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Research Article

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Abstract

Both ageing and bilingualism can have positive as well as adverse cognitive effects. We investigated their combined impact on subcomponents of attention. We used the Attention Network Task to examine alerting, orienting, executive control and task-switching costs. Group comparisons revealed age-related declines for alerting alongside benefits for executive control, for mono- and bilinguals alike. For orienting, age-related decline was more pronounced for bilinguals than monolinguals. Task-switching was unaffected by age or language group. Within bilinguals, we found limited impact of individual differences in L2 proficiency, language switching or mixing: proficiency improves orienting and decreases switch costs, for young and older bilinguals alike; but no other individual differences effects were found. Thus, attention is a multi-faceted network, with clear adverse (alerting) and protective (executive control) ageing effects. We found these to be largely similar for mono- and bilinguals, with variability within bilinguals having only limited impact.

Introduction

Ageing and bilingualism have been documented to confer a complex picture of positive and adverse effects on cognition (Donnelly et al., 2019; Ferguson et al., 2021; Guerrero et al., 2022; Veríssimo et al., 2022). Our focus in this study is on attention, a multifaceted cognitive process involving the selective concentration on salient environmental features while disregarding others. The Attention Network Task (ANT) serves as an optimal tool for examining the intricate impact of ageing and bilingualism on attention, disentangling the effects on its subcomponents: ALERTING, ORIENTING, and EXECUTIVE CONTROL. It also enables us to further examine TASK-SWITCHING EFFECTS (Fan et al., 2002). Ageing and bilingualism may impact on each of these components in different ways, possibly interacting with each other (e.g., Dash et al., 2022b, 2022a; Incera & McLennan, 2018). In this paper, we systematically investigate the effects of bilingualism and ageing on the subcomponents of attention. We acquired a large-scale dataset which allowed us to examine also individual differences within bilinguals in function of language proficiency, mixing, and switching using objective measures.

Alerting, orienting, executive control, and task switching

Attention encompasses early (alerting and orienting) and complex attentional mechanisms (executive control). Early attentional mechanisms involve the initial processing of sensory information and the selection of relevant stimuli. These mechanisms operate rapidly and automatically, allowing us to quickly orient our attention toward relevant or salient stimuli (i.e., ALERTING, ORIENTING*)*. On the other hand, complex attentional mechanisms entail higher-order cognitive processes like executive control, allowing for flexible attentional control and adaptation to changing contexts and conflicting information (Posner & Fan, 2008). Alerting, orienting, and executive control are clearly distinct and theoretically motivated functions (Fan et al., 2005). The efficiency of these functions can be examined in the ANT (Fan et al., 2002), which is a combination of the cued response time (Posner et al., 1980) and flanker task (Eriksen & Eriksen, 1974). In the attention network task, participants are presented with a central arrow pointing either left or right and asked to respond to the direction of this central arrow. The central arrow is surrounded by flankers, which can either be congruent (facing the same direction as the central arrow) or incongruent (facing the opposite direction). Preceding the onset of the arrows, participants see cues that convey temporal and/ or spatial information about the upcoming target stimuli. The CENTRE and DOUBLE cues inform about when but not where the

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stimulus will appear, whereas the SPATIAL cues inform about both temporal and spatial information of the upcoming stimulus.

Specifically, ALERTING in the ANT refers to the increase in readiness to respond after a warning signal to incoming information. Alerting performance is evaluated by calculating the response time average for no cue minus the response time average for double cue. When no cue is presented, attention is diffused between potential stimulus locations. The double cue elicits similar diffused attention, but also heightened preparedness to respond. ORIENTING refers to the ability to direct processing resources to a given location. In the ANT, orienting performance is measured by subtracting the average response time for centre cue from the average response time for spatial cue. Both cue types aid alerting, but only the spatial cue provides information that allows attention to be shifted to the upcoming stimulus location. Finally, EXECUTIVE CONTROL refers to the top-down inhibitory processing of conflicting information. The executive control effect (also known as the conflict/congruency effect) is measured by subtracting the average response time for the incongruent flanker minus the average response time for the congruent flanker (regardless of cue type). Executive control relies on detecting and resolving conflict (created by the incongruent flankers) and inhibiting the conflicting distractors (Fan et al., 2005).

The ANT is ideally suited for the study of both ageing and bilingualism. Firstly, it measures different subcomponents of attention within a single task. Secondly, this measurement relies minimally on linguistic and memory processes which could interact with group level characteristics. The ANT has been shown to have high reliability, and construct and criterion validity in older adults (Ishigami et al., 2016; MacLeod et al., 2010). Moreover, the ANT enables us to examine task-switching costs, which are particularly interesting for the language group comparisons. Task-switching costs are related to a shift in 'changing mindset' which relies on heightened cognitive resources compared to simple rule holding (Costa et al., 2008). In a switch condition (e.g., incongruent trials that are preceded by congruent trials), one must inhibit the tendency to respond in line with distractors that remain from the previous trial. This switch is more costly than when rules stay the same over consecutive trials (stay condition). The switch trials can be further divided into easy and difficult switches. Congruent trials preceded by incongruent trials are deemed to be more difficult compared to incongruent trials that are preceded with congruent trials. In the former, individuals need to overcome the strong inhibition elicited by the flankers from the previous incongruent trial, which may result in a longer response time. In the latter, there is less need to overcome inhibition of the distractors as these are not 'harmful' in the preceding congruent trial.

The impact of ageing on the attention network

Since attention comprises a range of distinct processes, one may expect a multi-faceted impact of healthy ageing. Indeed, this is what previous studies have found (see Veríssimo et al., 2022 for a comprehensive review). ALERTING efficiency decreases with age: generally, older adults are less likely to make efficient use of alerting cues to increase preparedness in the upcoming trial (Dash et al., 2019, 2022a; Gamboz et al., 2010; Jennings et al., 2007; Knight & Mather, 2013; Veríssimo et al., 2022; Westlye et al., 2011; Williams et al., 2016; Zhou et al., 2011).

On the other hand, the narrative regarding the impact of healthy ageing on ORIENTING and EXECUTIVE CONTROL in the ANT is not so clear cut (see Veríssimo et al., 2022 for a comprehensive review). Recently, Dash et al. (2019, 2022a) have shown that orienting, similarly to alerting, also decreases with age. Contrary to this, Veríssimo et al. (2022) reported that older adults are able to use the spatial cues more effectively compared to their younger counterparts (though this advantage may only hold until mid-70s). Other studies have shown lack of age-related effects on orienting (Gamboz et al., 2010; Jennings et al., 2007; Knight & Mather, 2013; Westlye et al., 2011; Williams et al., 2016; Young-Bernier et al., 2015; Zhou et al., 2011).

Moreover, previous research has shown that healthy older adults are more efficient (in comparison to young adults) at conflict resolution arising from incongruent distractors (Dash et al., 2019; Veríssimo et al., 2022; Westlye et al., 2011), suggesting age-related executive control improvements. However, this pattern is not consistent across all studies, with some suggesting the opposite (Zhou et al., 2011) and others showing no age-related effects on executive control (Gamboz et al., 2010; Jennings et al., 2007; Knight & Mather, 2013; Williams et al., 2016; Young-Bernier et al., 2015). Taken together, previous research highlights the differential impact of ageing on attentional subcomponents.

