originality ratings per item and per participant. As in earlier creativity studies involving bilinguals (e.g., Kharkhurin, 2008) the raters themselves were highly proficient in both the tested languages.

3.5. Behavioural analyses

Data pre-processing was conducted using the Tidyverse package

[2] Calculated based on the language dominance score in LHQ, where values closer to 1 indicate higher/greater balance between languages.

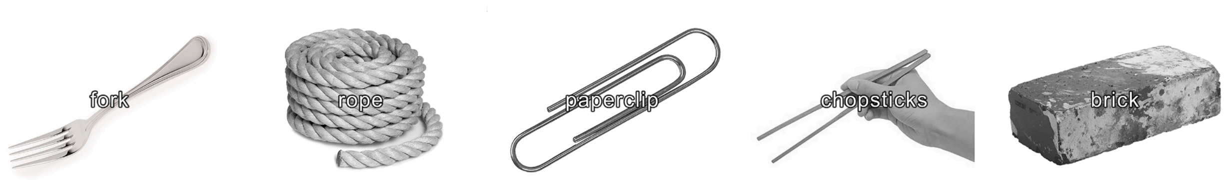

Fig. 5. Examples of stimuli used in the study.

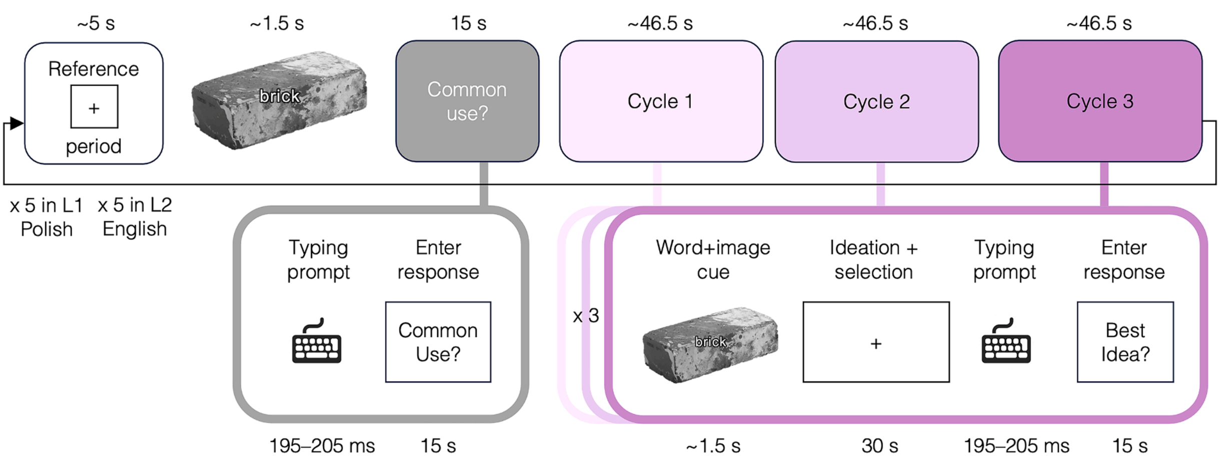

Fig. 6. Schematic of the experimental procedure: structure of trials and cycles.

(Wickham et al., 2019) in R. Creativity scores were subjected to analysis using a linear-mixed model (LMM) utilizing the lme4 (Bates et al., 2015) and lmerTest (Kuznetsova et al., 2017) packages. A maximal model with a full random-effect structure was initially computed, including subject- and item-related variance components for intercepts and by-subject and by-item random-slopes for fixed-effects (Barr et al., 2013). All fixed effects were coded using sum contrast coding (−0.5;0.5). The maximal model turned out to be overparametrized and not supported by the data. Following recommendations by Bates et al., more parsimonious LMMs were progressively selected. Small variance parameters were removed using the lme4::rePCA and lme4::VarCorr functions until the LMM was supported by the data. The final structure of each model was as follows:

$$\text{Rating} \sim \text{language} * \text{cycle} + (1 + \text{language}|\text{Subject}) + (1|\text{item})$$

Estimates of effect size were calculated using the *effectsize* package in R (Ben-Shachar et al., 2020). The model did not show collinearity (Variance Inflection Factor < 1.1).

