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The effect of reward type on cognitive control in young and old adults*

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Recent studies on cognitive control have integrated motivational factors into the control process. However, how motivation affects cognitive control processes remains unclear. Based on previous findings, we assumed that the intensity of control would change flexibly with the age difference in value system and the ability to allocate cognitive resources depending on reward value would be well-maintained in older age. In this study, we examined this hypothesis by varying the feedback presented to young and older adults in the Eriksen flanker task. which presents three different types of feedback: emotional, monetary, and neutral. Each age group showed their best performance in the feedback condition which was the most appealing to them. This result suggests that the level of control engagement is modulated by reward value and there is no age difference in the ability to allocate the optimal amount of the control resource. These findings provide a novel perspective in understanding individual differences in cognitive control.

Key words : cognitive control, aging, reward, motivation, feedback type

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Cognitive control refers to the ability to guide thoughts and actions in accordance with one's inner goal (Miller & Cohen, 2001). One of the most important questions about cognitive control is how exactly the control system determines when and how strongly the control process should be engaged. The conflict monitoring theory, which is the predominant hypothesis of cognitive control, postulates that the control system serves this goal by monitoring conflicts, suggesting that the detection of conflict acts as a signal which specifies the amount of control needed to resolve the conflict (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick, Cohen, & Carter, 2004; Carter & van Veen, 2007).

However, this conflict-control loop lacks information regarding the optimal level of control to be engaged. Theoretically, the best way to resolve conflict is to exert the maximum level of control. However, the resource of cognitive control is limited and top-down processing is effortful, making the exertion of control the last choice for most of us (Kool, McGuire, Rosen, & Botvinick, 2010; Westbrook, Kester, & Braver, 2013). Westbrook et al. (2013) found that people consistently chose a control-free task until the reward for the control-demanding task became significantly bigger than that for the other task, using a 'free-choice' task paradigm in which participants could choose between two different task conditions and were awarded with different amounts of money depending on their choices. If one should decide to spend the control resource, the amount of expenditure is adjusted to maximize the expected benefit with minimum effort. Behavioral economics studies have repeatedly confirmed that the control system involves the process of evaluating the costs and benefits (Dixon & Christoff, 2012; Kool & Botvinick, 2014; Saunders, Milyavskaya, & Inzlicht, 2015).

Many studies have reported that rewards enhance control signal intensities (Boehler, Schevernels, Hopf, Stoppel, & Krebs, 2014; Kleinsorge & Rinkenauer, 2012; Krebs, Boehler, Appelbaum, & Woldorff, 2013; Leotti, Iyengar, & Ochsner, 2010). Padmala and Pessoa (2011) reported that participants responded faster and more accurately when they were given a trial pre-cue that signaled a possible monetary reward in a revised Stroop task. Enhanced conflict adaptation effect, which is the result of persistent up-regulation of control by conflict detection in the previous trial (Egner, 2007; Gratton, Coles, & Donchin, 1992), is another evidence of the effect of reward on cognitive control. The conflict adaptation effect **based on reaction time data** was larger when monetary reward was expected (Braem, Verguts, Roggeman, & Notebaert, 2012; Sturmer, Nigbur, Schacht, & Sommer, 2011). The effect of reward on cognitive control indicates that the optimal level of control engagement is determined through the evaluation of the expected result.

Neuroscience studies have also reported the effects of reward on the brain's cognitive control network (Adcock, Thangavel, Whitfield-Gabrieli, Knutson, & Gabrieli, 2006; Engelmann, Damaraju, Padmala, & Pessoa, 2009; Jimura, Locke, & Braver, 2010; Kouneiher, Charron, & Koechlin, 2009; Krebs et al., 2013; Krebs, Boehler, Roberts, Song, & Woldorff, 2012; Wittmann et al., 2005). The conflict monitoring model proposed that the dorsal anterior cingulate cortex(ACC) monitors and detects the conflict, whereas the dorsolateral prefrontal cortex resolves conflict by reinforcing the top-down biasing signal (Kerns et al., 2004; MacDonald, Cohen, Stenger, & Carter, 2000). Recent studies found that the activation of these two regions is stronger when there is an expected reward (Beck, Locke, Savine, Jimura, & Braver, 2010; Chiew & Braver, 2011; Jimura et al., 2010). Rowe, Eckstein, Braver, and Owen (2008) reported that ACC activity increased when there was the possibility of a reward and that this is accompanied by stronger connectivity between the dorsolateral prefrontal cortex and other prefrontal cortical regions that are related to the task dimension.

