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Implicit motivation improves executive functions of older adults

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ABSTRACT

It is widely accepted that while controlled processes (e.g., working memory and executive functions) decline with age, implicit (automatic) processes are not affected by age. In this paper we challenge this view by arguing that high-level automatic processes (e.g., recruiting motivation) decline with age, and that this decline plays an unappreciated role in cognitive aging. Specifically, we hypothesized that due to their decline, automatic motivational processes are less likely to be spontaneously activated in old age; thus, implicit external activation of them 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 using the Wisconsin Card Sorting Test. In both experiments, implicit modulation of motivation resulted in improved executive functioning for older adults. The framework we propose is general and offers a new look at various aspects of cognitive aging.

1. Introduction

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. Second, it will help us better cope with the social and monetary challenges associated with aging, that are expected to dramatically increase in the coming decades (Kinsella & Wan, 2009; Ortman, Velkoff, & Hogan, 2014; Vincent & Velkoff, 2010).

A 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; Peters, Hess, Västfjäll, & Auman, 2007; Queen & Hess, 2010). Here we challenge this view on theoretical grounds, and report findings that suggest that aging-related cognitive deficits can result from decline in implicit processes.

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, Uleman, & Bargh, 2005). This 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 historically associated with conscious awareness can occur automatically, outside of conscious awareness (Bargh, Gollwitzer, Lee-Chai, Barndollar, & Trötschel, 2001; Capa, Bouquet, Dreher, & Dufour, 2013; Custers & Aarts, 2010; Hassin & Sklar, 2014; Hassin, 2013; Lau & Passingham, 2007;

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Sklar et al., 2012; Soto & Silvanto, 2014; Soto, Mäntylä, & Silvanto, 2011; van Gaal, Ridderinkhof, van den Wildenberg, & Lamme, 2009).[1] While accepting the view that low-level automatic processes are relatively immune to aging (e.g., Park, 2000), we suggest that high-level automatic processes 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 the parallel conscious processes of goal pursuit and inhibition (Hassin & Sklar, 2014; Hassin, 2013). 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 (i.e., frontal lobes, among other brain areas which are affected by aging), and tend to deteriorate with age (Head, Snyder, Girton, Morris, & Buckner, 2005; Nyberg & Salami, 2010; Raz, 2000). Given the similarities described above, it is reasonable to hypothesize that high-level automatic processes would deteriorate with age similarly to their conscious counterparts. Put in more technical terms, the principle of parsimony suggests that we should hypothesize no differences between the two types of processes.

1.1. 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.[2] 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), 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 in EFs impairs cognitive flexibility (Rhodes, 2004), the main outcome variable on which we focus here (However, see Verhaeghen, 2011 for a different perspective on age-related changes in a subset of EFs).

1.2. 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 (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, respectively. 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 research focused on the associations between age, motivation and cognition. A prominent example is the well-established selection, optimization, and compensation (SOC) theory of successful aging (Baltes & Baltes, 1990). According to this theory, older adults optimize their performance by selecting motivationally relevant, attainable goals, and by doing so they successfully compensate for their deficits. A more recent example is the selective engagement theory (SET; Hess, 2014), which argues that explicit intrinsic motivation to do well in a difficult cognitive task decrease with age, as the costs associated with engaging in such cognitive activity increases (Hess & Smith, 2016; Queen & Hess, 2017). Moreover, it has been suggested that older adults become less interested

[1] While some replication failures question specific parts of this literature (see Hesselmann & Moors, 2015), the overwhelming evidence seems to suggest that high-level priming works, although it is weaker than previously thought (Goldstein & Hassin, 2017)

[2] 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.

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). Accordingly, manipulations to increase motivation (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, these perspectives focus on explicit, conscious motivation, and data on the effectiveness of implicit motivational manipulations in older adults is still largely lacking.

2. 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 EFs 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. We suggest that older people have inferior high-level automatic processes (i.e., automatic motivation recruitment) and hence that the effects of priming among old people would generally be *stronger*.

One may wonder, though: if older people have inferior automatic processes, why shouldn't we expect the effects of priming to be *weaker*? We suggest 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, increasing automatic motivation should have stronger effects on older (vs. younger) adults, thereby reducing what seems today to be an inescapable age gap in EFs. Initial support for this idea can be found in several studies which showed that implicit priming of positive aging stereotypes improves older – but not younger – adults' cognitive control (Aisenberg et al., 2015), memory performance (Hess, Hinson, & Statham, 2004), and physical function (Levy, Pilver, Chung, & Slade, 2014).

We report two experiments in which we either implicitly increase motivation or not, and we then measure EFs of younger (college students) and older (community dwelling) adults. In both experiments we use a gold standard measure of EFs, the Wisconsin Card Sorting Test (WCST; Heaton, Chelune, Talley, Kay, & Curtiss, 1993; see *Materials*).

Increasing motivation levels was done in two different ways. First, we subtly increase motivation by using 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 Harris, Coburn, Rohrer, & Pashler, 2013; Klein et al., 2014; Open Science Collaboration, 2015 for failures of replication). 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 complete the WCST, an allegedly unrelated task.

The second way to subtly increase motivation is by changing the relevance and engagement of the task (Higgins & Trope, 1990; Higgins, 2006). It is likely that tasks such as the WCST may differentially motivate college students and older adults given that the former are being routinely evaluated for cognitive skills in their daily lives, while the latter are not (Labouvie-Vief, 1985; Zimerman, Hasher, & Goldstein, 2011). Moreover, Stimuli that are more relevant to older adults' daily life are more likely to automatically activate motivational processes that will influences subsequent behavioral responses (Eitam & Higgins, 2010). Hence, we created an altered version of the WCST, which is designed to be more relevant and engaging for older adults than the original WCST. In line with our reasoning above, in both experiments we hypothesized an interaction, such that the motivation manipulations would improve performance of both older and younger adults, but performance of older adults will improve more than that of younger adults.

3. Experiment 1

In experiment 1 we tested whether motivation to succeed in the WCST can be automatically recruited through processing success-related words in a prior, unrelated, task. We again predicted that the motivation manipulation would have stronger effects on older (vs. younger) adults.

3.1. Method

3.1.1. Participants and design.

Forty-four older adults (26 female, 18 male; age range 65–79, 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, and received monetary compensation of 20 New Israeli shekels (NIS; approximately $5) for their participation. The younger adults were Hebrew University students who received either course credit or monetary compensation of 20 NIS for their participation. The design was a 2 (Motivation: Low vs. High) × 2 (Population: Younger vs. Older adults), and older and younger participants were randomly assigned to one of the two conditions of the study (High vs. Low motivation).

Table 1
Demographic characteristics of participants in Experiments 1 and 2.