3.6. Electrophysiological analyses

EEG data were acquired at a sample rate of 2048 Hz from 64 Ag/AgCl electrodes using a BioSemi ActiveTwo amplifier (BioSemi, Amsterdam) and four peri-ocular electrodes (two vertical and two horizontal EOGs), placed according to the international 10–20 system. Preprocessing steps and analyses were performed using EEGLAB (v2023.0; Delorme and Makeig, 2004) in Matlab R2022b (The MathWorks, Inc.). Offline, continuous EEG data were downsampled to 500 Hz, high-pass filtered at 0.5 Hz and low-pass filtered at 30 Hz using the Hamming windowed sinc Finite Impulse Response filter (pop_eegfiltnew function). Large unsystematic artefacts in continuous EEG data were manually detected and removed. Bad channels were identified using the clean_rawdata function (Mullen et al., 2015; correlation threshold= 0.8; $M = 1.23$, min= 0, max= 4). Data were re-referenced to the activity of all channels (excluding EOGs) and subjected to the Adaptive Mixture Independent Component Analysis (AMICA; Palmer et al., 2008). IClabel was then applied to detect artefacts in EEG data (Pion-Tonachini et al., 2019). Independent components characterised by ocular activity, line noise, or noisy channels were rejected from the data ($M = 5.13$; min= 3; max= 7). Artefact-free continuous data were segmented for further analysis. We introduced six unique trigger codes within each ideation cycle (30 s), each marking a successive five-second window within a cycle, amounting to six windows per cycle. This allowed us to directly compare EEG activity in the ideation (activation) windows with pre-stimulus activity recorded during the reference period (baseline). Activation and baseline periods were segmented into 8.5 s windows between –2 s and 6.5 s surrounding a trigger. Longer epochs were selected to allow discarding edge artefacts (Cohen, 2014). The mean number of included epochs per participant and individual 30 s-cycle within language was 9.4 (S.D.= 1.15). We computed task related power (TRP) changes for each electrode and trial in the lower (8–10 Hz) and upper (10–12 Hz) alpha band as well as the low beta (12.5–16 Hz), mid beta (16.5–20 Hz), and high beta (20.5–28 Hz) bands in activation and baseline periods. Time/frequency decomposition was computed using sinusoidal wavelet transforms (*newtimef* function in Matlab; wavelet scale expansion factor of 0.5), with three cycles at the lowest frequency (2 Hz), increasing linearly up to 22.5 cycles at the highest frequency (30 Hz). To establish changes in the activation period relative to the power during the baseline period, we computed the percentage change value at each time-frequency point at each electrode relative to baseline power, following Cohen (2014): $\text{prctchange}_{tf} = 100 * (\text{activity}_{tf} - \text{baseline}_{f})/\text{baseline}_{f}$.

A power decrease in the activation period from the baseline is reflected by negative TRP values (i.e., event-related desynchronization; ERD), while an increase in power from baseline is reflected by positive TRP values (i.e., event-related synchronization; ERS). Here, we focus on the relative difference in TRP between ideation cycles and languages. Because we are interested in analysing entire 30 second cycles of ideation, following time~frequency computation, 30 s cycles were reconstructed by joining back together six segments between 0 and 5 s of each successive window. TRP values in each of the frequency bands of interest were subjected to a repeated measures ANOVA with Cycle (cycle 1, cycle 2, cycle 3), Language (Polish, English), and Hemisphere (left, right) as within-subject independent variables. All analyses have been computed predictively at left and right parieto-occipital sites of maximal relevance (P1, P3, P5, P7, P9, PO7, PO3, O1, P2, P4, P6, P8, P10, PO8, PO4, O2).

CRediT authorship contribution statement

Rafał Jończyk: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Iga Krzysik:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Olga Witczak:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Katarzyna Bromberek-Dyzman:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Guillaume Thierry:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

None

Data availability

Stimuli, raw data, and analysis scripts are openly available at https://osf.io/9cxh6/ .

