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Implicit Motivation Makes the Brain Grow Younger: Improving Executive Functions of Older Adults

By

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Implicit Motivation Makes the Brain Grow Younger:

Improving Executive Functions of Older Adults

Research article

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Abstract

The dominant view of cognitive aging holds that while controlled processes (e.g., working memory and executive functions) decline with age, implicit (automatic) processes do not. In this paper we challenge this view by arguing that high-level automatic processes (e.g., implicit motivation) decline with age, and that this decline plays an important and as yet unappreciated role in cognitive aging.

Specifically, we hypothesized that due to their decline, high-level automatic processes are less likely to be spontaneously activated in old age, and so their subtle, external activation should have stronger effects on older (vs. younger) adults. In two experiments we used different methods of implicitly activating motivation, and measured executive functions of younger and older adults via the Wisconsin Card Sorting Test. In Experiment 1 we used goal priming to subtly increase achievement motivation. In Experiment 2 motivation was manipulated by subtly increasing engagement in the task. More specifically, we introduce the Jerusalem Face Sorting Test (JFST), a modified version of the WCST that uses cards with faces instead of geometric shapes. In both experiments, implicitly induced changes in motivation improved older- but not younger- adults' executive functioning.

The framework we propose is general, and it has implications as to how we view and test cognitive functions. Our case study of older adults offers a new look at various aspects of cognitive aging. Applications of this view to other special populations (e.g., ADHD, schizophrenia) and possible interventions are discussed.

Keywords: cognitive aging; motivation; executive functions; task engagement; goal priming

Advancing our understanding of cognitive aging is a key theoretical challenge for the cognitive and brain sciences. Like the study of every special population, studying older adults holds two promises. First, improved understanding of cognitive aging will reflect back on our theories and understanding of human cognition more generally. It will allow us to better understand human cognition. Second, it will allow improved understanding of cognitive aging, and will help us better cope with the associated social and monetary challenges, that are expected to dramatically increase in the coming decades (Kinsella & Wan, 2009; Ortman, Velkoff, & Hogan, 2014; Vincent & Velkoff, 2010).

The dominant view of cognitive aging holds that consciously controlled processes decline with age (Craik & Salthouse, 2008; Gazzaley, Cooney, Rissman, & D'Esposito, 2005; Hasher, Lustig, & Zacks, 2007; Park et al., 2002; Sorel & Pennequin, 2008), whereas implicit, automatic processes do not (Chauvel et al., 2012; Hoyer & Verhaeghen, 2006; Jennings & Jacoby, 1993; Park, 2000; Peters, Hess, Västfjäll, & Auman, 2007; Queen & Hess, 2010). Here we challenge this view on theoretical grounds, and report findings that suggest that the current view should be modified.

Crucial to our argument is the distinction between low-level automatic processes such as perception and associative memory, and high-level automatic processes such as executive functions, goal pursuit, and rule-based computations over abstract symbols (Hassin, 2013). This relatively new distinction is based on the accumulation of evidence in cognitive and social psychology, as well as in cognitive and social neurosciences. This evidence suggests that even high-level functions that were traditionally associated with conscious awareness can occur automatically, outside of conscious awareness (e.g., Bargh, Gollwitzer, Lee-Chai, Barndollar, & Trötschel, 2001; Custers & Aarts, 2010; Hassin & Sklar, 2014; Hassin, 2013; Hassin, Bargh, Engell, & McCulloch, 2009; Kleiman & Hassin, 2013; Lau & Passingham, 2007; Sklar et al., 2012; Soto, Mäntylä, & Silvanto, 2011; van Gaal, Ridderinkhof, van den Wildenberg, & Lamme, 2009).

The present proposal concurs with the modal view in suggesting that low-level automatic processes are relatively immune to aging. The disagreement lies in the area of high-level automatic processes, where we propose that aging *does* matter. High-level automatic processes, we argue, may decline with age.

The rationale behind the current proposal is simple. Non-conscious, automatic high-level cognitive processes such as goal pursuit and inhibition are functionally similar to their conscious counterparts (Hassin, 2013; Hassin & Sklar, 2014). There is also evidence to suggest that they occur in roughly the same brain areas (Lau & Passingham, 2007; Pessiglione et al., 2007; Ursu, Clark, Aizenstein, Stenger, & Carter, 2009; van Gaal & Lamme, 2012; van Gaal, Scholte, Lamme, Fahrenfort, & Ridderinkhof, 2011).

Conscious high level functions are known to be affected by age-related biological changes in relevant brain areas, and tend to deteriorate with aging (Head, Snyder, Girton, Morris, & Buckner, 2005; Nyberg & Salami, 2010; Raz, 2000). Given the similarities described above, we see no reason to assume that the non-conscious counterparts would not deteriorate with age too. Put in more technical terms, the principle of parsimony suggests that we should hypothesize no differences between the two types of processes and, therefore, that we should hypothesize age-related decline in high-level automatic processes.

The Aging of Executive Functions

As we succinctly alluded to above, the prevalent understanding of cognitive changes in old age is based on the widely adopted distinction between two separate processing systems: one that is deliberate, slow, effortful, and mostly conscious, and one that is automatic, quick, effortless, and mostly unconscious (Craik & Bialystok, 2006a; Morewedge & Kahneman, 2010). The distinction between two processing systems appears in the literature in various forms (for reviews see Chaiken & Trope, 1999; Evans & Stanovich, 2013; Sherman, Gawrsonski, & Trope, 2014; however, see Keren & Schul, 2009, for a critical review), and for ease of communication we will henceforth refer to them as automatic vs. controlled[1]. Aging, holds the modal view, leads to a slow decline of controlled processes, whereas automatic processes remain relatively intact (Campbell, Zimerman, Healey, Lee, & Hasher, 2012; Craik & Bialystok, 2006a; Hess, Waters, & Bolstad, 2000; Liu & Park, 2004).

Since executive functions (EFs) are tightly associated with controlled processes, the modal view predicts that they decline with age. And indeed, a large and growing body of research finds evidence for age-related deficits in EFs. These include working memory capacity (Bopp & Verhaeghen, 2005), planning (Sorel & Pennequin, 2008), response inhibition (Troyer, Leach, & Strauss, 2006), and task management (Craik & Bialystok, 2006b; for a reviews see Park & Reuter-Lorenz, 2009; Phillips & Henry, 2008; Salthouse, Atkinson, & Berish, 2003). The changes in EFs are associated with underlying neurobiological developments, namely, the disproportionate age-related loss of frontal brain volume (Head et al., 2005; Raz, 2000).

The decline in EFs is assumed to underlie age-related difficulties in various domains such as memory (Clarys, Bugaiska, Tapia, & Baudouin, 2009),

[1] The dual process/system metaphor is likely to be too coarse for many fine-grained analyses of cognition (Kahneman, 2011). We use it as an approximation that allows easier communication.

understandings of others' beliefs and intentions (Phillips et al., 2011), social biases (Krendl, Heatherton, & Kensinger, 2009), and daily activities such as managing money (Vaughan & Giovanello, 2010) or even walking (Holtzer, Wang, Lipton, & Verghese, 2012). Specifically, it is widely accepted that age related decline can be found in the cognitive flexibility and shifting (Rhodes, 2004), the two executive functions on which we focus here (see Verhaeghen, 2011 for a different perspective on age-related changes in a subset of EFs).