Experiment and group	Age (years)		Education (years)		Mini-Mental State Exam	
	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 only older participants were screened for cognitive impairment using the Mini-Mental State Examination (Folstein et al., 1975).

3.1.2. 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 a 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). Words (in Hebrew) for both conditions were similar in length and frequency (Frost & Plaut, 2005). 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: 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 sorting,

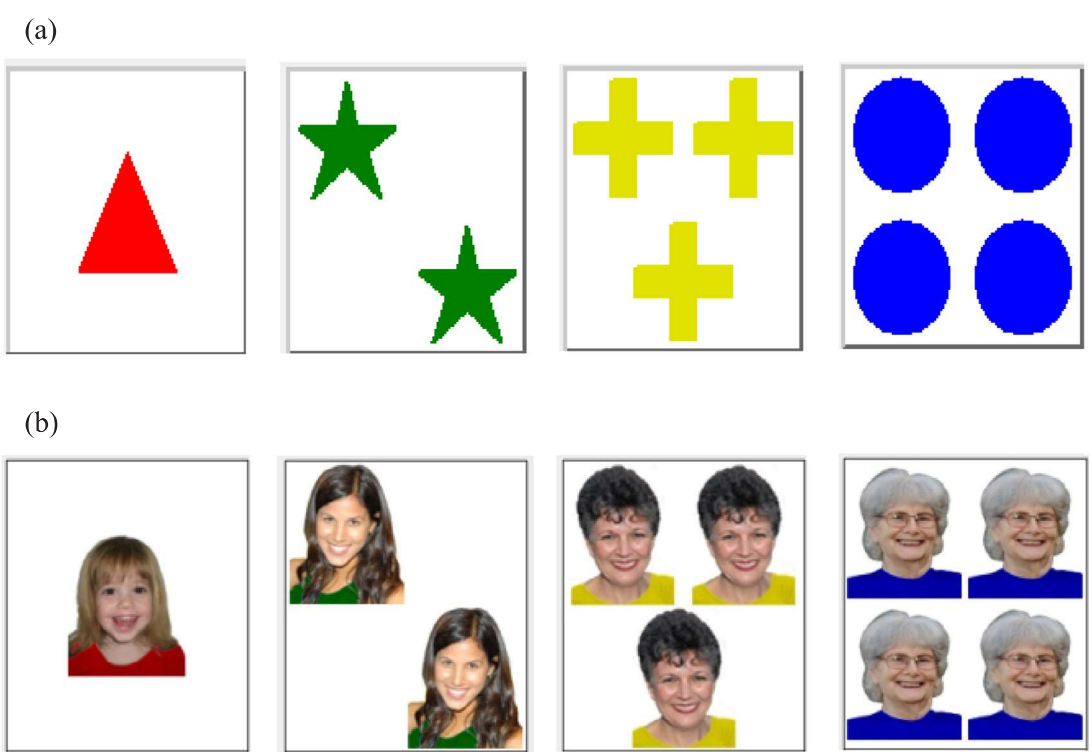

Fig. 1. a. Examples of cards used in the Wisconsin Card Sorting Test. b. Examples of cards used in the Jerusalem Face Sorting Test (Experiment 2).

and then changed (e.g., to number). No special instructions about the nature of the task or the sorting principles were given (Heaton et al., 1993), and 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, and the average completion time was 10–15 min. After they completed the task participants were asked to fill out a questionnaire that first assessed their motivation to do well in the session and later assessed their awareness of the relations between the "two experiments" (word search and WCST; see Bargh & Chartrand, 2000). Finally, participants were debriefed and thanked.

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, Howieson, & Loring, 2004; 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 all three measures for both experimental conditions.

3.2. Results

3.2.1. 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 reported, explicit 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.

3.2.2. 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 (4 from the control group) who did not complete even one category, since this level of performance deviates from the normal range and may reflect a cognitive impairment. 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 Supplementary Tables A1 and A2).

3.2.3. WCST performance

On average, task performance for both younger and older groups was within normal range according to age corrected norms (Heaton et al., 1993). We first analyzed the data of older adults. An independent *t*-test revealed that goal-priming significantly improved performance 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. $M = 4.11$, $SD = 1.79$), $t(30) = 3.20$, $p < 0.005$. The trends among younger adults were similar, yet weaker, and in contrast to our hypothesis, none of the reported measures improved significantly as a result of priming. (see Fig. 2; Supplementary Table A1).

Supporting our hypothesis, a 2 × 2 ANOVA revealed a significant Age × Motivation interaction on the number of categories completed ($F_{1,70} = 4.82$, $p < 0.05$, $\eta_p^2 = 0.064$), and a marginally significant interaction on correct sortings ($F_{1,70} = 3.49$, $p = 0.06$, $\eta_p^2 = 0.048$). The interaction on perseverative errors only approached significance ($F_{1,70} = 2.51$, $p = 0.11$, $\eta_p^2 = 0.035$). A repeated measures analysis with the three measures as a within-subject factor[3] revealed a marginally significant Age × Motivation interaction ($F_{1,70} = 3.62$, $p = 0.06$, $\eta_p^2 = 0.049$) (See Supplementary Table A2).

3.3. Discussion

As hypothesized, achievement priming improved older adult's performance on the WCST. We argue that priming of achievement related words automatically activated motivational processes which in turn guided behavior in a goal-directed manner (see Hassin et al., 2009, for a similar argument). Motivation priming, then, significantly narrowed the cognitive gap between younger and older adults. In fact, 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* $t(35) = 1.08$, $p > 0.2$].[4] Importantly, there were no differences in reported-motivation between the control and primed groups ($p = 0.60$).

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

[4] 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).