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.neuroimage.2024.120752.

References

Acar, S., Runco, M.A., 2014. Assessing associative distance among ideas elicited by tests of divergent thinking. Creat. Res. J. 26 (2), 229–238. https://doi.org/10.1080/10400419.2014.901095.

Alhashim, A., Marshall, M., Hartog, T., Jonczyk, R., Dickson, D., Van Hell, J., Okudan-Kremer, G., Siddique, Z., 2020. Work in progress: assessing creativity of alternative uses task responses: a detailed procedure. In: Proceedings of the 2020 ASEE Virtual Annual Conference Content Access Proceedings, p. 35612. https://doi.org/10.18260/1-2-35612.

Amabile, T.M., 1982. Social psychology of creativity: a consensual assessment technique. J. Pers. Soc. Psychol. 43 (5) https://doi.org/10.1037/0022-3514.43.5.997. Article 5.

Barr, D.J., Levy, R., Scheepers, C., Tily, H.J., 2013. Random effects structure for confirmatory hypothesis testing: keep it maximal. J. Mem. Lang. 68 (3), 255–278. https://doi.org/10.1016/j.jml.2012.11.001.

Bates, D., Mächler, M., Bolker, B., Walker, S., 2015. Fitting linear mixed-effects models using LME4. J. Stat. Softw. (1), 67. https://doi.org/10.18637/jss.v067.i01.

Beaty, R.E., Kenett, Y.N., 2023. Associative thinking at the core of creativity. Trends Cogn. Sci. 27 (7), 671–683. https://doi.org/10.1016/j.tics.2023.04.004.

Beaty, R.E., Kenett, Y.N., Hass, R.W., Schacter, D.L., 2023. Semantic memory and creativity: the costs and benefits of semantic memory structure in generating original ideas. Think. Reason. 29 (2), 305–339. https://doi.org/10.1080/13546783.2022.2076742.

Beaty, R.E., Silvia, P.J., 2012. Why do ideas get more creative across time? An executive interpretation of the serial order effect in divergent thinking tasks. Psychol. Aesthet. Creat. Arts. 6 (4) https://doi.org/10.1037/a0029171. Article 4.

Benedek, M., 2018. Internally directed attention in creative cognition. In: Jung, R.E., Vartanian, O. (Eds.), The Cambridge Handbook of the Neuroscience of Creativity, 1st ed. Cambridge University Press, pp. 180–194. https://doi.org/10.1017/9781316556238.011.

Benedek, M., Bergner, S., Könen, T., Fink, A., Neubauer, A.C., 2011. EEG alpha synchronization is related to top-down processing in convergent and divergent thinking. Neuropsychologia (12), 49. https://doi.org/10.1016/j.neuropsychologia.2011.09.004. Article 12.

Benedek, M., Mühlmann, C., Jauk, E., Neubauer, A.C., 2013. Assessment of divergent thinking by means of the subjective top-scoring method: effects of the number of top-ideas and time-on-task on reliability and validity. Psychol. Aesthet. Creat. Arts. 7 (4) https://doi.org/10.1037/a0033644. Article 4.

Benedek, M., Neubauer, A.C., 2013. Revisiting Mednick's model on creativity-related differences in associative hierarchies. evidence for a common path to uncommon thought. J. Creat. Behav. 47 (4) https://doi.org/10.1002/jocb.35. Article 4.

Ben-Shachar, M., Lüdecke, D., Makowski, D., 2020. Effect size: estimation of effect size indices and standardized parameters. J. Open Source Software 5 (56), 2815. https://doi.org/10.21105/joss.02815.

Bialystok, E., 2009. Bilingualism: the good, the bad, and the indifferent. Bilingualism 12 (1), 3–11. https://doi.org/10.1017/S1366728908003477.

Bialystok, E., Craik, F.I.M., Luk, G., 2012a. Bilingualism: consequences for mind and brain. Trends Cogn. Sci. 16 (4), 240–250. https://doi.org/10.1016/j.tics.2012.03.001.