Motivation and Executive Functions

Conscious EFs are difficult and effortful functions. Performing them, therefore, depends on how much one is willing to invest; namely, on one's motivation (Heitz, Schrock, Payne, & Engle, 2008; Krawczyk, Gazzaley, & D'Esposito, 2007). Motivation – in real-life situations as well as in laboratory tests – can be recruited either in a deliberate and controlled manner or automatically, in response to internal and environmental cues. To take an example, recent studies that tested younger adults' EFs found improvement in performance as a function of monetary incentives, both consciously perceived (Savine, Beck, Edwards, Chiew, & Braver, 2010) and subliminally presented (Capa, Bustin, Cleeremans, & Hansenne, 2011).

In daily life the difference between controlled and automatic motivation would be the difference between having to remind yourself that picking up your granddaughter from daycare is a good idea for everyone involved, and simply wanting to do it after seeing a picture of your granddaughter on your desk. In recent years many studies tested – and found evidence for – the idea that motivation and goal pursuit can be primed and then operate outside of conscious awareness (for reviews see Custers & Aarts, 2010; Dijksterhuis & Aarts, 2010; Hassin, 2013).

Recent findings suggest a unique role for motivation in cognitive aging. It has been suggested that older adults become less interested in spending effort on tasks that they perceive as less relevant to achieving their personal goals, and that they are therefore less likely to deliberately recruit motivation for some tasks (Braver et al., 2014; Carstensen, 2006; Hess, 2014). Accordingly, motivation-boosting manipulations (e.g., providing mainly positive rather than negative information in a decision making task) were recently presented as potentially promising strategies to promote better performance among older adults (Strough, de Bruin, & Peters, 2015). However, data on the effectiveness of subtle motivational manipulations in older adults is still largely lacking

The Current Research

Building on the general proposal outlined above, we suggest that automatic recruitment of motivation – a high-level automatic function (Braver et al., 2014; Fishbach & Ferguson, 2007) – declines with age. In other words, we propose that older adults are less likely than younger adults to automatically recruit motivation.

Given this hypothesized deficiency, and given that EFs are inherently motivational (Capa et al., 2011; Pessoa, 2009; Savine et al., 2010), our proposal predicts that older adults should fare worse on EF tasks. As we succinctly reviewed above, there are ample data to support this prediction. But the present proposal goes beyond predicting this well-established result. It suggests that "nudging" automatic motivation into action should have a stronger effect on older vs. younger adults – simply because the latter recruit it more easily and spontaneously.

Put differently, automatic-motivation recruitment declines with age, and hence happens less frequently in older adults. Thus, boosting automatic motivation should have stronger effects on older (vs. younger) adults, thereby reducing what seems today to be an inescapable age gap in EFs.

We report two experiments in which we either boost automatic motivation or not, and we then measure EFs of younger and older adults. In both experiments we use a gold standard measure of EFs, the Wisconsin Card Sorting Test (Heaton, Chelune, Talley, Kay, & Curtiss, 1993); see *Materials*) . Boosting motivation was done in two different ways. First, we used a goal-priming procedure that has been widely used in the past (Bargh et al., 2001; Fishbach, Friedman, & Kruglanski, 2003; Hassin, Bargh, & Zimerman, 2009; Kleiman & Hassin, 2013; Rim, Min, Uleman, Chartrand, & Carlston, 2013, but see Klein et al., 2014; Open Science Collaboration, 2015). In this procedure, motivation is primed in a first, “unrelated” task, via the priming of words that are related to this motivation. Participants then go on to do a second, allegedly unrelated task. The second way to subtly boost motivation is by increasing engagement in the task (Higgins & Trope, 1990; Higgins, 2006). Increasing engagement makes the task more motivationally relevant, thereby recruiting more motivation (Eitam & Higgins, 2010).

In line with our reasoning above, in both experiments we hypothesized an interaction, such that the motivation manipulations would improve performance of older adults more than it would improve performance of younger adults.

Experiment 1

Experiment 1 examines the effects of achievement priming on the performance of older and younger adults on the WCST. We predicted that the motivation manipulation would have stronger effects on older (vs. younger) adults.

Method

Participants and design. Forty-four older adults (26 female, 18 male; Mean age = 69.17) and 42 younger adults (14 female, 28 male; Mean age = 19.78) participated in this experiment (see Table 1). The older adults were community-dwelling, recruited through leaflets we distributed in public places or through the mail. The younger adults were Hebrew University students who received course credit for their participation. The participants received monetary compensation of 20 New Israeli shekels (NIS; approximately $5). The design was a 2 (Motivation: Low vs. High) x 2 (Population: Younger vs. Older adults), and participants were randomly assigned to one of the two conditions of the study (High vs. Low motivation).

Procedure and materials. Participants were told that they were about to take part in two different experiments (Bargh et al., 2001). The "first experiment" was in fact the priming manipulation, in which participants were asked to find 13 words in a word search. In this task participants were presented with a 10 × 10 matrix of letters, below which appeared a list of 13 words that were embedded in the matrix. In the goal-priming condition, 7 of these words were associated with achievement (ambitious, aspiration, competition, excellence, first, race, and win). In the control condition, these words were replaced by motivationally neutral ones (carpet, diamond, farm, hat, table, topaz, and window). In addition, each list contained the same set of 6 neutral words (chair, stamp, building, lamp, tree, and blue). Participants were instructed to take as much time as they needed to find all the words in their list.

After finishing the word-search task participants were thanked and went on to the "second experiment" – the WCST. Participants sat in front of a computer screen on which they saw four key cards. They were told that a single card would appear in the center of the screen on each trial, and that their task was to try and match that card to one of the four key cards (see Fig. 1a). Following the traditional instructions of the WCST participants were not informed about how to sort the cards, but they were instructed that they would be given feedback on every trial. We used a computerized version of the 128 cards WCST (Heaton et al., 1993). There were three possible sorting rules: color (red, green, blue, or yellow), number (1, 2, 3, or 4), or shape (circle, cross, star, or square). Following each trial participants received visual feedback (i.e., RIGHT or WRONG appeared on the screen). The sorting category (e.g., color) remained the same until the participant correctly performed 10 consecutive sortings. Then, the sorting rule changed (e.g., to number). Participants were unaware that the sorting criterion could (and would) change. Participants were instructed to take as much time as they needed for this task.

The two most commonly reported scores of the WCST are *Completed categories* (the number of classification categories the participant successfully completes) and *Perseverative errors* (the number of trials in which participants sort according to a rule that is no longer in effect). Both measures are highly correlated with other measures of EFs (Heaton et al., 1993; Lezak, 1995; Spreen & Strauss, 1998), and significantly decline with age (Rhodes, 2004). Another WCST measure that declines with age is the *Overall correct* score (the number of correctly sorted cards). We report this measure too.

After they completed the task participants were asked to fill out a questionnaire that assessed their awareness of the relations between the “two experiments” (word search and WCST), as well as their motivation to do well. Finally, participants were debriefed and thanked.