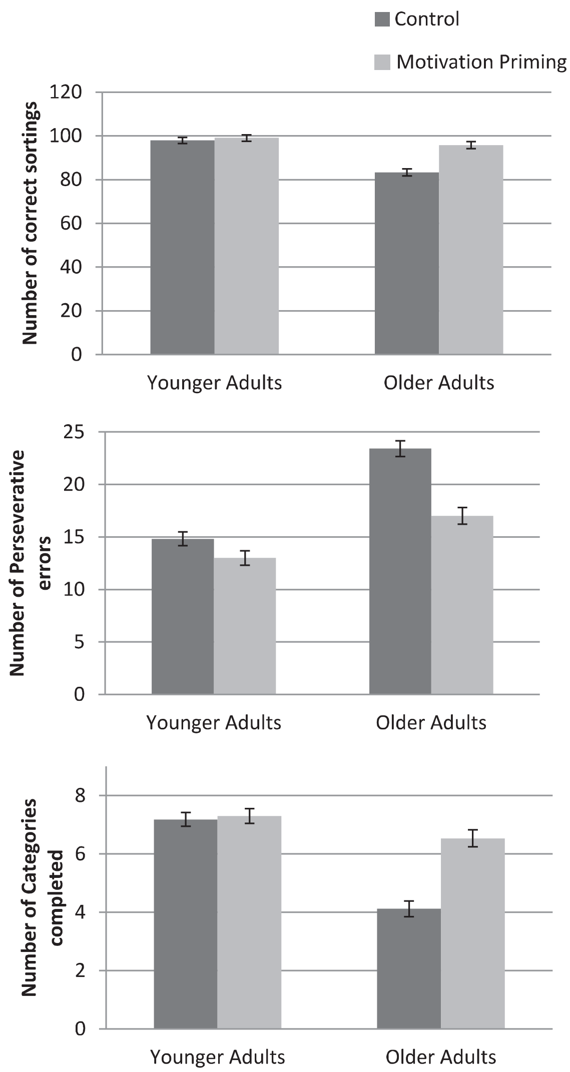

Fig. 2. Results for Experiment 1, presented for younger and older adults, in the motivation priming manipulation and the control condition. Note that the fewer perseverative errors one has, the better one's performance. Error bars denote standard error of measurement (SEM).

In contrast to out hypothesis and to previous findings (Hassin et al., 2009; Schubert, Waldzus, & Giessner, 2009), priming did not improve the performance of younger adults. In fact, since the performance of younger (vs. older) adults was better even in the control condition, one may be tempted to suggest that our results stem from a ceiling effect in the younger adult group. We argue that this is unlikely to be the case and discuss this possibility thoroughly in the general discussion.

4. Experiment 2

Experiment 2 is a conceptual replication of Experiment 1, with a different manipulation of motivation: in this experiment motivation was manipulated by subtly increasing the relevance of the stimuli (Eitam & Higgins, 2010; Mather & Carstensen, 2005), therefore 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 that the two tasks were identical. We call this task the Jerusalem Face Sorting Test (JFST). We specifically chose to use faces because they are very relevant for achieving social and emotional goals, which are highly important to older adults (Carstensen, Isaacowitz, & Charles, 1999).

4.1. Method

4.1.1. Participants and design

Sixty-three older adults (43 female, 20 male; age range 65–79, Mean age = 69.20) and 89 younger adults (52 female, 37 male; Mean age = 23.46) who did not participate in experiment 1 participated in experiment 2 (see Table 1). We included 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; We did not perfrom similar evaluation in experiment 1). 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 older participants received monetary compensation of 20 New Israeli shekels (NIS; approximately $5). Older and younger adults were randomly assigned to one of two experimental groups. The design of Experiment 2 was a 2 [Motivation: Low (WCST) vs. High (JFST)] × 2 (Population: Younger vs. Older adults).

4.1.2. 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 was presented with the JFST, which is identical to WCST in all but one feature: we replaced the original WCST shapes with 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, and we report the same performance measures as we did in experiment 1.

4.2. Results

4.2.1. 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 reported 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 reported 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 ($M_{WCST} = 7.32$, $SD = 1.29$; $M_{JFST} = 7.27$, $SD = 1.69$, $p > 0.5$). In other words, neither age group nor experimental group resulted in differences in reported motivation, which was high and similar among all groups.

4.2.2. 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 analyses[5] (see Experiment 1). 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 low-motivation condition and 1 from the high-motivation condition). In addition, we excluded participants who did not complete any category during the task (2 older participants, both from the low-motivation condition). Analyses with less strict criteria – 2 SDs above group mean for number of perseverative-errors – do not change the pattern of the results, although significance levels slightly change (see Supplementary Tables B1 and B2).

4.2.3. Task performance

We begin by examining the performance of older adults. An independent sample *t*-test revealed that, for the older adults group, the performance on the JFST was better than in the WCST: 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 contrast to our hypothesis, among the younger group none of the reported measures was significantly improved by JFST (see Fig. 3, Supplementary Table B1).

A 2 (Age: Young vs. Old) × 2 (Motivation: JFCT vs. WCST) ANOVA revealed a marginally significant Age × Motivation interaction on categories completed ($F_{1,129} = 3.08$, $p = 0.08$, $\eta_p^2 = 0.023$). Interaction on perseverative errors and number of correct sorting did not approach significance. Repeated measures with all three reported measure as one within-subject factor did not reveal a significant Age × Motivation interaction ($F_{1,129} = 1.06$, $p = .30$, $\eta_p^2 = 0.008$) (See Supplementary Table B2).

4.3. Discussion

As hypothesized, including motivationally relevant stimuli in the sorting test resulted in improved performance on the task for older adults. Although the effects here are small, they suggest that implicitly increasing motivation by using relevant stimuli narrows the gap between younger and older adults' executive performance. One may suggest that the difference in task experience between WCST and JFST (i.e., one task being more pleasant than the other) can help older adults by reducing anxiety (see Geraci & Miller, 2013 for a similar argument), or by making it less exhausting. Note, however, that in Experiment 1 the findings were similar, yet

[5] 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 et al., 2004). However, we did not use MMSE as our sole exclusion criteria because it does not thoroughly evaluate executive functioning, but rather serves a rough screening tool for dementia.

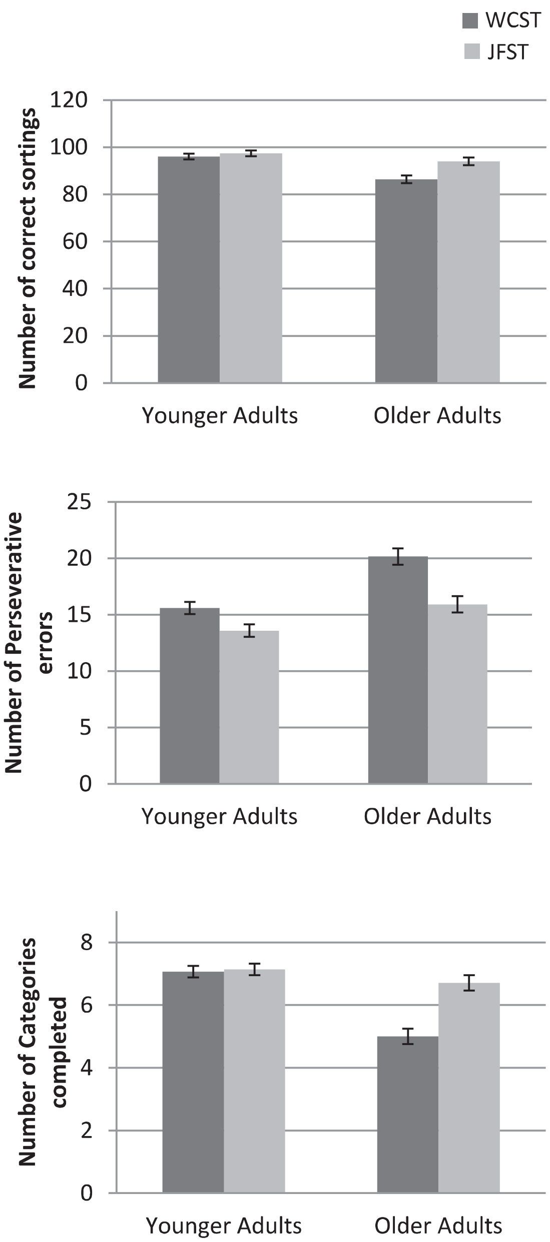

Fig. 3. Results for Experiment 2, presented for younger and older adults, in the Wisconsin Card Sorting Test (WCST) and the Jerusalem Face Sorting Test (JFST) conditions. Note that the less perseverative errors one has, the better one's performance. Error bars denote standard error of measurement (SEM).