The impact of bilingualism on the attention network

Attention (and other executive functions) may be impacted also by bilingualism (see Chung-Fat-Yim et al., 2022 for an overview of bilingualism on attention and Korenar et al., 2023 on cognition more broadly). Bilinguals (compared to monolinguals) often show enhanced performance in cognitive control tasks (Bialystok et al., 2004; Costa et al., 2008; see Donnelly et al., 2019; Lehtonen et al., 2018 for reviews). The proposed underlying reason for this enhanced cognitive control is the continuous management of two languages: both languages are constantly active, creating competition/conflict. For successful communication, this conflict needs to be resolved by inhibiting the non-relevant language (Abutalebi & Green, 2007; Bialystok et al., 2009). Dual language management is thought to be centred in the domain-general attention system (Bialystok et al., 2009; see Luk et al., 2012; Wong et al., 2016). The increased demands on language processing and control systems in turn lead to changes to brain structure and function (DeLuca et al., 2019; Li et al., 2014; Pliatsikas et al., 2020; Pliatsikas & Luk, 2016) and enhanced executive control (DeLuca et al., 2020).

However, similarly to ageing, the effects of bilingualism on the subcomponents of the attention network are not so clear cut (see Arora & Klein, 2020 for a meta-analysis). Studies employing the ANT or simple flanker tasks have shown divergent results, with some indicating overall advantages for bilinguals in terms of faster response times and more efficient executive control processes. However, the literature lacks consensus on which specific attentional component confers the bilingual advantage. For example, Costa et al. (2008) found that compared to monolinguals, young adult bilinguals were faster overall, benefited more from the alerting cue, and showed more efficient executive processes. Interestingly, bilinguals also showed reduced switch costs. Tao et al. (2011) found a similar executive control benefit for both early and late bilinguals (compared to monolinguals) when nonverbal intelligence and socio-economic status were controlled for, but no effects in alerting or orienting. Others have also reported executive control benefits in bilinguals (compared to monolinguals) in the ANT, reflected in an overall RT advantage

(Desideri & Bonifacci, 2018; Perovic et al., 2023) as well as more efficient conflict resolution effects (Desideri & Bonifacci, 2018; Marzecová et al., 2013; Ooi et al., 2018). On the other hand, Markiewicz et al. (2023) found a trend towards bilinguals being overall slower in a flanker task, reflected in significantly longer response distribution tails compared to monolinguals. Across different studies that show a bilingual benefit, there is thus little consistency about which component of the attention network confers a benefit. In addition, the bilingual advantage claim remains controversial because many studies do not demonstrate benefits at all (Antón et al., 2014; Lehtonen et al., 2018; Paap, 2019; Paap et al., 2015).

The combined impact of ageing and bilingualism on the attention network

Of interest in the context of ageing and bilingualism, is the claim that you might see a more pronounced bilingual advantage in older adults, especially in more demanding tasks. It has been suggested that young adults are less likely to show performance benefits (compared to children and older adults) due to ceiling effects. For example, Bialystok et al. (2005) examined executive control differences between mono- and bilinguals across the lifespan using a Simon task. In the Simon effect, the response times tend to be slower in incongruent trials – that is, when the response location does not align with the task-irrelevant stimulus location as opposed to instances when they do match (i.e., congruent trials). Bialystok et al. (2005) found that bilinguals outperformed monolinguals in early childhood, middle and late adulthood, but performance did not differ in young adulthood (Del Maschio et al., 2018; Paap & Greenberg, 2013). In line with this is the view that mono- and bilinguals may perform similarly on the surface (i.e., behaviourally), but bilinguals achieve this seemingly similar performance with less effort. Abutalebi et al. (2012) reported that despite comparable performance in a flanker task, bilinguals use the anterior cingulate cortex (involved in conflict detection and resolution: Botvinick et al., 2004; van Veen & Carter, 2002) less than monolinguals, implying more efficient and less effortful conflict processing. Ansaldo et al. (2015) reported comparable performance on the Simon task between mono- and bilingual older adults, but with differing underlying neural substrates: older monolinguals showed the classical posterior-anterior shift associated with ageing, whereas older bilinguals did not. Thus, cognitive benefits of bilingualism could be more prevalent in older adults (leading to the claim that bilingualism confers cognitive reserve in ageing – Anderson et al., 2018, 2020, 2021; Berkes & Bialystok, 2022; Bialystok, 2021a; Craik & Bialystok, 2006).

To date, few studies have examined the combined effects of ageing and bilingualism on ANT performance. Borsa et al. (2018) tested older (47-75 years) mono- and bilinguals on the ANT and found no significant overall language group differences. However, only in monolinguals did chronological age predict executive control performance, which contributed to the authors concluding that healthy ageing affects mono- and bilinguals differently, with only bilinguals being able to mitigate age-related declines. Note that the findings of this study do not converge with the typical finding for monolinguals, which is that ageing does not confer an inhibition deficit in most tasks (Rey-Mermet & Gade, 2018). Also, Vivas et al. (2020) tested mono- and bilinguals across the lifespan (including children) on the ANT. This time, the only difference found was that there was a relationship between increasing age and global RTs in monolinguals, which was present to a lesser extent in bilinguals. Lastly, the combined effect of ageing and bilingualism on attentional subcomponents in the ANT was examined by Dash et al. (2019). They found that the older bilinguals do not take as much advantage of the warning cues as their young counterparts and are more susceptible to spatial cue distractors (i.e., age-related effects within bilinguals for alerting and orienting). We aim to add to this field by focusing our comparison on young versus older adult mono- and bilinguals and by testing a large sample, enabling us to investigate possible effects of individual variation within the bilinguals.

The importance of considering individual differences within bilinguals

It is important to remember that bilinguals are a heterogenous population and that simplistic comparisons between mono- vs. bilinguals may ignore inherent confounds (Bialystok, 2021b; Dash et al., 2022b; Rothman et al., 2022). The trajectory of brain function and structure adaptations (which ultimately may lead to performance benefits) are influenced by various aspects of language use and exposure (DeLuca et al., 2020): age of acquisition, proficiency, and factors to do with the context and nature of language use such as the frequency of language switching and code switching (i.e., see the Adaptive Control Model; Green & Abutalebi, 2013; for more details on how the linguistic environment influences the adaptation of control processes). Understanding these variations is crucial for a more nuanced interpretation of the 'bilingual advantage' or lack thereof.

Previous research suggests a commonality in the mechanisms underlying both language switching and task-switching (Costa et al., 2008). Subsequent studies have reinforced this notion, indicating that individuals who engage in frequent language switching experience reduced task-switching costs compared to those who switch languages less frequently (Prior & Gollan, 2011). Further, it might also be the case that the bilingual benefit related to task switching is only seen in the more demanding conditions, evidenced in more pronounced switch costs for monolinguals compared to bilinguals in the difficult switch condition (i.e., incongruent to congruent trials – Costa et al., 2008). Alternatively, bilinguals might be unaffected by the task switching difficulty, while for monolinguals task related switch costs are higher in the more demanding condition. The latter possibility is also related to the levels of L2 proficiency in bilinguals and the language switching evidence (e.g., Costa & Santesteban, 2004): bilinguals with low L2 proficiency show asymmetrical switching costs (i.e., it is more demanding, and thus takes more time, to switch into their dominant language from the weaker L2), whereas proficient bilinguals show symmetrical language-related switch costs. L2 proficiency has therefore been shown to modulate switching difficulties and this effect has been linked to enhanced executive control in proficient bilinguals. Novitskiy et al. (2019) tested unbalanced bilinguals using the ANT and found higher L2 proficiency was correlated with enhanced conflict resolution. Tao et al. (2011) found that late bilinguals (more balanced in proficiency and use) showed decreased conflict costs, whereas early (less balanced) bilinguals showed more efficient monitoring. Gallo et al. (2022) found that both L2 years and proficiency were beneficial for performance on incongruent trials in a flanker task (but not congruent trials), with proficiency modulating the relationship between cognitive reserve and executive control in ageing. Note however there is also ample evidence that proficiency

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does not affect executive control measures in young (Paap et al., 2014; Von Bastian et al., 2016) and older participants (Mishra et al., 2019); though there was a positive relationship between L2 proficiency and orienting. Taken together, the available findings provide a complex picture which suggests that high proficient and less proficient bilinguals may have different language control mechanisms (Costa & Santesteban, 2004; Costa et al., 2006).