Results

Awareness and explicit motivation. Upon completion of the WCST participants were thoroughly debriefed in order to assess their awareness of the structure, hypotheses, and purposes of the study.

Participants were asked specific questions that assessed awareness of the experimental manipulation and intentional (controlled) changes in performance. None of the participants suspected that the two tasks were related, or that the first task may have affected their performance of the second. Participants also filled out a measure of conscious motivation: they were asked to specify how important it was for them to do well on the task, on a scale that ranged from 1(not at all) to 9 (extremely important). There were no differences in conscious-achievement motivation between the two older adults' groups ($M_{control}$=7.84, $SD_{control}$=1.18; $M_{motivation}$=7.87, $SD_{motivation}$= 1.02; $t(40)=0.80$, $p=0.93$). Due to a technical failure, we do not have these data for the younger group. Asking people about their phenomenology is always tricky. Decades of research has taught us that we have limited access to the workings of our minds (Nisbett & Wilson, 1977). There is also evidence suggesting that asking participants to rate their level of motivation may not always be predictive of performance, or the sole predictor of performance (Bargh et al., 2001; Hassin et al., 2009; Kleiman & Hassin, 2013). Yet, it is the simplest and most straightforward measure of conscious motivation, and hence a main tool for assessing motivation.

Exclusion criteria. Given that performance on the WCST may indicate cognitive impairment, to which older adults are susceptible, we adopted a strict criterion: participants whose perseverative-error rate exceeded that of their age group in more than one standard deviation were excluded from the analyses. Seven older adults were excluded (six from the control condition). Also excluded were 5 older adults who did not complete even one category (4 from the control group). Using a more lenient criterion and excluding subjects whose performance deviated more than 2 SDs from the mean does not change the nature of the results (see Appendix A1;A2).

WCST performance. Supporting our hypothesis, a 2 X 2 ANOVA revealed a significant Age x Motivation interaction on the number of categories completed ($F_{1,70}$= 4.82, $p<0.05$, ηp^2=0.064), and a marginally significant interaction on correct sortings ($F_{1,70}$=3.49, p=0.06, ηp^2=0.048). The interaction on perseverative errors only approached significance ($F_{1,70}$= 2.51, p=0.11, ηp^2=0.035). A repeated measures analysis with the three measures as a within-subject factor[2] revealed a marginally significant Age x Motivation interaction ($F_{1,70}$= 3.62, p=0.06 , ηp^2=0.049). (See Appendix A2).

When looking at each age group separately, an independent t-test revealed that goal priming significantly improved the performance of older adults on all three measures: participants in the primed group correctly sorted more cards (M=95.80 , SD = 10.31 vs. M=83.29, SD=10.29), t(30)= 3.42, p< 0.005; made less perseverative errors (M=17.00, SD =6.77 vs. M=23.41, SD=5.67), t(30) =-2.91, p<0.01; and completed more categories (M=6.53, SD =2.44 vs. M=4.11, SD=1.79), t(30)= 3.20, p<0.005. In line with our hypothesis, the trends among younger adults were similar, yet weaker, and none of the reported measures improved significantly as a result of priming (see Fig. 2; Appendix A1).

Discussion

As hypothesized, achievement priming affected performance on the WCST, and this effect was more pronounced in older adults. Motivation priming, then, significantly narrowed the cognitive gap between younger and older adults. In fact,

[2] The scale of perseverative errors was reversed (-1) to fit the other two scales.

primed older adults were not significantly different from younger adults in the control group on all measures [*Number of categories completed*: $t(35)=-.84$, $p>0.4$; *Number of correct sortings*: $t(35)=-.54$, $p>0.5$; *number of perseverative errors* $t(35)=1.08$, $p>0.2$][3].

Since the performance of younger adults was better even in the control conditions, one may be tempted to suggest that our results stem from a ceiling effect in the younger adult group. However, there are two good reasons to think otherwise. First, given the participants' level of performance, it seems unlikely. Participants' performance is very similar to the norms for their age (Heaton et al., 1993), and the norms are just that: they reflect normal performance, not an outstanding (ceiling) one.

For the sake of the argument, however, let us assume that this is indeed a ceiling effect. The view that we propose here is that while performance on EF tasks reflects "basic" ability, how much of this ability is used is a function of implicit and explicit motivation (this view is supported by the EF literature that was reviewed in the Introduction; (Heitz et al., 2008; Krawczyk et al., 2007; Savine et al., 2010)). To say that younger adults are at ceiling is to say that they recruited all of the possible explicit and implicit motivation (that one recruits in laboratory situations). But this is in line with our main point: younger adults automatically and easily recruit all of their available motivation. Older adults do not, and hence priming helps them more. This argument leaves open the idea that the documented effect originates from differences in conscious motivation. Put differently, one may suggest that older participants are simply less motivated to perform well, and hence consciously and strategically recruit fewer resources (Hess, 2014). Such a difference would indeed explain our results.

[3] While our results are stronger for *categories completed* than for of *perseverative errors*, it is important to note that these two measures are highly correlated and often load on the same factor (Boone, Pontón, Gorsuch, González, & Miller, 1998). In addition, both are commonly and equally used in cognitive aging studies and as measures of executive abilities or frontal integrity (Rhodes, 2004).

Note, however, that older participants come to the laboratory with ardent conscious motivation. They volunteer. Come from afar. Take the time to do so. They want to feel and know that they are doing well. This burning conscious motivation is reflected in their motivation ratings (M=8.03 on a scale that ranges from 1(not at all) to 9 (extremely important to do well in the task)). Crucially, there are no differences in motivation between the control and primed groups (p=0.60). Thus, conscious motivation does not seem to be able to explain the stark difference in performance between the two groups.

Experiment 2

Experiment 2 is a conceptual replication of Experiment 1, with a novel manipulation of motivation. In Experiment 2 motivation was manipulated by subtly increasing engagement in the task (Higgins, 2006). To do so, we modified the WCST and used pleasant faces instead of abstract geometric shapes. Other than replacing the geometric shapes with pleasant faces, the two tasks were identical (Fig. 1b). We call this task the Jerusalem Face Sorting Test, or JFST.

Method

Participants and design. Sixty-three older adults (43 female, 20 male; Mean age = 69.20) and 89 younger adults (52 female, 37 male; Mean age = 23.46) participated in this experiment (see Table 1). We added measures of years of education for all participants, and older participants were additionally screened for cognitive impairment using the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975). The younger adults were Hebrew University students who received course credit for their participation; the older adults were community-dwelling who were recruited through an ad we posted in a local newspaper. All the participants received monetary compensation of 20 New Israeli shekels (NIS; approximately $5).

The design of Experiment 2 was a 2 [Motivation: Low (WCST) vs. High (JFST)] x 2 (Population: Younger vs. Older adults), and participants were randomly assigned to one of the conditions of the study.