there the experimental task was identical. Moreover, 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. We therefore conclude that there is one mechanism that is shared by the two experiments – increase in implicit motivation – that was manipulated by priming of the concept of achievement (exp.1) or by increased relevance of stimuli (exp. 2). However, while parsimony suggests we should prefer the more general explanation, it might well be the case that the two experiments tap different underlying mechanisms.

Since the two experiments tested the same hypothesis using complementary methodologies, and since the effect sizes are small, we combined their data to increase power.

5. Joint analysis of the two experiments

When analyzing data from the two experiments jointly, A 2 (Age: Younger vs. Older adults) × 2 [Motivation: Low (control/WCST) vs. High (achievement priming/JFST)] × 2 (Experiment: 1 vs. 2) ANOVA revealed a significant interaction between Age and Motivation on *number of categories completed* ($F_{1,199} = 7.59$, $p < .01$, $\eta_p^2 = 0.037$), and a marginally significant interaction on *perseverative errors* ($F_{1,199} = 2.88$, $p = 0.09$, $\eta_p^2 = 0.014$) and *number of correct sortings* ($F_{1,199} = 3.56$, $p = 0.06$, $\eta_p^2 = 0.018$).[6] Repeated measures analysis, with the 3 measures as one within-subject factor, revealed a significant Age × Motivation interaction ($F_{1,199} = 4.15$, $p < 0.05$, $\eta_p^2 = 0.20$). (See Supplementary Table C2).

Focusing just on older adults, the independent samples *t*-test revealed that motivation improved performance on all measures: correct sorting [$t(78) = 3.38$, $p < 0.005$]; persevervative 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 Supplementary Table 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 reported 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, $p > 0.5$).[7] In addition, there were no differences in reported 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 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 reported, conscious motivation, and hence that conscious motivation cannot explain the differences in performance between the experimental and control conditions.

6. General discussion

Although theories of aging generally hold that automatic processes do not decline with age, we proposed that they do. Results from two experiments supports our predication, that implicit motivation will help older adults more than younger adults to succeed in executive functions tasks. 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.

Importantly, using a subtle, non-invasive manipulation we were able to improve older adults' performance on the WCST – an executive functions measure that consistently shows a decline with age (Rhodes, 2004). While effect sizes for the older group were small to moderate, they were replicated across two different manipulations, and were stronger in a joint analysis. The performance of implicitly motivated older adults in our study (mean age 69.2) fits the average expected performance for the 60–65 age group according to the WCST norms.[8] In other words, priming seems to have shed 5–10 years from our older participants, not a negligible effect.

We argue that the key factor that was manipulated in this study was motivation. Relevance and motivation are two highly related concepts, and, as we argued earlier (see *The Current Research* section), it seems likely to suggest that a more relevant stimuli will recruit more motivation (Eitam & Higgins, 2010). While the increased relevance of stimuli can explain the results of the second study, it cannot do the same for the first. Therefore, we argue that motivation is the general concept best explains results of the two experiments together. However, further research may help to untangle these two related concepts.

A possible limitation of this study is that the younger group did not improved due to a ceiling effect. We argue that this is not the case and address this option thoroughly in the limitations section below. However, For the sake of the argument, let us assume that there is indeed a ceiling effect. The view that we propose here is that while performance on EFs 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 EFs 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.

Note, however, that older participants come to the laboratory with ardent conscious motivation that is reflected in their high reported-motivation ratings in both experiments.

One may argue that since we report that priming and subtle motivational manipulations work better with older adults, the results simply suggest that high-level automatic motivational processes *improve* with age (for a similar argument regarding low-level priming

[6] 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 Supplementary Table D.

[7] 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).

[8] 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.

see Dew & Giovanello, 2010; Gopie, Craik, & Hasher, 2011).

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* section; 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. This theoretical advancement proposed here should help us improve our interventions, by more accurately targeting those abilities that diminish with age. Efforts of cognitive training for the elderly are mainly focused on training of the "basic" abilities (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).

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 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. Further investigation in this direction might reveal other populations that can benefit from increasing implicit motivation.

Before turning to discuss this study limitations, let us just highlight that we propose here a new tool for cognitive scientists at large, in the hopes that differences between JFST and WCST will help us better understand cognitive and motivational processes. Importantly, since this is a new task that was developed with our participants in mind, biases of gender, color, race and age should be addressed prior to administration to other populations.

6.1. Limitations

The reported study has few limitations that we wish to discuss here.

Implicit motivation did not improve younger adults' performance: while the experimental manipulations improved older adults' performance, they did not significantly affect younger adult's performance. These findings conflict with 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 "replication 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 and their age). It is important to note that this 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.

Potential ceiling effect in the younger adults group: Since the performance of younger adults reached close to the top of the scale, one may suggest that our results stem from a ceiling effect in the younger 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. Second, in a previous study younger adults with similar performance level did show a small but significant improvement in the number of perseverative errors (Hassin et al., 2009), so such improvement is not only theoretically possible but was also practically demonstrated. Yet, while the possibility of a ceiling effect seems unlikely to us, it does remain a potential alternative explanation of the results that should be addressed in future research.

Relying on self-reported measures: We used self-reports to assess explicit motivation. Asking people about their phenomenology is always tricky; Decades of research have 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 conscious motivation.

Older and younger groups were not randomly assigned: Both experiments compared community-dwelling older adults with undergraduate students. Given the nature of the different groups 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. Compared to longitudinal designs which are highly expensive and time-consuming, cross-sectional studies such as ours allow focused investigation of specific question in a relatively quick and affordable process. To avoid cohort effects we attempted to control for demographic 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, reported 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 fitness.

6.2. Conclusions

We suggested that a distinction between high- and low-level automatic processes is likely to improve our understanding of human behavior, broadly defined. We reported two experiments with results that lend support to the idea that automatic, high-level processes decline with age. The results also 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 non-conscious, high-level processes. These findings thus open new directions in research on cognitive aging, focusing on the role of high-level automatic processes. More broadly, we conclude 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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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.concog.2018.06.007.