The present study

The aims of the present study are two-fold. First, it aims to investigate individual and combined effects of healthy ageing and bilingualism on attention processes. Young and older English monolingual and Norwegian–English bilingual participants completed the ANT providing measures for alerting, orienting, executive control and task-switching. Healthy older adults (compared to young adults) are generally predicted to show worse performance, which in the ANT we expect to observe as general slowing and decreased alerting and orienting effects (Dash et al., 2019). Alongside this age-related decline, specific age-related improvements in executive control can be expected (Veríssimo et al., 2022). In terms of the language group comparisons, young bilinguals may outperform young monolinguals in the ANT outcomes, particularly in executive control (Costa et al., 2008). Additionally, given that task-switching relies on enhanced cognitive resources compared to simple rule holding, we may also expect young bilinguals to outperform young monolinguals on switch trials, particularly on the harder switches (Costa et al., 2008). Furthermore, we hypothesise that bilinguals may show less decline with age than monolinguals.

The second aim of the study is to examine how individual differences in language switching and mixing skills and L2 proficiency predict possible bilingual advantages in alerting, orienting, executive control and (non-verbal) task-switching. It is not straightforward to quantify these individual differences variables, which are often based on self-reported language history questionnaires. Our approach here is to use objective measures of proficiency (through an L2 vocabulary task) and language switching/mixing (through a language switching task) – similar approaches have been taken by others (e.g., Prior & Gollan, 2011). We may expect greater L2 proficiency to be linked with enhanced executive control in the ANT (e.g., Dash et al., 2022a; Gallo et al., 2022; Novitskiy et al., 2019; Tao et al., 2011). Further, we may expect a positive relationship between L2 proficiency and alerting in the older but not young bilinguals (Dash et al., 2019). Language switching and mixing cost (whether modulated by L2 proficiency) may also be predictive of the ANT scores.

Methods

Participants

The data for this study were collected as part of a larger project (fab-study.com) that was publicly registered on OSF (see https://osf.io/d7aw2/ for a description of all measures which were part of the project). The dataset consists of English monolinguals, (collected at the University of Birmingham) and Norwegian–English bilinguals (collected at the University of Agder). The study was approved by the Science, Technology, Engineering, and Mathematics (STEM) Ethical Review Committee at the University of Birmingham (ERN_20-1107) and the Regional Committee for Medical and Healthcare Research Ethics in Norway (REK sør-øst C, ref. 163931).

The monolingual participants were native speakers of British English who did not have any advanced knowledge of another language. They indicated they were unable to hold a simple conversation in a second language and that English was the only language spoken at home. We based bilingual participant inclusion on the following criteria: (i) Norwegian was the first acquired language or Norwegian and English were the two first languages acquired simultaneously; (ii) Norwegian was the dominant language and English was the second most dominant language; (iii) participants' self-rated speaking as well as reading proficiency in English was at least 3 on a 0-10 scale with 0 being "none" and 10 being "perfect" (collected using the Language Experience and Proficiency Questionnaire LEAP-Q; Marian et al., 2007)

Young monolinguals received either monetary compensation or course credit compensation for their participation. All other participants received monetary compensation. All older participants completed the Montreal Cognitive Assessment (MOCA; Nasreddine et al., 2005) and were excluded if they scored <23/30 (as per Carson et al., 2018). All participants in the reported sample achieved a score ≥23. All participants had normal or corrected-to-normal vision and gave informed consent.

For the group comparison part of the study, we rely on ANT data from a matched sample of 40 adults per group (i.e., 160 participants). However, due to technology-related data-loss, group comparisons analyses were performed using data from slightly smaller groups. The matched sample that the analyses were carried out on included: 40 young English-speaking monolinguals (age range 18-35, M age = 23.08, SD = 5.27, 20 females), 38 young Norwegian–English bilinguals (age range 19-30, M age = 23.03, SD = 2.72, 25 females), 37 older English-speaking monolinguals (age range 65-81, M age = 69.68, SD = 4.02, 20 females), and 37 older Norwegian–English bilinguals (age range 66-80, M age = 69.92, SD = 3.76, 16 females). Young monolinguals and bilinguals did not differ significantly in age (Welch Two Sample t-test, $t = -0.13$, df = 58.02, $p = 0.89$), nor did older monolinguals and bilinguals ($t = 0.72$, df = 77.94, $p = 0.48$).

Analyses of individual differences within bilinguals (the effects of proficiency, switching and mixing) are conducted with all available bilingual datapoints collected as part of the larger project (80 young bilinguals and 139 older bilinguals). From these, we use all available data (ANT, language switching and language proficiency task; for each of these some data-loss occurred due to technical difficulties), corresponding to 71 young bilinguals (M age = 22.39, SD = 2.57, 41 females) and 119 older bilinguals (M age = 68.47, SD = 5.86, 72 females).

Procedure

Older participants completed the MOCA. All participants completed the Attention Network Task (ANT). Bilingual participants also completed the language switching, and language proficiency tasks. Please note, as explained above, the data were collected as part of a larger project which is described in full and pre-registered on OSF.

Materials

Attention Network Task (ANT)

The ANT is a computerised task that allows assessment of orienting, alerting and executive control. The stimulus is a row of five arrows, each pointing left or right. Participants are asked to report, using the left and right arrow keyboard keys, in which direction the centre arrow points. They are asked to do this as fast and accurately as possible.

During each trial (Figure 1), a fixation cross is displayed for 400ms before a stimulus appears. Then a fixation cross (500ms) and cue (no cue, spatial, central, or double) are presented simultaneously. The cue stays on screen for 100ms, whereas the fixation cross continues for 400ms after the cue has disappeared. Once the fixation has elapsed, a target (congruent, neutral, or incongruent) is shown for a maximum of 1700ms or until a response is detected. The response window starts and finishes with the presence of the target.

The centre arrow can be congruent (i.e., pointing in the same direction as the flankers, N = 96), incongruent (i.e., pointing in the opposite direction to the flankers, N = 96) or neutral (i.e., central arrow flanked by target-irrelevant black blocks, N = 96). Moreover, the arrows can appear above or below the fixation cross and can either be cued by a black square (N = 216) or not cued (N = 72). There are four cue conditions: a spatial cue (i.e., the cue appears either above or below the fixation cross, N = 72), a centre cue (i.e., the cue appears in the centre of the screen, N = 72), a double cue (i.e., the cue appears both above and below the fixation cross, N = 72) or no cue (only the fixation cross appears on the screen, N = 72). Only the spatial cue provides information about where the stimulus will appear (above or below the fixation cross). For the centre and the double cue, the location of the upcoming stimuli remains ambiguous.

Participants complete 12 practice trials followed by three blocks of 96 trials (total of 288 trials). Feedback is only given during the practice trials. The task took approximately 10 minutes to complete. Only correct responses were analysed.