Procedure and materials. Participants were told that they were about to take part in a computerized card game. Half of the participants were presented with the WCST, exactly as it is described in Experiment 1. The other half of the participants were presented with the Jerusalem Face Sorting Test (JFST). The JFST is identical to WCST in all but one feature: we replaced the original WCST shapes with four faces (Fig. 1b). The three sorting principles remained shape (identity of the face), color (of the shirt), and number (of faces on the card). The JFST is identical to the WCST in its instructions, number of cards, card order, number of ambiguous cards, procedure, and scoring.

For both the WCST and the JFST, no special instructions about the nature of the task or the sorting principles were given (Heaton et al., 1993). Participants were instructed to take as much time as they needed for this task. After they finished sorting 128 cards the task ended and the participants were debriefed and thanked.

Results

Awareness and explicit motivation. Upon finishing the task participants were asked whether they understood the structure and goals of the experiment. None of the participants reported the true goal or any suspicions regarding the experimental manipulation. Participants were also asked to specify how important it was for them to do well on the task on a scale from 1 to 9, thereby assessing explicit motivation. There were no differences in conscious achievement motivation as a function of priming, both among the older group (M_{WCST}=7.36, SD=1.47; M_{JFST}=7.09, SD=2.03, $p > 0.5$), and among the younger group (M_{WCST}=7.29, SD=1.16; M_{JFST}=7.41, SD=1.38, p > 0.5). In addition, there were no differences in conscious achievement motivation between older and younger adults ($M_{younger}$=7.35, SD=1.27; M_{older}=7.22, SD=1.78, p > 0.5), or between the WCST and JFST conditions (M_{WCST}=7.32 , SD=1.29; M_{JFST}=7.27, SD=1.69, p > 0.5).

Exclusion criteria. We used the same exclusion criteria as in Experiment 1, and participants whose perseverative-error rate exceeded that of their age group in more than one standard deviation were excluded from the analyses4. Thirteen older adults were excluded from the analysis due to a high number of perseverative errors (4 participants from the low-motivation condition and 9 from the high-motivation condition), and 3 younger adults were excluded (2 from the control condition and 1 from the engaging condition). In addition we excluded participants who did not complete any category during the task (2 participants, both from the low-motivation condition). Analyses with less strict criteria – 2 SDs above group mean for number of perseverative-errors (see Experiment 1) – do not change the pattern of the results, although significance levels slightly change (see Appendix B1;B2).

Task performance. A 2 (Age: Young vs. Old) X 2 (Motivation: JFCT vs. WCST) ANOVA revealed a marginally significant Age x Motivation interaction on categories completed ($F_{1,129}$= 3.08, p=0.08, ηp^2=0.023). The interaction on perseverative errors and number of correct sortings did not approach significance. Repeated measures with all three DVs as one within-subject factor did not reveal a significant Age x Motivation interaction ($F_{1,129}$=1.06, p=.30, ηp^2=0.008). (See Appendix B2).

Looking on each age group separately, an independent sample t-test revealed that, for the older adults group, the performance on the JFST was better than in the WCST:

[4] In this experiment we collected MMSE scores for the older participants. None of our participants scored below 24 which is the accepted cut-off point for this test (Lezak, Howieson, & Loring, 2004). However, we did not use MMSE as our sole exclusion criteria because it does not evaluates executive functioning, but rather serves a rough screening tool for dementia.

participants made fewer preservative errors ($t(46) = -2.02$, $p < 0.05$) and they completed more categories ($t(46) = 2.45$, $p < 0.05$). Improvement on number of correct sorting was marginally significant ($t(46) = 1.86$, $p = 0.069$). In line with our hypothesis, the trends among the younger group were similar but weaker, and none of the reported measures was significantly improved by JFST (see Fig. 3, Appendix B1).

Discussion

As hypothesized, engagement manipulation moderately affected performance on the WCST, and this effect was more pronounced in older adults. Although the effects here are weaker than those of Experiments 1, they suggest, too, that implicitly boosting motivation narrows the gap between younger and older adults executive performance. It is important to highlight that there is no knowledge about the faces that could have helped participants perform the task. This is important, because age deficits may often be compensated for by knowledge or experience (i.e., crystallized intelligence; (Umanath & Marsh, 2014) – but neither could have contributed to the results.

Since the two experiments tested the same hypothesis using complementary methodologies, and since our results were not strong, we combined their data to increase power**.**

Joint Analysis of the Two Experiments

When analyzing data from two experiments jointly, A 2 (Age: Younger vs. Older adults) X 2 [Motivation: Low (control/WCST) vs. High (achievement priming/JFST)] X 2 (Experiment: 1 vs. 2) ANOVA revealed a significant interaction between Age and Motivation on *number of categories completed* ($F1,199 = 7.59$, $p < .01$, $\eta p2 = 0.037$), and a marginally significant interaction on *perseverative errors* ($F1,199 = 2.88$, $p = 0.09$, $\eta p2 = 0.014$) and *number of correct sortings* ($F1,199 = 3.56$, $p = 0.06$,

$\eta p2=0.018$).[5] Repeated measures analysis, with the 3 measures as one within-subject factor, revealed a significant Age x Motivation interaction ($F1,199 = 4.15$, $p <0.05$, $\eta p2=0.20$). (See Appendix C2).

Focusing just on older adults, the independent samples t-test revealed that motivation improved performance on all measures: correct sorting [$t(78)= 3.38$, $p < 0.005$]; perseververative errors [$t(78) = -3.36$, $p < 0.005$], and categories completed [t (78) =3.91, $p < 0.005$]. The trends among younger adults were similar and weaker, and none of the reported measures reached significance, all p's > .=0.1. When we use the more lenient criterion and exclude subjects whose performance deviated more than 2 SD from the mean (see Experiments 1 and 2) the nature of the results for older adults does not change, and younger adults show significant improvement in the number of perseverative errors following motivation manipulation (see Appendix C1).

We also used the combined data to examine the effects of the motivation manipulation on conscious motivation. As expected, explicit motivation was high overall (M=7.42, SD=1.44, on a scale from 1(no motivation) to 9 (extremely high motivation)). A set of t-tests revealed that there were no differences in conscious achievement motivation as a function of priming both for the older group ($M_{control}$ = 7.58, SD = 1.35; $M_{motivation}$= 7.34, SD =1.79, $p > 0.4$) and for the younger group ($M_{control}$ = 7.29 , SD = 1.16; $M_{motivation}$= 7.41, SD = 1.38, $p > 0.5$)[6]. In addition, there were no differences in conscious achievement motivation between older and younger groups ($M_{younger}$= 7.35, SD=1.27; M_{older}=7.47, SD=1.57, $t(187)=0.56$, $p > 0.5$), nor

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[5] This analysis also revealed a significant main effect for age on all measures (all ps < .001), and a significant main effect for motivation manipulation (all ps <.01). No other significant effects were found. See Appendix D.

[6] Due to a technical failure, explicit motivation reports were not collected for the younger group in Experiment 1 (see Results of Experiment 1, Section 3.1).

between control and primed conditions ($M_{control}$= 7.46, SD= 1.28; $M_{motivation}$= 7.38, SD = 1.60, t(187) = 0.39, p > 0.5).

These data strongly suggest that there were no differences in conscious motivation, and hence that conscious motivation cannot explain the robust differences in performance between the experimental and control conditions.