References

Aisenberg, D., Cohen, N., Pick, H., Tressman, I., Rappaport, M., Shenberg, T., & Henik, A. (2015). Social priming improves cognitive control in elderly adults – Evidence from the Simon task. *PLoS One, 10*(1).

Baltes, P. B., & Baltes, M. M. (1990). Psychological perspectives on successful aging: The model of selective optimization with compensation. In M. M. Baltes, & P. B. Baltes (Eds.). *Successful aging: Perspectives from the behavioral sciences* (pp. 1–34). Cambridge: Cambridge University Press. http://dx.doi.org/10.1017/CBO9780511665684.003.

Bargh, J. A., & Chartrand, T. L. (2000). The mind in the middle. *Handbook of research methods in social and personality psychology,* 253–285.

Bargh, J. A., Gollwitzer, P. M., Lee-Chai, a., Barndollar, K., & Trötschel, R. (2001). The automated will: Nonconscious activation and pursuit of behavioral goals. Retrieved from *Journal of Personality and Social Psychology, 81*(6), 1014–1027. <http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3005626&tool=pmcentrez&rendertype=abstract>.

Boone, K. B., Pontón, M. O., Gorsuch, R. L., González, J. J., & Miller, B. L. (1998). Factor analysis of four measures of prefrontal lobe functioning. *Archives of Clinical Neuropsychology, 13*(7), 585–595.

Bopp, K. L., & Verhaeghen, P. (2005). Aging and verbal memory span: A meta-analysis. Retrieved from *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences, 60*(5), P223–P233.

Braver, T. S., Krug, M. K., Chiew, K. S., Kool, W., Westbrook, J. A., Clement, N. J., ... Somerville, L. H. (2014). Mechanisms of motivation–cognition interaction: Challenges and opportunities. *Cognitive, Affective, & Behavioral Neuroscience, 14*(2), 443–472. http://dx.doi.org/10.3758/s13415-014-0300-0.

Braver, T. S., & West, R. (2008). Working memory, executive control, and aging. In F. I. M. Craik, & T. A. Salthouse (Eds.). *The handbook of aging and cognition* (pp. 311–372). (3rd ed.). New York, NY: Psychology Press.

Campbell, K. L., Zimerman, S., Healey, M. K., Lee, M. M. S., & Hasher, L. (2012). Age differences in visual statistical learning. *Psychology and Aging, 27*(3), 650–656. http://dx.doi.org/10.1037/a0026780.

Capa, R. L., Bouquet, C. A., Dreher, J.-C., & Dufour, A. (2013). Long-lasting effects of performance-contingent unconscious and conscious reward incentives during cued task-switching. *Cortex; A Journal Devoted to the Study of the Nervous System and Behavior, 49*(7), 1943–1954. http://dx.doi.org/10.1016/j.cortex.2012.05.018.

Capa, R. L., Bustin, G. M., Cleeremans, A., & Hansenne, M. (2011). Conscious and unconscious reward cues can affect a critical component of executive control: (Un) conscious updating? *Experimental Psychology, 58*(5), 370–375. http://dx.doi.org/10.1027/1618-3169/a000104.

Carstensen, L. L. (2006). The influence of a sense of time on human development. *Science (New York, N.Y.), 312*(5782), 1913–1915. http://dx.doi.org/10.1126/science.1127488.

Carstensen, L. L., Isaacowitz, D. M., & Charles, S. T. (1999). Taking time seriously: A theory of socioemotional selectivity. *American Psychologist, 54*(3), 165–181.

Chaiken, S., & Trope, Y. (1999). *Dual-process theories in social psychology.* New York, NY: Guilford Press.

Chauvel, G., Maquestiaux, F., Hartley, A.a., Joubert, S., Didierjean, A., & Masters, R. S. W. (2012). Age effects shrink when motor learning is predominantly supported by nondeclarative, automatic memory processes: Evidence from golf putting. *Quarterly Journal of Experimental Psychology (2006), 65*(1), 25–38. http://dx.doi.org/10.1080/17470218.2011.588714.

Clarys, D., Bugaiska, A., Tapia, G., & Baudouin, A. (2009). Ageing, remembering, and executive function. *Memory, 17*(2), 158–168. http://dx.doi.org/10.1080/09658210802188301.

Open Science Collaboration (2015). Estimating the reproducibility of psychological science. Science, 349(6251), aac4716–aac4716. 10.1126/science.aac4716.

Craik, F. I. M., & Bialystok, E. (2006a). Cognition through the lifespan: Mechanisms of change. *Trends in Cognitive Sciences, 10*(3), 131–138. http://dx.doi.org/10.1016/j.tics.2006.01.007.

Craik, F. I. M., & Bialystok, E. (2006b). Planning and task management in older adults: Cooking breakfast. Retrieved from *Memory & Cognition, 34*(6), 1236–1249. <http://www.ncbi.nlm.nih.gov/pubmed/17225505>.

Craik, F., & Salthouse, T. A. (2008). *The handbook of aging and cognition* (3rd ed.). New York, NY: Psychology Press.

Custers, R., & Aarts, H. (2010). The unconscious will: How the pursuit of goals operates outside of conscious awareness. *Science (New York, N.Y.), 329*(5987), 47–50. http://dx.doi.org/10.1126/science.1188595.

Dew, I. T. Z., & Giovanello, K. S. (2010). Differential age effects for implicit and explicit conceptual associative memory. *Psychology and Aging, 25*(4), 911–921. http://dx.doi.org/10.1037/a0019940.

Dijksterhuis, A., & Aarts, H. (2010). Goals, attention, and (un)consciousness. *Annual Review of Psychology, 61*, 467–490. http://dx.doi.org/10.1146/annurev.psych.093008.100445.

Dreher, J.-C., Koch, P., Kohn, P., Apud, J., Weinberger, D. R., & Berman, K. F. (2012). Common and differential pathophysiological features accompany comparable cognitive impairments in medication-free patients with schizophrenia and in healthy aging subjects. *Biological Psychiatry, 71*(10), 890–897. http://dx.doi.org/10.1016/j.biopsych.2012.01.002.

Eitam, B., & Higgins, E. T. (2010). Motivation in mental accessibility: Relevance of a representation (ROAR) as a new framework. *Social and Personality Psychology Compass, 4*(10), 951–967. http://dx.doi.org/10.1111/j.1751-9004.2010.00309.x.

Evans, J. S. B. T., & Stanovich, K. (2013). Dual-process theories of higher cognition: Advancing the debate. *Perspectives on Psychological Science, 8*, 223–241.