ALERTING is measured by subtracting the double cue response time from the no cue response time. ORIENTING is measured by subtracting the spatial cue response time from the centre cue response time. Executive control is measured by subtracting the congruent target response time from the incongruent target response time. Thus, high alerting and orienting scores and low executive control scores indicate better performance.

The ANT also allows us to further examine executive control – namely, TASK RELATED SWITCHING. The overall STAY condition is the mean RT of trials (either congruent or incongruent) that are preceded by the same trial type, whereas the overall SWITCH condition is the mean RT of trials (either congruent or incongruent) that are preceded by a different trial type (i.e., congruent into incongruent or incongruent into congruent). Following Costa et al. (2008), the direction of the switch may influence language group differences, therefore we further split switch trials depending on their difficulty (i.e., switch from congruent into incongruent is considered easier than switch from incongruent into congruent). Note that the neutral trials are disregarded in this context. The overall switch cost is measured by subtracting the stay response time from the switch response time. The easy switch cost is measured by comparing the switch into incongruent response time to the incongruent stay response time. The hard switch is measured by comparing the switch into congruent response time to the congruent stay response time.

Language switching

Bilingual participants named pictures of simple, non-cognate, objects (e.g., *castle, woman, cucumber*) in their first (Norwegian, L1) or second (English, L2) language as indicated by the colour of a squared frame around the picture (red for Norwegian and blue for English). There were 4 switching blocks of 30 trials (24 experimental items and 6 fillers), with an equal number of switching trials (change from L1 to L2 or L2 to L1) and stay trials (stay within the same language). The switching blocks were preceded, as well as followed, by two single-language blocks of 30 trials (Norwegian first, English second). There were two sets of 24 experimental pictures, with half of the participants viewing one set, and the other half, the other set.

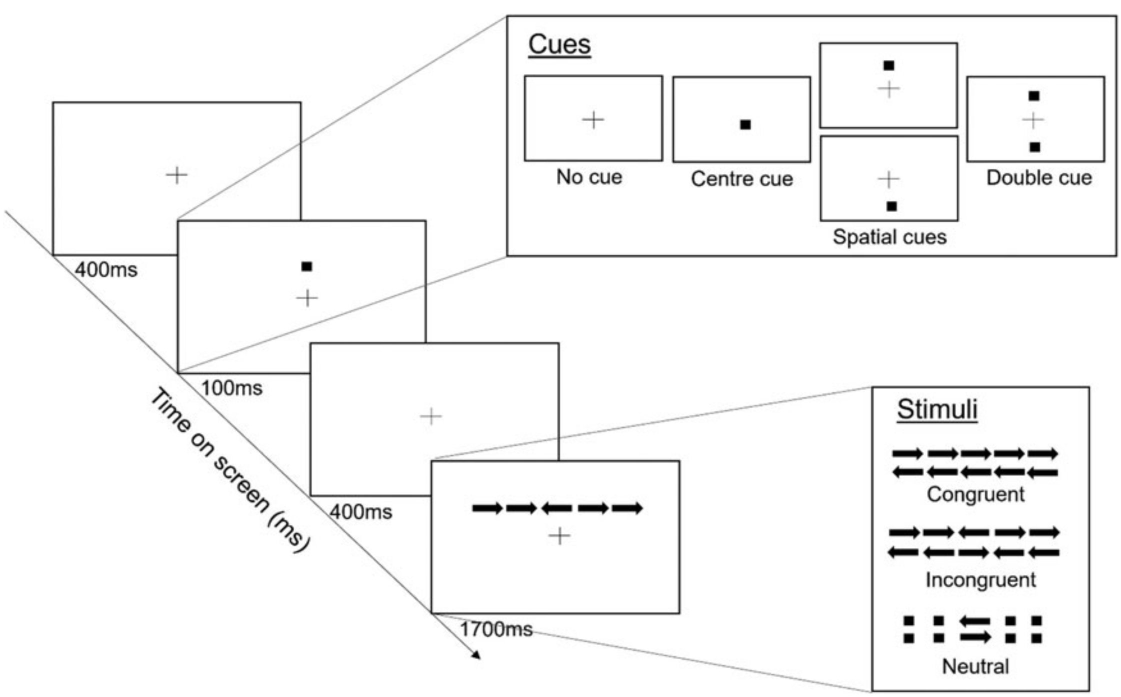

Figure 1. Schematic representation of the trial sequence of the ANT. The example represents an incongruent trial.

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Each trial started with a 50ms beep and a central fixation cross which appeared for 500ms, followed by a blank screen for 500ms. Then the picture was shown, and the voice key was activated. The picture stayed on screen until 600ms after speech offset. The experimenter then started the next trial. In the switching blocks, each experimental item occurred once per block, in a different condition in each block. Each block contained a similar number of items in each condition. We created four lists per picture set, to rotate switching-block order across participants. This task took 20 to 30 mins to complete. Only bilingual participants completed this task (on a different testing day from the ANT).

We calculated the average reaction time (RT) cost of switching into L1 and of switching into L2 separately. Switch costs from L2 to L1 (hereafter referred to as L1 SWITCH COSTS) were calculated by computing the mean RT for each condition (i.e., L1 switch and L1 stay) and deriving the difference between them (switch L1 minus stay L1). The same procedure was applied to calculating the RT switch costs from L1 to L2 (hereafter referred to as L2 switch costs).

Further, we also calculate the RT mixing cost for L1 and L2 separately. The mixing cost for L1 is the mean RT difference between the RT in L1 (Norwegian) stay trials and RT in L1 single language trials. The mixing cost for L2 is as above but for L2 (English) trials.

Language proficiency

Bilingual participants completed a vocabulary task in English (their L2). Participants are presented with non-cognate stimulus words for which they had to select either a synonym (15 trials) or an antonym (15 trials) between four options (target word plus three foils). The order of presentation of synonym and antonym blocks was randomized. This task took about 5 mins to complete, and the data were collected online (on a different day from data-collection for the ANT and language switching task). We used percentage of correct responses, computed for each participant, as the individual measure of proficiency.

Data analyses

All data cleaning and preparation procedures were conducted using in-house Python scripts. Data analyses were conducted in R (R Core Team, 2021). All scripts alongside the raw, cleaned, and merged datafiles are available on our OSF research project page: https://osf.io/d7aw2/

Attention Network Task (ANT)

Prior to carrying out any analyses, we cleaned each individual data set as follows. We first removed any incorrect trials (N = 15.17, SD = 20.79 for the *matched participant* data set, and N = 12.96, SD = 17.00) for the *full set of bilinguals*). We then removed outliers (<200ms and >1500ms) and responses that were 2SD below and above of the mean per participant of the following conditions: congruent, incongruent and neutral. The accuracy rate prior to removing incorrect responses for the *matched participant data set* was on average 94.73% with SD = 7.22%: young monolinguals 92.77% (SD = 8.73%), older monolinguals 96.62% (SD = 6.07%), young bilinguals 95.18% (SD = 6.67%), and older bilinguals 94.51% (SD = 6.71%); whereas for the full set of bilingual participants (*for individual differences analysis)* accuracy on average was 95.50% with SD = 5.90% (young bilingual participants 95.78% (SD = 5.61%) and older bilingual participants 95.33% (SD = 6.09%). The number of removed trials per participant for the MATCHED PARTICIPANT data set was on average 27.67 (SD = 20.79). The number of removed trials per participant for the full set of bilingual participants (FOR INDIVIDUAL DIFFERENCES ANALYSIS*)* was on average 26.44 (SD = 18.01).