Bialystok, E., Craik, F.I.M., Luk, G., 2012b. Bilingualism: consequences for mind and brain. Trends Cogn. Sci. 16 (4) https://doi.org/10.1016/j.tics.2012.03.001. Article 4.

Blom, E., Küntay, A.C., Messer, M., Verhagen, J., Leseman, P., 2014. The benefits of being bilingual: working memory in bilingual Turkish–Dutch children. J. Exp. Child Psychol. 128, 105–119. https://doi.org/10.1016/j.jecp.2014.06.007.

Bordag, D., Gor, K., Opitz, A., 2022. Ontogenesis model of the L2 lexical representation. Bilingualism 25 (2), 185–201. https://doi.org/10.1017/S1366728921000250.

Borodkin, K., Kenett, Y.N., Faust, M., Mashal, N., 2016. When pumpkin is closer to onion than to squash: the structure of the second language lexicon. Cognition 156, 60–70. https://doi.org/10.1016/j.cognition.2016.07.014.

Borragan, M., Martin, C.D., De Bruin, A., Duñabeitia, J.A., 2018. Exploring different types of inhibition during bilingual language production. Front. Psychol. 9, 2256. https://doi.org/10.3389/fpsyg.2018.02256.

Broersma, M., 2012. Increased lexical activation and reduced competition in second-language listening. Lang. Cogn. Process. 27 (7–8), 1205–1224. https://doi.org/10.1080/01690965.2012.660170.

Cohen, M.X., 2014. Analyzing Neural Time Series Data: Theory and Practice. The MIT Press. https://doi.org/10.7551/mitpress/9609.001.0001.

Colzato, L.S., Bajo, M.T., Van Den Wildenberg, W., Paolieri, D., Nieuwenhuis, S., La Heij, W., Hommel, B., 2008a. How does bilingualism improve executive control? A comparison of active and reactive inhibition mechanisms. J. Experim. Psychol. 34 (2) https://doi.org/10.1037/0278-7393.34.2.302. Article 2.

Colzato, L.S., Bajo, M.T., Van Den Wildenberg, W., Paolieri, D., Nieuwenhuis, S., La Heij, W., Hommel, B., 2008b. How does bilingualism improve executive control? A comparison of active and reactive inhibition mechanisms. J. Experim. Psychol. 34 (2), 302–312. https://doi.org/10.1037/0278-7393.34.2.302.

Delorme, A., Makeig, S., 2004. EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. J. Neurosci. Methods 134 (1), 9–21. https://doi.org/10.1016/j.jneumeth.2003.10.009.

Dijkstra, T., Wahl, A., Buytenhuijs, F., Van Halem, N., Al-Jibouri, Z., De Korte, M., Rekké, S., 2019. Multilink: a computational model for bilingual word recognition and word translation. Bilingualism 22 (04), 657–679. https://doi.org/10.1017/S1366728918000287.

Fernández-Fontecha, A., Kenett, Y.N., 2022. Examining the relations between semantic memory structure and creativity in second language. Think. Skills Creativity 45, 101067. https://doi.org/10.1016/j.tsc.2022.101067.

Fink, A., Benedek, M., 2014. EEG alpha power and creative ideation. Neurosci. Biobehav. Rev. 44, 111–123. https://doi.org/10.1016/j.neubiorev.2012.12.002.

Fink, A., Graif, B., Neubauer, A.C., 2009. Brain correlates underlying creative thinking: EEG alpha activity in professional vs. novice dancers. Neuroimage 46 (3). https://doi.org/10.1016/j.neuroimage.2009.02.036. Article 3.

Fink, A., Neubauer, A.C., 2006. EEG alpha oscillations during the performance of verbal creativity tasks: differential effects of sex and verbal intelligence. Int. J. Psychophysiol. 62 (1) https://doi.org/10.1016/j.ijpsycho.2006.01.001. Article 1.