Fishbach, A., & Ferguson, M. J. (2007). The goal construct in social psychology. In A. W. Kruglanski, & E. T. Higgins (Eds.). *Social psychology: Handbook of basic principles* (pp. 490–515). (2nd ed.). New York, NY, US: Guilford Press.

Fishbach, A., Friedman, R. S., & Kruglanski, A. W. (2003). Leading us not into temptation: Momentary allurements elicit overriding goal activation. *Journal of Personality and Social Psychology, 84*(2), 296–309. http://dx.doi.org/10.1037/0022-3514.84.2.296.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-Mental State": A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*, 189–198.

Frost, R., & Plaut, D. C. (2005). The word-frequency database for printed Hebrew. Retrieved from <http://word-freq.mscc.huji.ac.il/index.html>.

Gazzaley, A., Cooney, J. W., Rissman, J., & D'Esposito, M. (2005). Top-down suppression deficit underlies working memory impairment in normal aging. *Nature Neuroscience, 8*(10), 1298–1300. http://dx.doi.org/10.1038/nn1543.

Geraci, L., & Miller, T. M. (2013). Improving older adults' memory performance using prior task success. *Psychology and Aging, 28*(2), 340–345. http://dx.doi.org/10.1037/a0030332.

Goldstein, A., & Hassin, R. R. (2017). Commentary: Definitely maybe: Can unconscious processes perform the same functions as conscious processes? Retrieved from *Frontiers in Psychology.*.

Gopie, N., Craik, F. I. M., & Hasher, L. (2011). A double dissociation of implicit and explicit memory in younger and older adults. *Psychological Science, 22*(5), 634–640. http://dx.doi.org/10.1177/0956797611403321.

Harris, C. R., Coburn, N., Rohrer, D., & Pashler, H. (2013). Two failures to replicate high-performance-goal priming effects. *PloS One, 8*(8), e72467.

Hasher, L., Lustig, C., & Zacks, R. (2007). Inhibitory mechanisms and the control of attention. Retrieved from *Variation in Working Memory,* 227–249. <http://books.google.com/books?hl=en&lr=&id=qubgq-cnb0kC&oi=fnd&pg=PA227&dq=Inhibitory+mechanisms+and+the+control+of+attention&ots=fkOV_kgPsS&sig=sHvld-PWQxcFnpxh-cAIes7bsBw>.

Hassin, R. R. (2013). Yes it can: On the functional abilities of the human unconscious. *Perspectives on Psychological Science, 8*(2), 195–207. http://dx.doi.org/10.1177/1745691612460684.

Hassin, R. R., Bargh, J. A., & Zimerman, S. (2009). *Automatic and flexible the case of non-conscious goal pursuit, 27*(1), 20–36.

Hassin, R. R., & Sklar, A. Y. (2014). Here's to us: On unconscious processes and president Obama. In J. W. Sherman, B. Gawronski, & Y. Trope (Eds.). *Dual-process theories of the social mind*. New York, NY, US: Guilford Press.

Hassin, R. R., Uleman, J. S., & Bargh, J. A. (2005). *The new unconscious.* New York, NY: Oxford University Press.

Head, D., Snyder, A. Z., Girton, L. E., Morris, J. C., & Buckner, R. L. (2005). Frontal-hippocampal double dissociation between normal aging and Alzheimer's disease. *Cerebral Cortex (New York, N.Y.: 1991), 15*(6), 732–739. http://dx.doi.org/10.1093/cercor/bhh174.

Heaton, R. K., Chelune, G. J., Talley, J. L., Kay, G. G., & Curtiss, G. (1993). *Wisconsin Card Sorting Test manual revised and expanded.* Odessa, FL: Psychological Assessment Resources Inc.

Heitz, R. P., Schrock, J. C., Payne, T. W., & Engle, R. W. (2008). Effects of incentive on working memory capacity: Behavioral and pupillometric data. *Psychophysiology, 45*(1), 119–129. http://dx.doi.org/10.1111/j.1469-8986.2007.00605.x.

Hess, T. M. (2014). Selective engagement of cognitive resources: Motivational influences on older adults' cognitive functioning. *Perspectives on Psychological Science, 9*(4), 388–407. http://dx.doi.org/10.1177/1745691614527465.

Hess, T. M., Waters, S. J., & Bolstad, C. a. (2000). Motivational and cognitive influences on affective priming in adulthood. The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences, 55(4), P193-204. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/11584876>.

Hess, T. M., Hinson, J. T., & Statham, J. A. (2004). Explicit and implicit stereotype activation effects on memory: Do age and awareness moderate the impact of priming? *Psychology and Aging, 19*(3), 495–505. http://dx.doi.org/10.1037/0882-7974.19.3.495.

Hess, T. M., & Smith, B. T. (2016). Linkages between age-related changes in the costs of cognitive engagement, motivation, and behavior. Retrieved from In T. S. Braver, & T. S. Braver (Eds.). *Motivation and cognitive control* (pp. 339–360). New York, NY, US: Routledge/Taylor & Francis Group.

Hesselmann, G., & Moors, P. (2015). Definitely maybe: Can unconscious processes perform the same functions as conscious processes? *Frontiers in Psychology, 6*, 584. http://dx.doi.org/10.3389/fpsyg.2015.00584.

Higgins, E. T. (2006). Value from hedonic experience and engagement. *Psychological Review, 113*(3), 439–460. http://dx.doi.org/10.1037/0033-295X.113.3.439.

Higgins, E. T., & Trope, Y. (1990). Activity engagement theory: Implications of multiply identifiable input for intrinsic motivation. In E. T. Higgins, & R. M. Sorrentino (Vol. Eds.), *Handbook of motivation and cognition: Foundations of social behavior: Vol. 2*, (pp. 229–264). New York, NY: Guilford Press.

Holtzer, R., Wang, C., Lipton, R., & Verghese, J. (2012). The protective effects of executive functions and episodic memory on gait speed decline in aging defined in the context of cognitive reserve. *Journal of the American Geriatrics Society, 60*(11), 2093–2098. http://dx.doi.org/10.1111/j.1532-5415.2012.04193.x.

Hoyer, W. J., & Verhaeghen, P. (2006). Memory aging. Retrieved from In E. Birren, & K. Schaie (Eds.). *Handbook of the psychology of aging* (pp. 209–232). (6th ed.). San Diego: Academic Press.

Jennings, J. M., & Jacoby, L. L. (1993). Automatic versus intentional uses of memory: Aging, attention, and control. Retrieved from *Psychology and Aging, 8*(2), 283–293. <http://www.ncbi.nlm.nih.gov/pubmed/8323731>.

Kahneman, D. (2011). *Thinking, fast and slow.* Macmillan.

Keren, G., & Schul, Y. (2009). Two is not always better than one: A critical evaluation of two-system theories. *Perspectives on Psychological Science, 4*, 533–550.