As we were interested in RT data and the older adults are generally slower on the ANT compared to the young participants across all conditions, we first calculated the transformed proportion scores of the RTs. This was suggested by Faust et al. (1999) who proposed that transformed proportion RTs per condition will account for potential group differences in response latency in task effects. Similar approaches have also been used previously in the ageing ANT literature (Fernandez-Duque & Black, 2006; Gamboz et al., 2010). The transformed proportion scores were calculated by dividing, for each participant and restricted to correct trials, the mean RTs in each condition by the overall mean RT (the conditions were: congruent, incongruent, no cue, double cue, centre cue, spatial cue, and overall stay, stay (congruent), stay (incongruent), overall switch, switch into incongruent, switch into congruent). We then used these transformed proportion scores to derive the alerting, orienting, and executive control effects as well as task-switching costs (overall, easy, and hard). Note that similar logic was also applied to the language switching RTs.

Language switching

Each individual data set was cleaned prior to carrying out analyses as follows. We first removed any incorrect trials. We then removed outliers (<200ms and >2500ms) based on inspection of data distribution. We next removed responses 2SD below and above of the mean per participant of the following conditions: switch and stay (regardless of L1 and L2) and single language conditions (L1 and L2). The accuracy rate prior to removing incorrect responses for the young participants was 96.04% (SD = 4.36%), and for the older participants 86.49% (SD = 11.29%). Instead of using raw RTs in the analyses (see Suppl. Table 1 for raw RTs), we again calculated transformed proportions of RTs to account for age-related differences in response latencies for each condition (L1 and L2 switch, L1 and L2 stay, L1 and L2 single language). The transformed proportion of the L1 and L2 stay and switch trials was calculated by dividing each condition mean RT by the overall mean RT of all collapsed stay and switch conditions (L1, L2 switch and stay), whereas the transformed proportion of the L1 and L2 single language trials was calculated by dividing each condition mean RT by the overall mean RT of all collapsed single language conditions. These were then used to derive the L1 and L2 switch costs – L1 (or L2) switch minus L1 (or L2) stay – and mixing costs – L1 (or L2) stay minus L1 (or L2) single language.

Language proficiency

The language proficiency score in L2 for the young bilingual participants was 43.15% on average (SD = 15.47%, max = 80%, min = 13.33%), and for the older bilingual participants was 34.31% on average (SD = 13.82%, max = 86.67%, min = 6.67%).

Overall analysis approach

For matched group comparisons, we examined group differences using a 2 (Age group: older vs. young) x 2 (Language status:

bilinguals vs. Monolinguals) analysis of variance on ANT performance (transformed proportion of RTs) for each ANT component separately (Alerting, Orienting, and Executive control) as well as task-switching (*Overall* switch cost: switch vs. stay, *Easy* switch cost: switch into incongruent vs. Incongruent stay, and *Hard* switch cost: switch into congruent vs. congruent stay). Any significant age x language status interactions were followed up by independent samples t-tests.

To investigate individual difference effects within the bilingual sample of proficiency, switching and mixing, we used our full sample of bilingual participants and conducted a backward multiple regression analysis. At each step, variables were chosen based on a p-value threshold of .05. Data are reported only for variables that remained in the final model with a significance threshold of $p < .05$. We identified significant predictors of Alerting, Orienting, Executive control, overall switch cost, easy switch cost and hard switch cost (in separate sets of models) out of the following candidate variables: main effects of age group, L2 language proficiency, L1 switch cost, L2 switch cost, L1 mixing cost and L2 mixing cost alongside interactions between age group and each of these individual difference variables.

Results

Group comparisons between young and older mono- and bilinguals

Group comparison findings are illustrated in Figures 2 and 3.

Alerting

There was a significant main effect of Age group on the Alerting score, $F(1,148) = 22.483$, $p < .001$, $\eta^2 = .13$, 95% CI [.06, 1.00], indicating a larger alerting score (i.e., better performance) in the young group compared to the older group (Figure 2, left panel). There was no main effect of Language Status ($p = .79$), and no interaction between Age group and Language Status ($p = .16$).

Orienting

There was a significant main effect of Age group on the Orienting score, $F(1,148) = 30.63$, $p < .001$, $\eta^2 = .17$, 95% CI [.09, 1.00], indicating a larger orienting score (i.e., better performance) in the young group compared to the older group. There was also a significant interaction between Age group and Language status on the Orienting score, $F(1,148) = 9.36$, $p = .002$, $\eta^2 = .06$, 95% CI [.01, 1.00], (Figure 2, middle panel). Post-hoc independent samples t-tests revealed that: (1) within monolinguals, the orienting score was larger – although merely a trend – in the young group compared to the older group, $t(75) = 1.831$, $p = .071$, $d = .42$, 95% CI [-.04, .87]; (2) within bilinguals, the orienting score was significantly larger in the young group compared to the older group, $t(73) = 5.93$, $p < .001$, $d = 1.34$, 95% CI [.86. 1.87]; (3) within the young group, the orienting score was smaller, again, merely a trend, in the monolinguals compared to bilinguals $t(76) = -1.93$, $p = .059$, $d = -.44$, 95% CI [-.89, .02]; and finally (4) within the older group, the orienting score was larger in the monolinguals compared to the bilinguals, $t(72) = 2.55$, $p = .013$, $d = .59$, 95% CI [.13, 1.06].

Thus, for orienting, age-related decline was more pronounced for bilinguals than monolinguals.

Executive control

There was a significant main effect of Age group on the Executive control score, $F(1,148) = 15.687$, $p < .001$, $\eta^2 = .10$, 95% CI [.03, 1.00], indicating a larger executive control score (i.e., worse performance) in the young group compared to the older group. There was no main effect of Language Status ($p = .12$), and no interaction between Age group and Language Status ($p = .53$).

Overall switch cost

There was no main effect of either age group, $F(1,148) = .00$, $p = .99$ or language status, $F(1,148) = .016$, $p = .90$ on the overall switch cost. There was no interaction between Age group and Language status ($p = .367$).

Easy switch cost

There was no main effect of either age group, $F(1,148) = .59$, $p = .44$ or language status, $F(1,148) = .45$, $p = .50$ on the easy switch cost. There was also no interaction between Age group and Language status ($p = .87$).

Hard switch cost

There was no main effect of either age group, $F(1,148) = .18$, $p = .68$ or language status $F(1,148) = 1.64$, $p = .20$ on the hard