General Discussion

In sum, results from two experiments supported our hypothesis that priming motivation has stronger effects on older vs. younger adults. The modal theories of aging generally hold that automatic processes do not decline with age. We proposed here that this view should be updated, and that high-level automatic processes do decline with age. The findings from two experiments support our predictions. This paper, then, paves the way for new approaches to understanding cognitive aging, in all areas of cognition. It poses the challenge of trying to figure out whether automatic or controlled components deteriorate with age, and how.

While the effect sizes were indeed small to moderate, they replicated across two different manipulations, and were also significant in a meta analysis. It is important to note that we propose a subtle, non-invasive manipulation that can modestly improve older adults' performance on the WCST- an executive functions measure that consistently shows a decline with age (Rhodes, 2004). Importantly, it is interesting to note that using the international norms of the WCST, priming seems to have shed approximately 10 years from our older participants, not a negligible effect in any way.[7]

This theoretical advancement proposed here should help us significantly cope with old age and improve our interventions, by more accurately targeting those abilities

[7] We used the Heaton et al. (1993) norms, adjusted to the version we used of the WCST in which the task ended only when the participant finished sorting all 128 cards.

that diminish with age. Efforts of cognitive training for the elderly are mainly focused on training of the "basic" ability (Miller et al., 2013; Owen et al., 2010; von Bastian, Langer, Jäncke, & Oberauer, 2013). Our results may suggest, for example, that designing the environment of older adults in ways that will more easily trigger motivation may be very helpful (Stine-Morrow et al., 2014).

But the framework suggested here is not confined to older adults. In a way, older adults are just a case study for a much broader perspective: we propose that in order to understand human behavior, broadly defined, we need to understand how automatic high-level processes develop, function, change, and decline.

One intriguing question for future research would be to explore relevant clinical populations with the tools we used here. Schizophrenic patients, for example, suffer from dysfunction of the dorsolateral prefrontal cortex (DLPFC) and parahippocampal region, as well as from poor working memory performance (see Dreher et al., 2012). Another interesting population in this context is ADHD patients. In fact, preliminary data (Yishayahu & Pollack, 2012) demonstrate that achievement priming (similar to that used in Experiment 1) significantly affects the performance of children diagnosed with ADHD. Further investigation in this direction might reveal other populations that can benefit from boosting implicit motivation.

Before turning to discuss an alternative explanation of our results, let us just highlight that we propose here a new tool for cognitive scientists at large. The JFST can be downloaded from our website (http://labconscious.huji.ac.il/), in the hopes that differences between JFST and WCST will help us better understand cognitive and motivational processes.

Limitations

The reported study has few limitations that we wish to discuss here. First, both experiments compared community-dwelling older adults with undergraduate students. Given the nature of the different group such comparison might include cohort effects. It is important to note that this is the common practice in cognitive aging research, and it has many advantages (i.e., compared to longitudinal designs which are highly expensive and time-consuming, cross-sectional studies such as ours allows focused investigation of specific question in a relatively quick and affordable process). To avoid cohort effects we attempted to control for demographical factors such as education, economic and health status. On all measures, when we found group differences they showed difference favoring the older group (older adults were more educated, reports better health condition and were better well-off). Such age differences are unlikely to account for a reasonable alternative explanation to our data. In fact, improving performance of the older (advantageous) but not the younger group implies that our manipulation does not rely on factors such as years of education, financial status or physical shape

Second, while the experimental manipulations improved older adults' performance, their effects on younger adults was more limited; it only reached significance in one measure (perseverative errors) in the second experiment. This finding may conflict with a previous findings of our group, which show improved performance in WCST as a function of achievement priming (Hassin et al., 2009). It is hard to know what to make of this failure. One alternative is that our previous finding was a fluke. Yet, it might simply be a power issue, and there are also differences between these studies that might have mattered (e.g., population of students, their age, language, and so on). It is important to note that this (almost) failure in replication does not change the nature of our findings: using a very subtle manipulation we did find- as hypothesized- improved performance for older more than younger adults, suggesting that the older population can benefit more from such implicit manipulations.

Third, One may argue that the results simply suggest that high-level automatic motivational processes *improve* with age (for a similar argument regarding low-level priming see Dew & Giovanello, 2010; Gopie, Craik, & Hasher, 2011). Put simply, we report that priming and subtle motivational manipulations work better with older adults, and hence one possible conclusion might be that automatic processes *improve* with age. While this is a viable possible interpretation, it seems to us un-parsimonious and less likely than our interpretation. We reviewed ample evidence for age-related decline in high-level processes such as EFs and working memory (see Introduction; see also Bopp & Verhaeghen, 2005; Braver & West, 2008; Sorel & Pennequin, 2008). We see no reason to assume that one family of functions (non-conscious EFs) will improve with age, whereas a very similar family (conscious EFs) will diminish. This idea is also rendered implausible by the general biological changes that the brain undergoes in aging. Note that although this question is crucial for our theories of aging, it is less crucial for building a translational science that will improve the well-being of older adults.

Conclusions

We suggested that a distinction between high- and low-level automatic processes is likely to improve our understanding of human behavior, broadly defined. This view suggested that our current understanding of cognitive aging should be significantly updated. We reported two experiments with results that indeed challenge the modal view of cognitive aging. They lend support to the idea that automatic, high-level processes decline with age, and suggest that (at least some of) the documented difficulties of older adults, which were previously attributed to failures in controlled, conscious processes, should be attributed to failures in automatic, high-level processes. These findings thus suggest new directions in research on cognitive aging, focusing on the role of high-level automatic processes. More broadly, they suggest that one may gain new insights into the development, function, and decay of the cognitive system by examining high-level automatic processes and their interaction with controlled processes.

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Table 1

Demographic Characteristics of Participants in Experiments 1 and 2

	Age (Years)		Education (Years)		Mini-Mental State Exam	
Experiment and group	M	SD	M	SD	M	SD
Experiment 1						
Younger (n=42)	19.78	2.82				
Older (n=44)	69.17	6.51	15.44	2.62		
Experiment 2						
Younger (n=89)	23.46	3.05	13.83	2.20	-	-
Older (n=63)	69.20	7.19	16.24	3.21	28.78	1.52

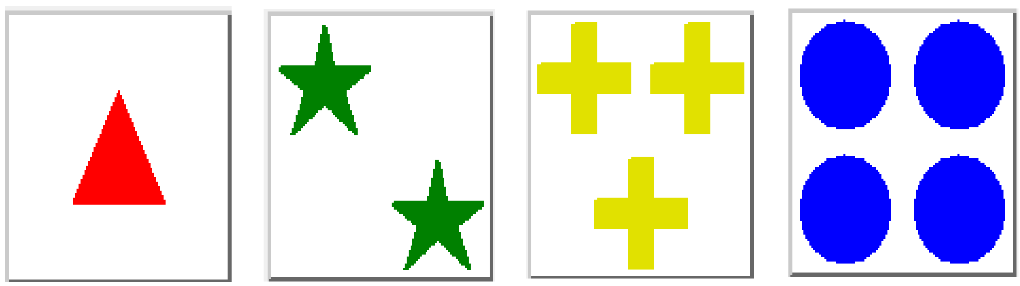
Note: No participant reported having a psychiatric or neurological history or taking medications known to interfere with cognitive functioning. In the second experiment older participants were screened for cognitive impairment using the Mini-Mental State Examination (Folstein et al., 1975).