Fink, A., Neubauer, A.C., 2008. Eysenck meets Martindale: the relationship between extraversion and originality from the neuroscientific perspective. Pers. Individ. Dif. 44 (1) https://doi.org/10.1016/j.paid.2007.08.010. Article 1.

Gao, S., Luo, L., Gou, T., 2020. Criticism in a foreign language hurts less. Cogn. Emotion 34 (4), 822–830. https://doi.org/10.1080/02699931.2019.1668751.

Gilhooly, K.J., Fioratou, E., Anthony, S.H., Wynn, V., 2007. Divergent thinking: strategies and executive involvement in generating novel uses for familiar objects. Br. J. Psychol. 98 (4) https://doi.org/10.1111/j.2044-8295.2007.tb00467.x. Article 4.

Goff, K., Torrance, E.P., 2002. Abbreviated Torrance Test For Adults Manual. Scholastic Testing Service.

Grabner, R.H., Fink, A., Neubauer, A.C., 2007. Brain correlates of self-rated originality of ideas: evidence from event-related power and phase-locking changes in the EEG. Behav. Neurosci. 121 (1) https://doi.org/10.1037/0735-7044.121.1.224. Article 1.

Guilford, J.P., 1956. The structure of intellect. Psychol. Bull. 53 (4) https://doi.org/10.1037/h0040755. Article 4.

Guilford, J.P., 1967. Creativity: yesterday, today and tomorrow. J. Creat. Behav. 1 (1), 3–14. https://doi.org/10.1002/j.2162-6057.1967.tb00002.x.

Holmes, R.M., Gardner, B., Kohm, K., Bant, C., Ciminello, A., Moedt, K., Romeo, L., 2019. The relationship between young children's language abilities, creativity, play, and storytelling. Early Child. Dev. Care 189 (2), 244–254. https://doi.org/10.1080/03004430.2017.1314274.

Holmes, R.M., Romeo, L., Ciraola, S., Grushko, M., 2015. The relationship between creativity, social play, and children's language abilities. Early Child. Dev. Care 185 (7), 1180–1197. https://doi.org/10.1080/03004430.2014.983916.

Hommel, B., Colzato, L.S., Fischer, R., Christoffels, I.K., 2011. Bilingualism and creativity: benefits in convergent thinking come with losses in divergent thinking. Front. Psychol. 2 https://doi.org/10.3389/fpsyg.2011.00273.

Jauk, E., Benedek, M., Neubauer, A.C., 2012. Tackling creativity at its roots: evidence for different patterns of EEG alpha activity related to convergent and divergent modes of task processing. Int. J. Psychophysiol. 84 (2) https://doi.org/10.1016/j.ijpsycho.2012.02.012. Article 2.

Jausovec, N., 1997. Differences in EEG activity during the solution of closed and open problems. Creat. Res. J. 10 (4) https://doi.org/10.1207/s15326934crj1004_3. Article 4.

Jaušovec, N., 2000. Differences in cognitive processes between gifted, intelligent, creative, and average individuals while solving complex problems: an EEG study. Intelligence 28 (3). https://doi.org/10.1016/S0160-2896(00)00037-4. Article 3.

Jensen, O., Mazaheri, A., 2010. Shaping functional architecture by oscillatory alpha activity: gating by inhibition. Front. Hum. Neurosci. 4 https://doi.org/10.3389/fnhum.2010.00186.

Jończyk, R., Dickson, D.S., Bel-Bahar, T.S., Kremer, G.E., Siddique, Z., Van Hell, J.G., 2022. How stereotype threat affects the brain dynamics of creative thinking in female students. Neuropsychologia 173, 108306. https://doi.org/10.1016/j.neuropsychologia.2022.108306.

Jończyk, R., Naranowicz, M., Dębowska-Kozłowska, K., Bromberek-Dyzman, K., 2024. Negative mood constrains creative thinking in the native but not in the second language. Think. Skills Creativity 51, 101457. https://doi.org/10.1016/j.tsc.2023.101457.