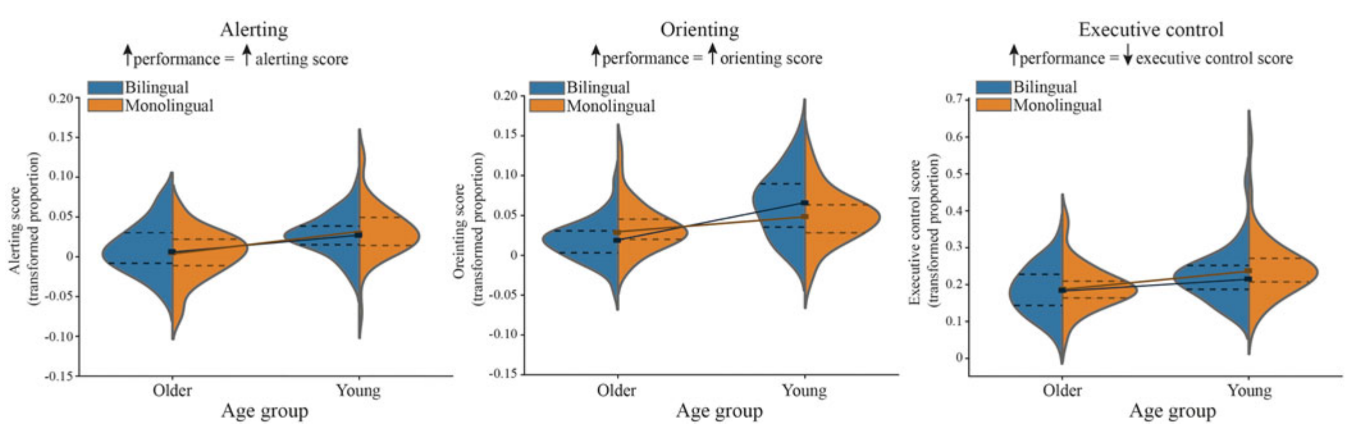

Figure 2. Distributions and means of transformed proportion of Alerting (left panel), Orienting (middle panel) and Executive control (right panel) from the ANT per age group (older vs. younger) and language status (bilingual in blue, and monolingual in orange). The squares within the violin plots represent the average transformed proportion effect, the dashed lines represent the quartiles of the distribution. Larger Alerting and Orienting scores indicate better performance, whereas smaller Executive control scores indicate better performance.

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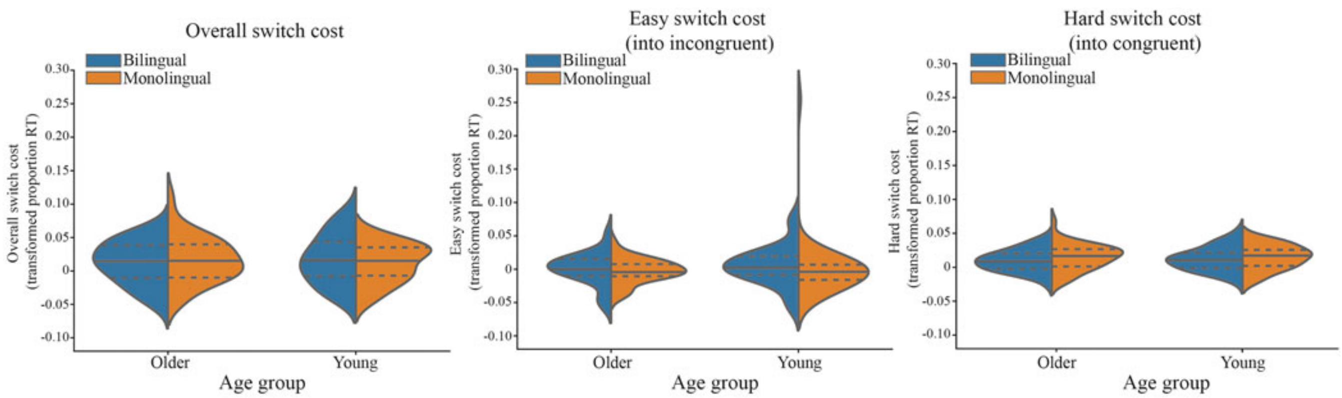

Figure 3. Distributions and means of transformed proportion of Overall switch cost (left panel), Easy switch cost (middle panel) and Hard switch cost (right panel) from the ANT per age group (older vs. younger) and language status (bilingual in blue, and monolingual in orange). The solid lines within the violin plots represent the average transformed proportion RT, the dashed lines represent the quartiles of the distribution. Note that there were no significant differences between the age groups or language status on any of the outcome measures. We depicted switch costs (i.e., condition differences) to be internally consistent with the ANT outcome variables – we would like to refer those readers who would like to see individual conditions (and compare to Costa et al. (2008)) to the supplemental materials (and Suppl. Fig. 1).

switch cost. There was also no interaction between Age group and Language status ($p = .66$).

Individual differences within bilinguals

Individual differences within bilinguals' findings are illustrated in Figure 4.

Alerting

The reduced model was statistically significant, $R^2 = .044$, $F(1,187) = 8.506$, $p = .004$, and revealed that alerting was significantly predicted by age group ($\beta = -.209$, $p = .004$).

Orienting

The reduced model was statistically significant, $R^2 = 2.81$, $F(2,186) = 36.257$, $p < .001$, and revealed that orienting was significantly predicted by age group ($\beta = -.475$, $p < .001$), and by L2 proficiency ($\beta = .134$, $p = .04$), indicating that the greater the L2 proficiency, the greater the orienting score.

Executive control

The reduced model was statistically significant, $R^2 = .048$, $F(1,187) = 9.436$, $p = .002$, and revealed that executive control was significantly predicted by age group ($\beta = -.219$, $p = .002$).

Overall switching cost

The reduced model was not statistically significant ($p = .09$), overall switching cost was not predicted by any of the variables.

Easy switching cost

The reduced model was not statistically significant ($p = .114$); overall *easy* switching cost was not predicted by any of the variables.

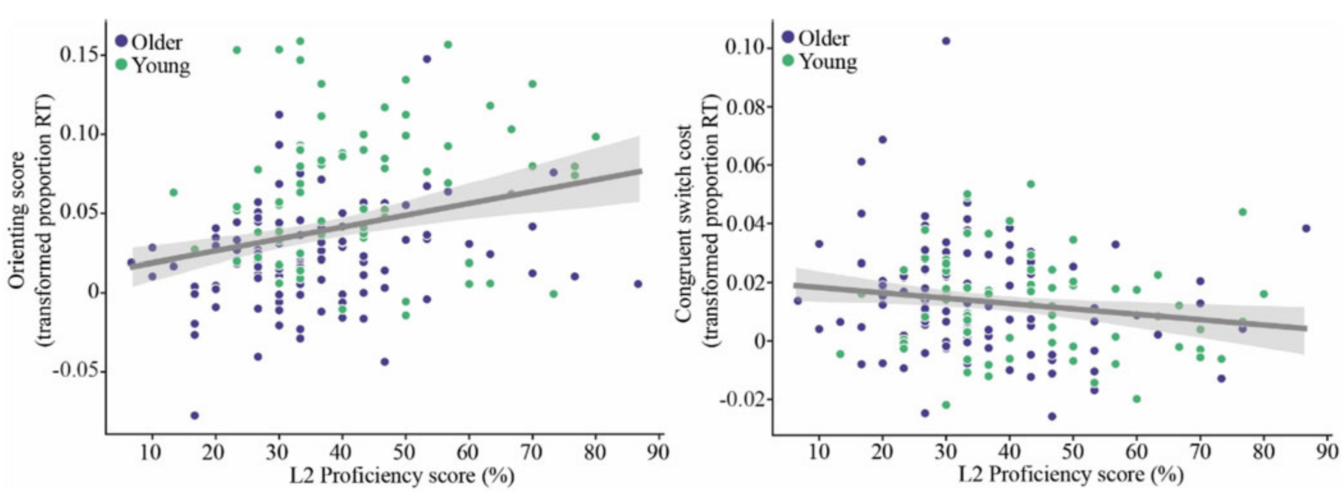

Figure 4. *Left panel*: The relationship between L2 proficiency score (%) and orienting score (transformed proportion). Findings showed that larger L2 proficiency was associated with larger Orienting Scores, irrespective of group. *Right panel:* The relationship between L2 proficiency score (%) and congruent switch cost (transformed proportion). Findings showed that larger L2 proficiency was associated with smaller switch cost (into congruent). Each dot represents individual participant data with the older group in purple and young group in green. Note that the data are split by group for illustrative purposes only. The regression line is fitted based on ungrouped data.