<u>Fig. 1</u>

a. Examples of cards used in the Wisconsin Card Sorting Test.

b. Examples of cards used in the Jerusalem Face Sorting Test (Experiment 2)

(a)



(b)

Fig. 2

Results for Experiment 1. Note that the fewer perseverative errors one has, the better one's performance. Error bars denote standard error of measurement (SEM).

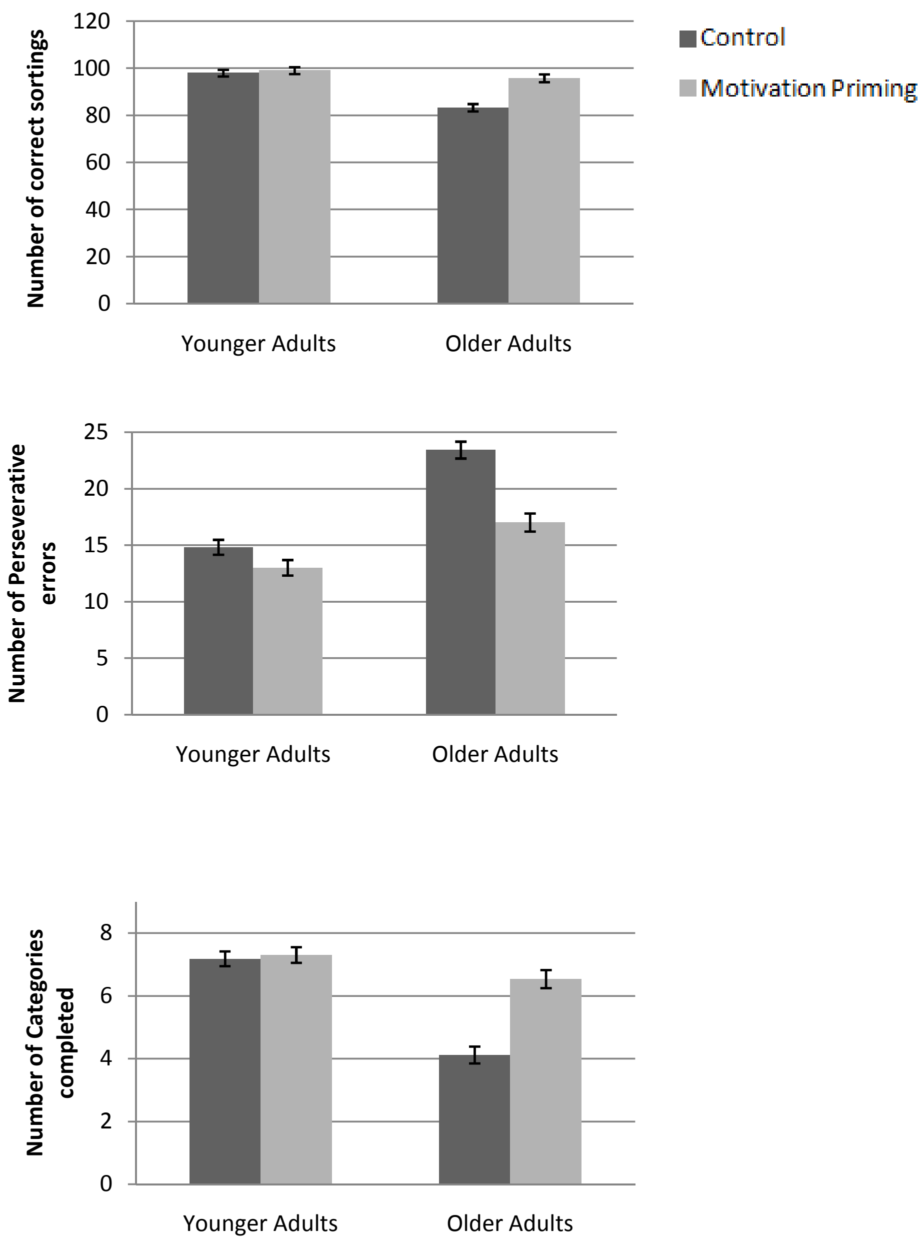
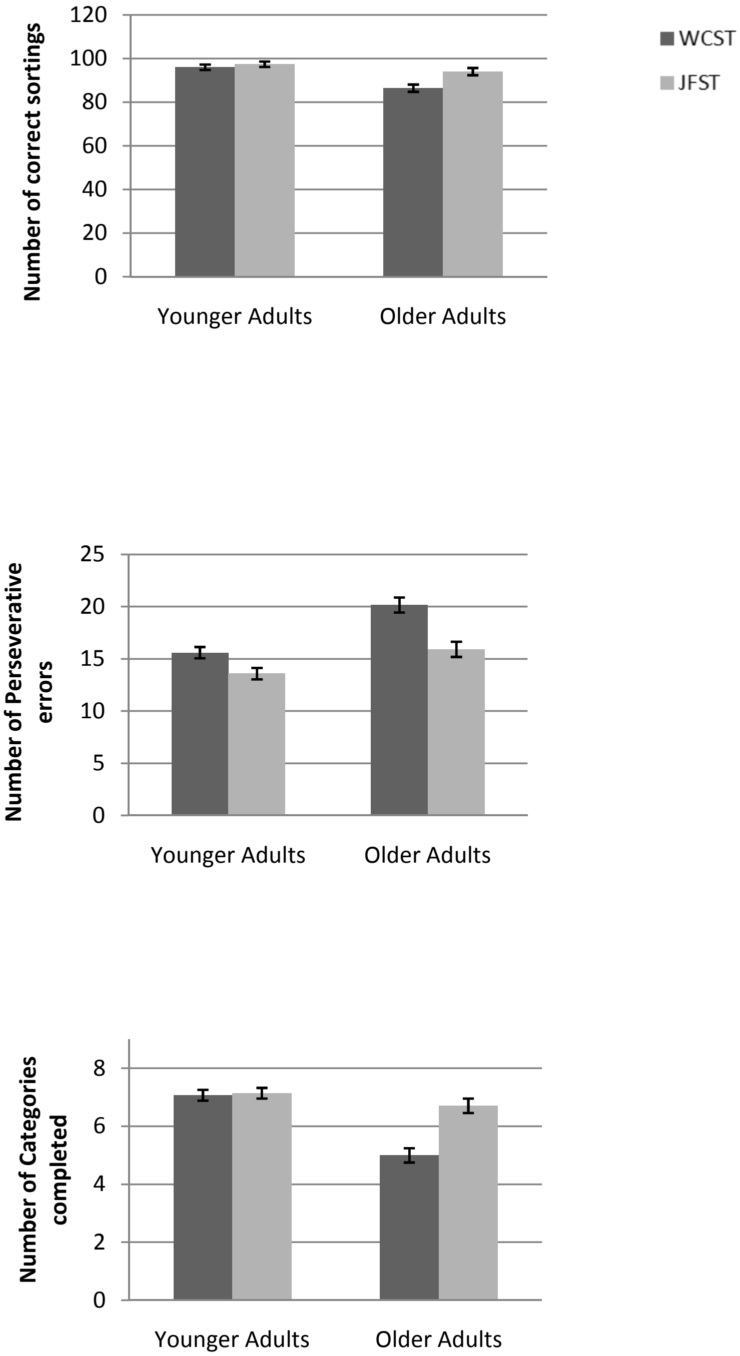


Fig. 3

Results for Experiment 2. Note that the less perseverative errors one has, the better one's performance. Error bars denote standard error of measurement (SEM).