Kasirer, A., Mashal, N., 2018. Fluency or similarities? cognitive abilities that contribute to creative metaphor generation. Creat. Res. J. 30 (2), 205–211. https://doi.org/10.1080/10400419.2018.1446747.

Kharkhurin, A.V., 2008. The effect of linguistic proficiency, age of second language acquisition, and length of exposure to a new cultural environment on bilinguals' divergent thinking. Bilingualism 11 (2), 225–243. https://doi.org/10.1017/S1366728908003398.

Kharkhurin, A.V., 2009. The role of bilingualism in creative performance on divergent thinking and invented alien creatures tests. J. Creat. Behav. 43 (1) https://doi.org/10.1002/j.2162-6057.2009.tb01306.x. Article 1.

Kharkhurin, A.V., 2010. Bilingual verbal and nonverbal creative behavior. Int. J. Bilingualism 14 (2). https://doi.org/10.1177/1367006910363060. Article 2.

Kharkhurin, A.V., 2011. The role of selective attention in bilingual creativity. Creat. Res. J. 23 (3) https://doi.org/10.1080/10400419.2011.595979. Article 3.

Kharkhurin, A.V, 2018. Bilingualism and creativity. In: Altarriba, J., Heredia, R.R. (Eds.), An Introduction to bilingualism: Principles and Processes, 2nd ed. Psychology Press, pp. 159–189.

Klimesch, W., 2012. Alpha-band oscillations, attention, and controlled access to stored information. Trends Cogn. Sci. 16 (12), 606–617. https://doi.org/10.1016/j.tics.2012.10.007.

Klimesch, W., Sauseng, P., Hanslmayr, S., 2007. EEG alpha oscillations: the inhibition–timing hypothesis. Brain Res. Rev. 53 (1), 63–88. https://doi.org/10.1016/j.brainresrev.2006.06.003.

Kroll, J.F., Stewart, E., 1994. Category interference in translation and picture naming: evidence for asymmetric connections between bilingual memory representations. J. Mem. Lang. 33 (2), 149–174. https://doi.org/10.1006/jmla.1994.1008.

Kroll, J.F., Van Hell, J.G., Tokowicz, N., Green, D.W., 2010. The revised hierarchical model: a critical review and assessment. Bilingualism 13 (3), 373–381. https://doi.org/10.1017/S136672891000009X.

Kuznetsova, A., Brockhoff, P.B., Christensen, R.H.B., 2017. LMER test package: tests in linear mixed effects models. J. Stat. Softw. (13), 82. https://doi.org/10.18637/jss.v082.i13.

Lemhöfer, K., Broersma, M., 2012. Introducing LexTALE: a quick and valid lexical test for advanced learners of English. Behav. Res. Methods 44 (2). https://doi.org/10.3758/s13428-011-0146-0. Article 2.

Li, P., Zhang, F., Yu, A., Zhao, X., 2020. Language History Questionnaire (LHQ3): an enhanced tool for assessing multilingual experience. Bilingualism 23 (5). https://doi.org/10.1017/S1366728918001153. Article 5.

Luft, C.D.B., Zioga, I., Thompson, N.M., Banissy, M.J., Bhattacharya, J., 2018. Right temporal alpha oscillations as a neural mechanism for inhibiting obvious associations. Proc. Natl. Acad. Sci. 115 (52) https://doi.org/10.1073/pnas.1811465115. Article 52.

Mann, S., Cadman, R., 2014. Does being bored make us more creative? Creat. Res. J. 26 (2), 165–173. https://doi.org/10.1080/10400419.2014.901073.

Martindale, C., Hasenfus, N., 1978. EEG differences as a function of creativity, stage of the creative process, and effort to be original. Biol. Psychol. 6 (3) https://doi.org/10.1016/0301-0511(78)90018-2. Article 3.

Martindale, C., Mines, D., 1975. Creativity and cortical activation during creative, intellectual and EEG feedback tasks. Biol. Psychol. 3 (2) https://doi.org/10.1016/0301-0511(75)90011-3. Article 2.

Mednick, S., 1962. The associative basis of the creative process. Psychol. Rev. 69 (3) https://doi.org/10.1037/h0048850. Article 3.