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Hard switching cost

The reduced model was statistically significant, R^2 =.024, F (1,187) = 4.638, $p < .03$, and revealed that *hard* switching cost was significantly predicted by L2 proficiency ($\beta = -.156$, $p = .03$), indicating that the greater the L2 proficiency, the smaller the *hard* switching cost.

Discussion

The current study investigated the combined impact of bilingualism and ageing on subcomponents of attention (alerting, orienting, and executive control) and task-switching, using the ANT. We further examined the impact of individual differences within bilinguals on these functions using objective measures of language proficiency (L2 vocabulary), language switching and mixing costs (L1 and L2 switch and mixing costs). In monolinguals, we found that healthy ageing decreased performance in alerting, we found no age-related effects in orienting (merely a trend in favour of the young participants), and found that executive control performance improved with age. Bilinguals showed very similar age-related changes as the monolinguals in both alerting and executive control, with the former decreasing and the latter increasing with age. The picture was more complex for orienting: being a bilingual speaker seemed to boost orienting performance in the young individuals (although again, merely a trend), but to impede orienting performance in the older adults. In other words, bilinguals showed age-related decline in orienting which was more pronounced than for the monolinguals. We found that neither age group nor language status influenced task-switching effects. Effects of individual differences in function of L2 proficiency, switching and mixing were limited. L2 proficiency was predictive of orienting and hard task-switching in (both older and young) bilinguals: higher L2 proficiency was related with larger orienting skills (i.e., more efficient use of spatial cues to direct attention) and negatively linked with hard task-switching cost (i.e., reduced switch costs for switch vs. stay in congruent trials). We will now discuss these findings in more detail.

Age decreases alerting (and orienting) but increases executive control performance in monolinguals

Given the multifaceted nature of attention, it is unsurprising that the current study found a mixture of age-related decline, preservation and improvement in the ANT outcomes. In this section, we discuss our findings for monolinguals (findings on bilinguals are elaborated on in the next section).

In line with previous studies (Gamboz et al., 2010; Jennings et al., 2007; Kaufman et al., 2016), we found that alerting skills decrease with age. Older individuals are less efficient at using alerting cues to prepare them for incoming information. This effect has previously been assigned to age-related decreased levels of noradrenaline (Zhou et al., 2011). The reduced alerting effect in older adults is further supported by EEG evidence (Kaufman et al., 2016): older adults have a reduced N1 alerting effect which explains the lack of facilitation that should arise from the cue. Note, though, that this is inconsistent with Fernandez-Duque and Black (2006) who found enhanced alerting with age and proposed that older adults use a more conservative response strategy overall, and therefore the alerting cue benefits them more.

Similarly, for orienting, we found that performance generally declines in older adults (shown via the significant main effect of age group), although this was merely a trend within our monolingual participants. This is in line with Dash et al. (2019), who has also shown reduced ability to use spatial cues to direct attention in older adults compared to young participants (albeit for bilinguals). On the other hand, the lack of age-related changes in orienting has also previously been shown (Fernandez-Duque & Black, 2006; Jennings et al., 2007; Zhou et al., 2011) and it is often concluded that older individuals benefit from spatial cues to direct their attention to the target just as much as young individuals do.

Furthermore, we found enhanced executive control in older compared to young adults, again in line with previous studies (Veríssimo et al., 2022; Westlye et al., 2011; Young-Bernier et al., 2015). However, note that Veríssimo et al. (2022) found a non-linear age-related change, with decreases in performance only visible in those over 76 years of age; representation of the oldest-old may not have been large enough in our sample to see the executive control benefit be eliminated or reversed. Rey-Mermet et al. (2018) highlighted the importance of more fine-grained scrutiny of different forms of inhibition (i.e., resistance to distractor conflict, measured via flanker-like tasks; vs. the inhibition of pre-potent responses, measured in tasks such as stop-signal tasks). They concluded that resistance to distractor conflict is enhanced with healthy ageing whereas inhibition of pre-potent responses declines with healthy ageing. Our finding of age-related increased executive control supports this hypothesis, as the ANT encompasses a flanker paradigm as its component measuring inhibition. This also further strengthens the argument that attention is a multifaceted mechanism and the age-related change trajectory for each component of these networks is different.

Bilinguals show similar age-related changes in alerting and executive control to monolinguals, but more pronounced age-related declines in orienting

Age-related changes in the alerting and executive control component were identical and of a similar size for bilinguals and monolinguals: just like monolinguals, older bilinguals showed increased performance in alerting, and decreased performance in executive control (compared to their younger counterparts). Our findings for monolinguals, which are in line with the literature, extend to the bilingual population: healthy ageing holds detriments, as well as benefits, for the attention networks.

The lack of language group differences between mono- and bilinguals for alerting and executive control could be ascribed to the type of bilinguals that our sample consisted of. In Norway, it is quite typical for most of the population to be proficient in both Norwegian and English. Many of the bilinguals in our sample could thus often function as 'dense code switchers', whereby the speakers intertwine the two languages in one conversation or even single utterance. In this case, our findings are in line with the Adaptive Control Model (Green & Abutalebi, 2013), which states that dense code switchers have an increased demand for opportunistic planning only, and no other control processes such as interference control, or selective cue detection, which were of interest in the current study. Our findings are also consistent with some previous studies (e.g., Antón et al., 2014; Paap & Greenberg, 2013) that did not find differences in how monolinguals and bilinguals performed in ANT and flanker tasks – although see, for example, Costa et al. (2008), who found clear bilingual benefits in alerting and executive functions.

On the other hand, for orienting, while the monolinguals did not show a significant change with age (the decline was merely a

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trend), the bilinguals did show significant age-related decline. The detriment of age for orienting skills was thus more pronounced for bilinguals than monolinguals. This is a novel and interesting finding, especially when considering that young bilinguals showed better orienting scores compared to the young monolinguals. This bilingual advantage seems not to be retained in older age.

Alerting, orienting and executive (inhibitory) control are each supported by functional networks that are (at least partially) non-overlapping (Fan et al., 2005; Niogi et al., 2010; Westlye et al., 2011) and associated with different processing mechanisms (Petersen & Posner, 2012; Posner et al., 2006; H. Wang et al., 2004). Alerting is associated with fronto-parietal cortical activation and activation of the thalamus, orienting is linked to activity in the left and right superior parietal lobe, and executive control is reflected in the activity in the anterior cingulate and right and left frontal areas (Fan et al., 2005). In our study, we only assessed the potentially interacting impacts of ageing and bilingualism using performance as an outcome variable. Evidently, even when there are no effects demonstrated on a performance variable, it is still possible that different functional neural mechanisms are bringing about this seemingly similar performance. In fact, both in the ageing and the bilingualism literature, this is a common observation (e.g., Carter et al., 2023; Markiewicz et al., 2023). In future studies, it may therefore be interesting to investigate the functional neural mechanisms subserving ANT performance in the context of the impact of both bilingualism and ageing.