Appendix A1

Mean scores, SDs, t's and p-value for older and younger adults based on data from Experiment 1, presented for two different exclusion criteria. Note that the fewer perseverative errors one has, the better one's performance.

Number of participants*: 1 SD*=* Younger adults: n $_{low\ motivation}$= 22; n $_{High\ motivation}$=20; Older adults: n $_{low\ motivation}$=17; n $_{High\ motivation}$= 15

2 SD=* Younger adults: n $_{low\ motivation}$= 22; n $_{High\ motivation}$=20; Older adults: n $_{low\ motivation}$=23; n $_{High\ motivation}$= 16

Exclusion Criteria	1 SD*						2 SD**					
	Low motivation		High motivation				Low motivation		High motivation			
Measure	M	SD	M	SD	t	p-value	M	SD	M	SD	t	p-value
Correct Sorting												
Younger adults	97.95	12.81	99.05	16.50	.24	.81	97.95	12.81	99.05	16.50	.24	.81
Older adults	83.29	10.29	95.8	10.31	3.42	.002	75.86	15.92	92.5	16.53	3.15	.003
Perseverative Errors												
Younger adults	14.81	5.48	13.0	6.76	-.96	.34	14.81	5.48	13.0	66.76	-.96	.34
Older adults	23.41	5.67	17.0	6.77	-2.91	.007	28.52	10.12	20.31	14.77	-2.06	.046
Categories Completed												
Younger adults	7.18	2.17	7.30	2.43	.16	.86	7.18	2.17	7.30	2.43	.16	.86
Older adults	4.11	1.79	6.53	2.44	3.20	.003	3.34	2.03	6.18	2.73	3.52	.002

*1 SD= participants included in this analysis are those for whom number of perseverative errors was within 1 standard deviation from the mean. For other exclusion criteria, see Methods section.

**2 SD= participants included in this analysis are those for whom number of perseverative errors was within 2 standard deviations from the mean. For other exclusion criteria, see Methods section.

Appendix A2

Age X Motivation interaction for Experiments 1.

This table presents F, p-value and Partial Eta Squared (η_p^2) for Age X Motivation interaction. We first report results based on A 2 (Age: Younger vs. Older adults) X 2 (Motivation: Low vs. High) ANOVA for each of the three depended variables separately. In the bottom of the table we present results of a repeated measures analysis with the three depended variables as a within-subject factor[8]. Results are presented for two different exclusion criteria.

Number of participants*:*

*1 SD**= Younger adults: n $_{\text{low motivation}}$= 22; n $_{\text{High motivation}}$=20

Older adults: n $_{\text{low motivation}}$=17; n $_{\text{High motivation}}$= 15

*2 SD**= Younger adults: n $_{\text{low motivation}}$= 22; n $_{\text{High motivation}}$=20

Older adults: n $_{\text{low motivation}}$=23; n $_{\text{High motivation}}$= 16

Exclusion Criteria	1 SD*			2 SD**		
	F	p-value	η_p^2	F	p-value	η_p^2
measure						
Correct Sorting	3.49	.07	.05	5.03	.03	.06
Preservative Errors	2.51	.12	.03	2.22	.14	.03
Categories Completed	4.82	.03	.06	6.82	.01	.08
Three variables as a within-subject factor	3.62	.06	.05	4.40	.04	.05

*1 SD= participants included in this analysis are those for whom number of perseverative errors was within 1 standard deviation from the mean. For other exclusion criteria see Methods section.

**2 SD= participants included in this analysis are those for whom number of perseverative errors was within 2 standard deviation from the mean. For other exclusion criteria see Methods section.

[8] The scale of perseverative errors was reversed (-1) to fit the other two scales.

Appendix B1

Mean scores, SDs, t's and p-value for older and younger adults based on data from Experiment 2, presented for two different exclusion criteria. Note that the fewer perseverative errors one has, the better one's performance.

Number of participants*: 1 SD*=* Younger adults: n $_{WCST}$= 43; n $_{JFST}$=43; Older adults: n $_{WCST}$ =24; n $_{JFST}$ = 24

2 SD=* Younger adults: n $_{WCST}$ = 45; n $_{JFST}$ =43; Older adults: n $_{WCST}$ =27; n $_{JFST}$ = 28

Exclusion Criteria	1 SD*						2 SD**					
	WCST		JFST				WCST		JFST			
Measure	M	SD	M	SD	t	p-value	M	SD	M	SD	t	p-value
Correct Sorting												
Younger adults	96.02	17.71	97.39	16.59	.37	.71	94.17	19.53	97.39	16.59	.83	.40
Older adults	86.41	15.91	94.0	12.03	1.86	.06	82.96	18.25	88.64	18.47	1.14	.25
Perseverative Errors												
Younger adults	15.60	7.32	13.59	6.66	-1.32	.19	16.66	8.72	13.59	6.66	-1.83	.07
Older adults	20.16	7.65	15.91	6.85	2.20	.04	22.66	10.34	19.96	12.04	.89	.37
Categories Completed												
Younger adults	7.06	2.57	7.13	2.28	.13	.89	6.84	2.73	7.13	2.28	.54	.58
Older adults	5.0	2.84	6.70	1.87	2.45	.01	4.55	2.96	6.0	2.49	1.95	.056

*1 SD= participants included in this analysis are those for whom number of perseverative errors was within 1 standard deviation from the mean.

**2 SD= participants included in this analysis are those for whom number of perseverative errors was within 2 standard deviations from the mean.

Appendix B2

Age X Motivation interaction for Experiments 2.

This table presents F, p-value and Partial Eta Squared (η_p^2) for Age X Motivation interaction. We first report results based on a 2 (Age: Younger vs. Older adults) X 2 (Motivation: WCST vs. JFST) ANOVA for each of the three depended variables separately. In the bottom of the table we present results of a repeated measures analysis with the three depended variables as a within-subject factor[9]. Results are presented for two different exclusion criteria.

Number of participants*:*

*1 SD**= Younger adults: n_{WCST}= 43; n_{JFST}=43

Older adults: n_{WCST} =24; n_{JFST} = 24

*2 SD**= Younger adults: n_{WCST} = 45; n_{JFST} =43

Older adults: n_{WCST} =27; n_{JFST} = 28

Exclusion Criteria	1 SD*			2 SD**		
	F	p-value	η_p^2	F	p-value	η_p^2
measure						
Correct Sorting	.83	.36	.006	.055	.81	>.001
Preservative Errors	.76	.38	.006	.013	.90	>.001
Categories Completed	3.08	.08	.023	1.33	.25	.01
Three variables as a within-subject factor	1.03	.30	.008	.04	.83	>.001

*1 SD= participants included in this analysis are those for whom number of perseverative errors was within 1 standard deviation from the mean. For other exclusion criteria see Methods section.