Kinsella, K., & Wan, H. (2009). An aging world: 2008. US Census Bureau, International Population Reports. Washington, DC. Retrieved from <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:An+Aging+World+:+2008#1>.

Kleiman, T., & Hassin, R. R. (2013). When conflicts are good: Nonconscious goal conflicts reduce confirmatory thinking. *Journal of Personality and Social Psychology, 105*(3), 374–387. http://dx.doi.org/10.1037/a0033608.

Klein, R. A., Ratliff, K. A., Vianello, M., Adams, R. B. J., Bahník, Š., Bernstein, M. J., ... Nosek, B. A. (2014). Investigating variation in replicability: A "many labs" replication project. *Social Psychology, 45*(3), 142–152. http://dx.doi.org/10.1027/1864-9335/a000178.

Krawczyk, D. C., Gazzaley, A., & D'Esposito, M. (2007). Reward modulation of prefrontal and visual association cortex during an incentive working memory task. *Brain Research, 1141*, 168–177. http://dx.doi.org/10.1016/j.brainres.2007.01.052.

Krendl, A. C., Heatherton, T. F., & Kensinger, E.a. (2009). Aging minds and twisting attitudes: An fMRI investigation of age differences in inhibiting prejudice. *Psychology and Aging, 24*(3), 530–541. http://dx.doi.org/10.1037/a0016065.

Labouvie-Vief, G. (1985). Intelligence and cognition. In J. E. Birren, K. W. Schaie, J. E. Birren & K. W. Schaie (Eds.), Handbook of the psychology of aging (2nd ed., pp. 500–530). New York, NY, US: Van Nostrand Reinhold Co. Retrieved from <http://search.ebscohost.com/login.aspx?direct=true&db=psyh&AN=1985-98143-019&site=ehost-live>.

Lau, H. C., & Passingham, R. E. (2007). Unconscious activation of the cognitive control system in the human prefrontal cortex. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience, 27*(21), 5805–5811. http://dx.doi.org/10.1523/JNEUROSCI.4335-06.2007.

Levy, B. R., Pilver, C., Chung, P. H., & Slade, M. D. (2014). Subliminal strengthening: Improving older individuals' physical function over time with an implicit-age-stereotype intervention. *Psychological Science, 25*(12), 2127–2135. http://dx.doi.org/10.1177/0956797614551970.

Lezak, M., Howieson, D., & Loring, D. (2004). *Neuropsychological assessment* (4th ed.). Oxford, UK: Oxford University Press.

Liu, L. L., & Park, D. C. (2004). Aging and medical adherence: The use of automatic processes to achieve effortful things. *Psychology and Aging, 19*(2), 318–325. http://dx.doi.org/10.1037/0882-7974.19.2.318.

Mather, M., & Carstensen, L. L. (2005). Aging and motivated cognition: The positivity effect in attention and memory. *Trends in Cognitive Sciences, 9*(10), 496–502. http://dx.doi.org/10.1016/j.tics.2005.08.005.

Miller, K. J., Dye, R. V., Kim, J., Jennings, J. L., O'Toole, E., Wong, J., & Siddarth, P. (2013). Effect of a computerized brain exercise program on cognitive performance in older adults. *The American Journal of Geriatric Psychiatry: Official Journal of the American Association for Geriatric Psychiatry, 21*(7), 655–663. http://dx.doi.org/10.1016/j.jagp.2013.01.077.

Morewedge, C. K., & Kahneman, D. (2010). Associative processes in intuitive judgment. *Trends in Cognitive Sciences, 14*(10), 435–440. http://dx.doi.org/10.1016/j.tics.2010.07.004.

Nisbett, R. E., & Wilson, T. D. (1977). Telling more than we can know: Verbal reports on mental processes. *Psychological Review, 84*(3), 231–259. http://dx.doi.org/10.1037/0033-295X.84.3.231.

Nyberg, L., & Salami, A. (2010). Longitudinal evidence for diminished frontal cortex function in aging. *Proceedings of the, 107*(52), 22682–22686. http://dx.doi.org/10.1073/pnas.1012651108/-/DCSupplemental.www.pnas.org/cgi/doi/10.1073/pnas.1012651108.

Ortman, J. M., Velkoff, V. A., & Hogan, H. (2014). *An aging nation: The older population in the United States, current population reports.* Washington, DC: U.S. Census Bureau.

Owen, A. M., Hampshire, A., Grahn, J.a., Stenton, R., Dajani, S., Burns, A. S., ... Ballard, C. G. (2010). Putting brain training to the test. *Nature, 465*(7299), 775–778. http://dx.doi.org/10.1038/nature09042.

Park, D. C. (2000). The basic mechanism, accounting for age-related decline in cognitive function. In D. C. Park, & N. Schwarz (Eds.). *Cognitive aging: A primer* (pp. 3–21). Philadelphia: Psychology Press.

Park, D. C., Lautenschlager, G., Hedden, T., Davidson, N. S., Smith, A. D., & Smith, P. K. (2002). Models of visuospatial and verbal memory across the adult life span. *Psychology and Aging, 17*(2), 299–320. http://dx.doi.org/10.1037//0882-7974.17.2.299.

Park, D., & Reuter-Lorenz, P. (2009). The adaptive brain: Aging and neurocognitive scaffolding. *Annual Review of Psychology, 173–196*. http://dx.doi.org/10.1146/annurev.psych.59.103006.093656.The.

Pessiglione, M., Schmidt, L., Draganski, B., Kalisch, R., Lau, H., Dolan, R. J., & Frith, C. D. (2007). How the brain translates money into force: A neuroimaging study of subliminal motivation. *Science (New York, N.Y.), 316*(5826), 904–906. http://dx.doi.org/10.1126/science.1140459.

Pessoa, L. (2009). How do emotion and motivation direct executive control? *Trends in Cognitive Sciences, 13*(4), 160–166. http://dx.doi.org/10.1016/j.tics.2009.01.006.

Peters, E., Hess, T. M., Västfjäll, D., & Auman, C. (2007). Adult age differences in dual information processes: Implications for the role of affective and deliberative processes in older adults' decision making. *Perspectives on Psychological Science, 2*(1), 1–23. http://dx.doi.org/10.1111/j.1745-6916.2007.00025.x.

Phillips, L. H., & Henry, J. D. (2008). Adult aging and executive functioning. In V. Anderson, R. Jacobs, & P. J. Anderson (Eds.), Executive functions and the frontal lobes: A lifespan perspective. Neuropsychology, neurology, and cognition (pp. 57–79). Philadelphia, PA: Taylor & Francis.

Phillips, L. H., Bull, R., Allen, R., Insch, P., Burr, K., & Ogg, W. (2011). Lifespan aging and belief reasoning: Influences of executive function and social cue decoding. *Cognition, 120*(2), 236–247. http://dx.doi.org/10.1016/j.cognition.2011.05.003.