No task-switching differences between bilinguals and monolinguals

We also examined the impact of age and bilingualism in task-switching costs. We found typical switching costs in the overall and *hard* conditions but not in the *easy* condition (i.e., faster RT on stay vs. switch trials; see supplementary material). However, task-switching (overall, easy, or hard) was not affected by age group or language status. As suggested by Costa et al. (2008) the mechanisms underlying language switching are similar to those that drive task-switching. Therefore, we expected monolinguals to be more affected by task-switching costs compared to bilinguals and this effect to be more pronounced for *hard* switches. Our lack of language group differences in task-switching is consistent with our above suggestion that our bilingual sample consisted mostly of dense code switchers. For dense code switchers, instead of the language schemas being in constant competition with each other (as in the single and dual language contexts), there is a co-operative relationship between them. Therefore, dense code switchers may be more similar to the monolingual group in the context of language and task-switching. Our results are also in line with Ramos et al. (2017) who found no improvement in the switch costs (in a colour-shape switching task) amongst older adults who undertook a language learning course for a year. However, our results are inconsistent with Calabria et al. (2015) who found an age-related difference in switch costs in a shape-colour task across bilingual speakers, with the switch cost being more pronounced in the elderly compared to young adults. Further, our results are inconsistent with the inhibitory control advantages related to lifelong bilingualism. For example, Gold et al. (2013) found that older bilinguals switched more efficiently in a colour-shape switching task compared to their monolingual counterparts. This behavioural advantage was present alongside the lesser activation of frontal brain regions associated with effortful processing.

Individual differences in the bilingual sample

In addition to group comparisons for matched sets of mono-and bilinguals, we also examined individual variability within a larger sample of bilinguals. We investigated whether and how individual differences in bilingual experience predicted attention, orienting, executive control and task-switching in the ANT. This aim is in line with many previous papers who called for moving this research field from binary comparisons (mono- vs. bilingual) to more of a continuum of bilingualism (Bialystok, 2021b; Poarch & Krott, 2019; Rothman et al., 2022). However, it is often difficult to accurately assess switching behaviour in bilinguals' everyday language use. We opted therefore for objective experimental measures of language switching, mixing and L2 proficiency.

Firstly, we found that neither language switch costs nor mixing costs were predictive of any attention subcomponent outcomes in the ANT. Local switch costs are thought to reflect the ability to inhibit task-relevant instruction from a previous trial and shift the mindset, adapt and respond to the new task rule (Monsell, 2003). Global switch costs reflect the working memory capacity to constantly hold both task rules and monitor for any demand changes related to switching (Los, 1996). Our null finding is inconsistent with previous research – for example, Q. Wang et al. (2022) found that switch cost positively related to cognitive control (using a Simon task) in low but not high proficient bilinguals, whereas mixing cost was positively related to cognitive control in high but not low proficient bilinguals. Q. Wang et al. (2022) thus demonstrated a shift on the dependency of language control from local to global cognitive control with the development of L2 in bilinguals. This pattern of results is consistent with studies that have shown: (1) significant relationships in language switching and cognitive control in unbalanced or less proficient bilinguals (Declerck & Grainger, 2017); (2) no relationship between language switching and cognitive control in proficient bilinguals (Calabria et al., 2012; Timmer et al., 2019; also in line with our findings); (3) relationships between mixing and cognitive control in more proficient bilinguals (Jylkkä et al., 2021; Prior & Gollan, 2013; Timmer et al., 2019; opposite to our findings); and (4) no relationship between language mixing and cognitive control in less proficient bilinguals (Jylkkä et al., 2018; Segal et al., 2019). Given that the sample of bilinguals who participated in the present study was relatively proficient in their L2, we thus expected to see reliance on general language control for domain general cognitive control (i.e., for the mixing cost to be predictive of executive control), which was not supported by the data.

Secondly, we found that L2 proficiency is a key determiner of both orienting performance and the hard switch costs. It was somewhat surprising that out of all ANT outcomes, we found orienting to be predicted by L2 proficiency. It has previously been shown that higher L2 proficiency is related to more efficient executive control and enhanced conflict monitoring (Gallo et al., 2022; Tao et al., 2011). However, these studies used self-reported language background questionnaires to assess L2 proficiency (whereas we used an experimental task). In contrast, Mishra et al. (2019) examined L2 proficiency using a mixture of objective semantic and vocabulary tests as well as a language background questionnaire and found that L2 proficiency was linked to orienting performance in older adult participants (though, note that their Bayesian t-test favoured the null hypothesis). Therefore, it may be that self-reported measures and objective tasks for L2 proficiency yield different results. On the other hand, consistent with our results (but using self-reported proficiency measures), Mishra

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et al. (2012) also found that highly proficient bilinguals were more effective at disengaging their attention from non-relevant spatial cues compared to less proficient bilinguals. This further supports the finding of a relationship between L2 proficiency and orienting in the current study.

Furthermore, the current study found that L2 proficiency predicted task-switching costs in the *hard* condition (not the overall or *easy* switch costs). As suggested before by Costa et al. (2008) language switching and nonverbal switching share similar control mechanisms. Individuals with higher proficiency in their second language were better or more efficient at 'mind shifting' and reconfiguring their executive control mechanisms to respond to the switch from incongruent to congruent trials (*hard* switch). Although in our study the mono- versus bilingual group comparisons on task related switching were not significant, it seems that L2 proficiency does modulate (in a faciliatory fashion) some aspects of switching behaviour within bilinguals. This finding underpins the importance of combining group comparisons with an individual differences approach. Taken together, highly and less proficient bilinguals may have different language control mechanisms (Costa & Santesteban, 2004; Costa et al., 2006) which in turn aids their task-switching abilities.

Although the bilingual sample in our study is relatively proficient, it is important to note here that there is still a high degree of variability within the L2 proficiency scores (which is what allowed us to carry out the individual differences analysis). Our bilingual sample showed asymmetry in language switching potentially suggesting that they were not as proficient in L2 as they were in L1. This asymmetry is shown via the longer RTs for L1 switching vs. L2 switching. Costa et al. (2008) showed that less proficient bilinguals take more time to switch from the weaker L2 into the more dominant L1 (in line with Goldrick & Gollan, 2023; Gollan & Ferreira, 2009). Perhaps future studies could include bilinguals who do not show these asymmetrical costs, hence are more proficient. In addition, our objective language proficiency measure of vocabulary depth admittedly captures a limited aspect of language proficiency. It is therefore possible that other aspects of language proficiency, related to more active aspects of language use, such as grammatical skills, speech fluency, or even frequency of L1/L2 switching (Verreyt et al., 2016) may underpin switching behaviour. Language proficiency is multi-faceted, and more research is required to understand its intersect with cognitive control.

Conclusion

Based on findings from the present study, we can conclude that healthy ageing leads to declines as well as improvements in the different subcomponents of attention. The impact of healthy ageing is network-specific: attention, orienting and executive control should be seen as separate components. We showed adverse effects of ageing on alerting and protective effects of ageing on executive control, which are in line with previous studies. The impact of combined impact of bilingualism and ageing on the attention networks is less clear-cut: the age-related declines for alerting, and benefits for executive control, were demonstrated for mono- and bilinguals alike; for orienting, the age-related decline was more pronounced for the bilinguals than monolinguals. There has been a call for the bilingualism field to move away from binary group comparisons (Bialystok, 2021b; Rothman et al., 2022) to understand the specific characteristics of bilinguals that may lead to differences. Our study aimed to do exactly that, but we found limited impact of language switching, mixing and proficiency on the attention network. Through looking at individual variability within bilinguals and relating it to specific outcomes with the attention and executive control network, we can learn what the characteristics are of those bilinguals who are going to differ from monolinguals the most.

Supplementary Material. For supplementary material accompanying this paper, visit https://doi.org/10.1017/S1366728924000154

Data availability. The materials used in the study and the data that support the findings of this study are openly available on OSF at https://osf.io/d7aw2/

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