Misra, M., Guo, T., Bobb, S.C., Kroll, J.F., 2012. When bilinguals choose a single word to speak: electrophysiological evidence for inhibition of the native language. J. Mem. Lang. 67 (1), 224–237. https://doi.org/10.1016/j.jml.2012.05.001.

Mullen, T.R., Kothe, C.A.E., Chi, Y.M., Ojeda, A., Kerth, T., Makeig, S., Jung, T.-P., Cauwenberghs, G., 2015. Real-Time neuroimaging and cognitive monitoring using wearable dry EEG. IEEE Trans. Biomed. Eng. 62 (11), 2553–2567. https://doi.org/10.1109/TBME.2015.2481482.

Ning, S., Hayakawa, S., Bartolotti, J., Marian, V., 2020. On language and thought: bilingual experience influences semantic associations. J. Neurolinguistics. 56, 100932 https://doi.org/10.1016/j.jneuroling.2020.100932.

Osborn, A.F., 1942. How to Think up. McGraw-Hill.

Paap, K.R., Johnson, H.A., Sawi, O., 2015. Bilingual advantages in executive functioning either do not exist or are restricted to very specific and undetermined circumstances. Cortex 69, 265–278. https://doi.org/10.1016/j.cortex.2015.04.014.

Palmer, J.A., Makeig, S., Kreutz-Delgado, K., Rao, B.D., 2008. Newton method for the ICA mixture model. In: Proceedings of the 2008 IEEE International Conference on Acoustics, Speech and Signal Processing, pp. 1805–1808. https://doi.org/10.1109/ICASSP.2008.4517982.

Pion-Tonachini, L., Kreutz-Delgado, K., Makeig, S., 2019. ICLabel: an automated electroencephalographic independent component classifier, dataset, and website. Neuroimage 198, 181–197. https://doi.org/10.1016/j.neuroimage.2019.05.026.

Poarch, G.J., Krott, A., 2019. A bilingual advantage? An appeal for a change in perspective and recommendations for future research. Behav. Sci. 9 (9), 95. https://doi.org/10.3390/bs9090095.

Poarch, G.J., Van Hell, J.G., 2019. Chapter 14. Does performance on executive function tasks correlate?: evidence from child trilinguals, bilinguals, and second language learners. In: Sekerina, I.A., Spradlin, L., Valian, V. (Eds.), Studies in Bilingualism. John Benjamins Publishing Company, pp. 223–236. https://doi.org/10.1075/sibil.57.14poa. Vol. 57.

Rataj, K., Nazareth, D.S., Van Der Velde, F, 2018. Use a spoon as a spade?: changes in the upper and lower alpha bands in evaluating alternate object use. Front. Psychol. 9, 1941. https://doi.org/10.3389/fpsyg.2018.01941.

Rodriguez-Fornells, A., De Diego Balaguer, R., Münte, T.F, 2006. Executive control in bilingual language processing. In: Lang. Learn., 56 https://doi.org/10.1111/j.1467-9922.2006.00359.x. Article s1.

Ross, J., Melinger, A., 2017. Bilingual advantage, bidialectal advantage or neither? Comparing performance across three tests of executive function in middle childhood. Dev. Sci. 20 (4) https://doi.org/10.1111/desc.12405. Article 4.

Runco, M.A., 2018. Implicit theories of creativity ☆. Reference Module in Neuroscience and Biobehavioral Psychology. Elsevier. https://doi.org/10.1016/B978-0-12-809324-5.06210-6. B9780128093245062106.

Sauseng, P., Klimesch, W., Stadler, W., Schabus, M., Doppelmayr, M., Hanslmayr, S., Gruber, W.R., Birbaumer, N., 2005. A shift of visual spatial attention is selectively associated with human EEG alpha activity. Eur. J. Neurosci. 22 (11), 2917–2926. https://doi.org/10.1111/j.1460-9568.2005.04482.x.