Queen, T. L., & Hess, T. M. (2010). Age differences in the effects of conscious and unconscious thought in decision making. *Psychology and Aging, 25*(2), 251–261. http://dx.doi.org/10.1037/a0018856.

Queen, T. L., & Hess, T. M. (2017). Linkages between resources, motivation, and engagement in everyday activities. *Motivation Science*. http://dx.doi.org/10.1037/mot0000061.

Raz, N. (2000). Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings. In F. I. M. Craik, & T. A. Salthouse (Eds.). *The handbook of aging and cognition* (pp. 1–90). (2nd ed.). Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers.

Rhodes, M. G. (2004). Age-related differences in performance on the Wisconsin card sorting test: A meta-analytic review. *Psychology and Aging, 19*(3), 482–494. http://dx.doi.org/10.1037/0882-7974.19.3.482.

Rim, S., Min, K. E., Uleman, J. S., Chartrand, T. L., & Carlston, D. E. (2013). Seeing others through rose-colored glasses: An affiliation goal and positivity bias in implicit trait impressions. *Journal of Experimental Social Psychology, 49*(6), 1204–1209.

Salthouse, T.a., Atkinson, T. M., & Berish, D. E. (2003). Executive functioning as a potential mediator of age-related cognitive decline in normal adults. *Journal of Experimental Psychology. General, 132*(4), 566–594. http://dx.doi.org/10.1037/0096-3445.132.4.566.

Savine, A. C., Beck, S. M., Edwards, B. G., Chiew, K. S., & Braver, T. S. (2010). Enhancement of cognitive control by approach and avoidance motivational states. *Cognition & Emotion, 24*(2), 338–356. http://dx.doi.org/10.1080/02699930903381564.

Schubert, T. W., Waldzus, S., & Giessner, S. R. (2009). Control over the association of power and size. *Social Cognition, 27*(1), 1–19. http://dx.doi.org/10.1521/soco.2009.27.1.1.

Sherman, J. W., Gawrsonski, B., & Trope, Y. (2014). *Dual process theories of the social mind.* New York, NY: Guilford Press.

Sklar, A. Y., Levi, N., Goldstein, A., Mandel, R., Maril, A., & Hassin, R. R. (2012). Reading and doing arithmetic nonconsciously. *Proceeding of the National Academy of Sciences, 109*(48), 19614–19619.

Sorel, O., & Pennequin, V. (2008). Aging of the planning process: The role of executive functioning. *Brain and Cognition, 66*(2), 196–201. http://dx.doi.org/10.1016/j.bandc.2007.07.006.

Soto, D., Mäntylä, T., & Silvanto, J. (2011). Working memory with-out consciousness. *Current Biology, 21*, 912–913.

Soto, D., & Silvanto, J. (2014). Reappraising the relationship between working memory and conscious awareness. *Trends in Cognitive Sciences, 18*(10), 520–525. http://dx.doi.org/10.1016/j.tics.2014.06.005.

Spreen, O., & Strauss, E. A. (1998). Compendium of neuropsychological tests. Administration, norms, and commentary. New York, NY: Oxford University Press.

Stine-Morrow, E. A. L., Payne, B. R., Roberts, B. W., Kramer, A. F., Morrow, D. G., Payne, L., … Parisi, J. M. (2014). Training versus engagement as paths to cognitive enrichment with aging. Psychology and Aging, 29si(4), 891–906. 10.1037/a0038244.

Strough, J., de Bruin, W. B., & Peters, E. (2015). New perspectives for motivating better decisions in older adults. *Frontiers in Psychology, 6*, 783. http://dx.doi.org/10.3389/fpsyg.2015.00783.

Troyer, A. K., Leach, L., & Strauss, E. (2006). Aging and response inhibition: Normative data for the Victoria Stroop Test. *Neuropsychology, Development, and Cognition. Section B, Aging, Neuropsychology and Cognition, 13*(1), 20–35. http://dx.doi.org/10.1080/138255890968187.

Umanath, S., & Marsh, E. J. (2014). Understanding how prior knowledge influences memory in older adults. *Perspectives on Psychological Science, 9*(4), 408–426.

Ursu, S., Clark, K.a., Aizenstein, H. J., Stenger, V. A., & Carter, C. S. (2009). Conflict-related activity in the caudal anterior cingulate cortex in the absence of awareness. *Biological Psychology, 80*(3), 279–286. http://dx.doi.org/10.1016/j.biopsycho.2008.10.008.

van Gaal, S., Ridderinkhof, K. R., van den Wildenberg, W. P. M., & Lamme, V. a. F. (2009). Dissociating consciousness from inhibitory control: Evidence for unconsciously triggered response inhibition in the stop-signal task. Journal of Experimental Psychology. Human Perception and Performance, 35(4), 1129–1139. 10.1037/a0013551.

van Gaal, S., Scholte, H. S., Lamme, V. a. F., Fahrenfort, J. J., & Ridderinkhof, K. R. (2011). Pre-SMA graymatter density predicts individual differences in action selection in the face of conscious and unconscious response conflict. Journal of Cognitive Neuroscience, 23(2), 382–390. 10.1162/jocn.2010.21444.

van Gaal, S., & Lamme, V.a. F. (2012). Unconscious high-level information processing: Implication for neurobiological theories of consciousness. *The Neuroscientist: A Review Journal Bringing Neurobiology, Neurology and Psychiatry, 18*(3), 287–301. http://dx.doi.org/10.1177/1073858411404079.

Vaughan, L., & Giovanello, K. (2010). Executive function in daily life: Age-related influences of executive processes on instrumental activities of daily living. *Psychology and Aging, 25*(2), 343–355. http://dx.doi.org/10.1037/a0017729.

Verhaeghen, P. (2011). Aging and executive control: Reports of a demise greatly exaggerated. *Current Directions in Psychological Science, 20*(3), 174–180. http://dx.doi.org/10.1177/0963721411408772.

Vincent, G. K., & Velkoff, V. A. (2010). The next four decades: The older population in the United States: 2010 to 2050 (No. 1138). US Department of Commerce, Economics and Statistics Administration, US Census Bureau. US Department of Commerce, Economics and Statistics Administration, US Census Bureau.

von Bastian, C. C., Langer, N., Jäncke, L., & Oberauer, K. (2013). Effects of working memory training in young and old adults. *Memory & Cognition, 41*(4), 611–624. http://dx.doi.org/10.3758/s13421-012-0280-7.

Zimerman, S., Hasher, L., & Goldstein, D. (2011). Cognitive ageing: A positive perspective. In N. Kapur (Ed.). *The paradoxical brain* (pp. 130–150). Cambridge, U.K.: Cambridge University Press.