**2 SD= participants included in this analysis are those for whom number of perseverative errors was within 2 standard deviation from the mean. For other exclusion criteria see Methods section.

[9] The scale of perseverative errors was reversed (-1) to fit the other two scales.

Appendix C1

Mean scores, SDs, t's, and p-value for older and younger adults based on data from Experiments 1 and 2, presented for two different exclusion criteria. Note that the fewer perseverative errors one has, the better one's performance.

Number of participants*: 1 SD*=* Younger adults: n $_{low\ motivation}$= 65; n $_{High\ motivation}$=63; Older adults: n $_{low\ motivation}$=67; n $_{High\ motivation}$= 63

2 SD=* Younger adults: n $_{low\ motivation}$=41; n $_{High\ motivation}$= 39; Older adults: n $_{low\ motivation}$=50; n $_{High\ motivation}$= 43

Exclusion Criteria	1 SD*						2 SD**					
	Low motivation		High motivation				Low motivation		High motivation			
Measure	M	SD	M	SD	t	p-value	M	SD	M	SD	t	p-value
Correct Sorting												
Younger adults	96.67	16.14	97.92	16.45	.43	.66	95.41	17.59	97.92	16.45	.83	.40
Older adults	85.12	13.79	94.69	11.30	3.38	.001	79.70	17.42	91.13	16.33	3.24	.002
Perseverative Errors												
Younger adults	15.33	6.72	13.40	6.64	-1.63	.10	16.05	7.81	13.40	6.64	-2.07	.04
Older adults	21.51	7.01	16.33	6.75	-3.36	.001	25.36	10.55	18.93	10.51	-2.93	.004
Categories Completed												
Younger adults	7.10	2.43	7.19	2.31	.19	.84	6.95	2.55	7.19	2.31	.54	.58
Older adults	4.63	2.47	6.64	2.08	3.91	>.001	4.0	2.62	6.18	2.46	4.11	<.001

*1 SD= participants included in this analysis are those for whom number of perseverative errors was within 1 standard deviation from the mean. For other exclusion criteria, see Methods section.

**2 SD= participants included in this analysis are those for whom number of perseverative errors was within 2 standard deviations from the mean. For other exclusion criteria, see Methods section.

Appendix C2

Age X Motivation interaction for Experiments 1 and 2 together.

This table presents F, p-value and Partial Eta Squared (ηp2) for Age X Motivation interaction. We first report results based on a 2 (Age: Younger vs. Older adults) X 2 [Motivation: Low (control/WCST) vs. High (achievement priming/JFST)] X 2 (Experiment: 1 vs. 2) ANOVA for each of the three depended variables separately. In the bottom of the table we present results of a repeated measures analysis with the three depended variables as a within-subject factor[10]. Results are presented for two different exclusion criteria.

Number of participants*:*

*1 SD**= Younger adults: $n_{\text{low motivation}}$= 65; $n_{\text{High motivation}}$=62

Older adults: $n_{\text{low motivation}}$=41; $n_{\text{High motivation}}$= 39

*2 SD**= Younger adults: $n_{\text{low motivation}}$=67; $n_{\text{High motivation}}$= 62

Older adults: $n_{\text{low motivation}}$=50; $n_{\text{High motivation}}$= 43

Exclusion Criteria	1 SD*			2 SD**		
	F	p-value	η_p^2	F	p-value	η_p^2
measure						
Correct Sorting	3.56	.06	.02	4.52	.035	.021
Preservative Errors	2.88	.09	.01	3.53	.062	.016
Categories Completed	7.59	>.01	.04	8.47	.004	.038
Three variables as a within-subject factor	4.15	.045	.020	4.88	.028	.022

*1 SD= participants included in this analysis are those for whom number of perseverative errors was within 1 standard deviation from the mean. For other exclusion criteria see Methods section.

**2 SD= participants included in this analysis are those for whom number of perseverative errors was within 2 standard deviation from the mean. For other exclusion criteria see Methods section.

[10] The scale of perseverative errors was reversed (-1) to fit the other two scales.

Appendix D

Full results for the 2 (Age: Younger vs. Older adults) X 2 [Motivation: Low (control/WCST) vs. High (achievement priming/JFST)] X 2 (Experiment: 1 vs. 2) ANOVA for each of the three depended variables separately.

This table presents F, p-value and Partial Eta Squared (ηp2). Results are presented for two different exclusion criteria.

Number of participants*:*

*1 SD**= Younger adults: n $_{\text{low motivation}}$= 65; n $_{\text{High motivation}}$=62

Older adults: n $_{\text{low motivation}}$=41; n $_{\text{High motivation}}$= 39

*2 SD**= Younger adults: n $_{\text{low motivation}}$=67; n $_{\text{High motivation}}$= 62

Older adults: n $_{\text{low motivation}}$=50; n $_{\text{High motivation}}$= 43

Exclusion Criteria	1 SD*			2 SD**		
	F	p-value	η_p^2	F	p-value	η_p^2
Motivation						
Correct Sorting	7.17	>.01	.03	10.50	>.01	.04
Preservative Errors	12.97	>.01	.06	14.81	>.01	.06
Categories Completed	10.26	>.01	.04	13.48	>.01	.05
Age						
Correct Sorting	13.15	>.01	.06	23.54	>.01	.09
Preservative Errors	23.44	>.01	.10	36.67	>.01	.14
Categories Completed	21.74	>.01	.09	33.58	>.01	.13
Experiment						
Correct Sorting	.02	.88	>.01	.22	.63	>.01
Preservative Errors	.53	.46	>.01	>.01	.92	>.01
Categories Completed	.43	.51	>.01	.04	.83	>.01
Age X Motivation						
Correct Sorting	3.56	.06	.02	4.52	.03	.02
Preservative Errors	2.88	.09	.01	3.53	.06	.01
Categories Completed	7.59	>.01	.04	8.47	>.01	.03
Experiment X Motivation						
Correct Sorting	.17	.68	>.01	1.35	.24	>.01
Preservative Errors	.24	.62	>.01	2.32	.12	.01
Categories Completed	.20	.64	>.01	1.05	.30	>.01
Age X Experiment						
Correct Sorting	.19	.65	>.01	.20	.64	>.01

Preservative Errors	2.01	.15	.01	1.15	.28	>.01
Categories Completed	.76	.38	>.01	.55	.45	>.01
Age X Motivation X Experiment						
Correct Sorting	.49	.48	>.01	3.317	.07	.01
Preservative Errors	.34	.55	>.01	4.114	.04	.01
Categories Completed	.31	.57	>.01	2.104	.14	.01

*1 SD= participants included in this analysis are those for whom number of perseverative errors was within 1 standard deviation from the mean. For other exclusion criteria see Methods section.

**2 SD= participants included in this analysis are those for whom number of perseverative errors was within 2 standard deviation from the mean. For other exclusion criteria see Methods section.