Silvia, P.J., Winterstein, B.P., Willse, J.T., Barona, C.M., Cram, J.T., Hess, K.I., Martinez, J.L., Richard, C.A., 2008. Assessing creativity with divergent thinking tasks: exploring the reliability and validity of new subjective scoring methods. In: Psychol. Aesthet. Creat. Arts., 2 https://doi.org/10.1037/1931-3896.2.2.68. Article 2.

Sternberg, R.J., 1998. Handbook of Creativity, 1st ed. Cambridge University Press. https://doi.org/10.1017/CBO9780511807916.

Stevens, C.E., Zabelina, D.L., 2020. Classifying creativity: applying machine learning techniques to divergent thinking EEG data. Neuroimage 219, 116990. https://doi.org/10.1016/j.neuroimage.2020.116990.

Storme, M., Çelik, P., Camargo, A., Forthmann, B., Holling, H., Lubart, T., 2017. The effect of forced language switching during divergent thinking: a study on bilinguals' originality of ideas. Front. Psychol. 8, 2086. https://doi.org/10.3389/fpsyg.2017.02086.

Van Dijk, M., Kroesbergen, E.H., Blom, E., Leseman, P.P.M., 2019. Bilingualism and creativity: towards a situated cognition approach. J. Creat. Behav. 53 (2) https://doi.org/10.1002/jocb.238. Article 2.

Wang, M., Hao, N., Ku, Y., Grabner, R.H., Fink, A., 2017. Neural correlates of serial order effect in verbal divergent thinking. Neuropsychologia 99, 92–100. https://doi.org/10.1016/j.neuropsychologia.2017.03.001.

Wessel, J.R., Anderson, M.C., 2023. Neural mechanisms of domain-general inhibitory control. Trends Cogn. Sci. https://doi.org/10.1016/j.tics.2023.09.008. S1364661323002589.

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T., Miller, E., Bache, S., Müller, K., Ooms, J., Robinson, D., Seidel, D., Spinu, V., Yutani, H., 2019. Welcome to the tidyverse. J. Open Source Software 4 (43), 1686. https://doi.org/10.21105/joss.01686.

Wilks, C., Meara, P., 2002. Untangling word webs: graph theory and the notion of density in second language word association networks. Second. Lang. Res. 18 (4), 303–324. https://doi.org/10.1191/0267658302sr203oa.

Wilks, C., Meara, P., 2007. Implementing graph theory approaches to the exploration of density and structure in L1 and L2 word association networks. In: Daller, H., Milton, J., Treffers-Daller, J. (Eds.), Modelling and Assessing Vocabulary Knowledge, 1st ed. Cambridge University Press, pp. 167–181. https://doi.org/10.1017/CBO9780511667268.012.

Wilks, C., Meara, P., Wolter, B., 2005. A further note on simulating word association behaviour in a second language. Second. Lang. Res. 21 (4), 359–372.

Witczak, O., Krzysik, I., Bromberek-Dyzman, K., Thierry, G., Jończyk, R., 2024. Controlling stimulus ambiguity reduces spurious creative ideation variance in a cyclic adaptation of the alternative uses task. Sci. Rep. 14 (1) https://doi.org/10.1038/s41598-024-63225-2.

Wu, Y.J., Thierry, G., 2013. Fast Modulation of Executive Function by Language Context in Bilinguals. J. Neurosci. 33 (33) https://doi.org/10.1523/JNEUROSCI.4760-12.2013. Article 33.

Wu, Y.J., Thierry, G., 2017. Brain potentials predict language selection before speech onset in bilinguals. Brain Lang. 171, 23–30. https://doi.org/10.1016/j.bandl.2017.04.002.

Xia, T., An, Y., Guo, J., 2022. Bilingualism and creativity: benefits from cognitive inhibition and cognitive flexibility. Front. Psychol. 13, 1016777 https://doi.org/10.3389/fpsyg.2022.1016777.

Ye, Z., Zhou, X., 2009. Executive control in language processing. Neurosci. Biobehav. Rev. 33 (8) https://doi.org/10.1016/j.neubiorev.2009.03.003. Article 8.