The flexible change of control intensity by reward valuation can account for selective engagement of cognitive control in older adults. Accumulating evidence has suggested that older adults show a decline in cognitive control capabilities (Braver & West, 2008; Braver & Barch, 2002; de Fockert, Ramchurn, van Velzen, Bergstrom, & Bunce, 2009; Hedden & Gabrieli, 2004; Lucci, Berchicci, Spinelli, Taddei, & Di Russo, 2013; Raz, 2000; Themanson, Hillman, & Curtin, 2006; Verhaeghen, 2011). However, the age effect on cognitive control is attenuated when the task involves emotional material (Mikels, Larkin, Reuter-Lorenz, & Carstensen, 2005; Samanez-Larkin, Robertson, Mikels, Carstensen, & Gotlib, 2009). Monti, Weintraub, and Egner (2010) asked participants to categorize the gender (gender discrimination) or emotional expression (emotion discrimination) of face stimuli while ignoring distractor words written on the face using a revised Stroop task. The elderly performed worse in the gender discrimination condition, but this deficit disappeared in the emotion discrimination condition.

This asymmetry might result from a distractor-specific conflict resolution mechanism of cognitive control in the brain(Egner, Etkin, Gale, & Hirsch, 2008; Etkin, Egner, Peraza, Kandel, & Hirsch, 2006). Egner et al. (2008) suggested that a distinct brain network deals with conflict that originates from emotional stimuli. With the flanker-like discrimination task mentioned above, they found that the rostral ACC, not the lateral prefrontal cortex, resolves conflict in the emotion discrimination condition. Monti et al. (2010) suggested that this dissociable affective control mechanism partly explains the selective preservation of cognitive control in older adults. However, studies in the effect of aging on cognitive control have consistently confirmed the age effect on brain regions associated with control process, including the dorsal ACC (Lucci et al., 2013; Mathalon et al., 2003; Metzler-Baddeley et al., 2012; Pardo et al., 2007). If the inconsistent effect of aging on cognitive control results from the dissociable brain networks, the effects of aging on subregions of the ACC must be asymmetric. However, it seems unlikely that those two neighboring brain regions would be differentially affected by aging.

Motivational shift in later life is another possible explanation for this. According to the socioemotional selectivity theory, people put priority on emotional values when they feel that they are nearing the end of their lifespan (Carstensen, 1992; Carstensen, Isaacowitz, & Charles, 1999). Thus, resolving the conflict caused by emotional information can be more significant for older adults. In other words, it might be the subjective value of the emotional information for older adults which results in the asymmetric effect of aging on cognitive control.

Neural evidence strongly supports the motivational shift hypothesis. Older adults showed selective activation in the cognitive control network in the brain while dealing with conflicts originating from emotional information (Allard & Kensinger, 2014; Ford & Kensinger, 2014; Jacques, Dolcos, & Cabeza, 2009; Waldinger, Kensinger, & Schulz, 2011). Samanez-Larkin, Robertson, Mikels, Carstensen, and Gotlib (2009) reported that older adults showed a significant interference effect in the lateral frontal cortex in the non-emotional word condition whereas the interference effect was smaller in the emotional condition than younger adults in a lexical discrimination task. Ford and Kensinger (2014) reported that structural and functional connectivity was negatively correlated between the amygdala and dorsal ACC only in older adults when they retrieve memories of negative events, but this relation was not found when retrieving neutral events.

Taken together, the cognitive control mechanism involves the evaluation process of expected reward. Based on the previous findings, we presumed that the intensity of control is modulated by the age difference in value system. However, previous studies have not directly examined the effect of age difference in evaluating the reward on cognitive control. If the asymmetric effects of aging on cognitive control is the a result of the reward evaluation process of the control mechanism, then modulation of control intensity by different reward types would be also found in younger adults. This could be evidence demonstrating that the ability to set optimal control signal strength is well maintained in later life. However, if the asymmetry in older adults is due to an adaptive strategy to compensate for cognitive decline, the effect of reward type would appear in older adults only. The present study aimed to examine the effect of different reward types on cognitive control in younger and older adults.

The current study sought to investigate two assumptions. One is that the control signal intensity is modulated in accordance with the significance of reward for each individual. The other is that the ability to set the optimal control intensity remains intact in later years of life. We predicted that the performance of executive task would be enhanced in older adults when emotional reward is given. At the same time, younger adults would do so when monetary reward is expected.

Methods

Participants

Thirty-two younger adults (15 males and 17 females, age *M* = 22.36, *SD* = 2.27) participated for course credit. Thirty-one older adults (13 males and 18 females, age *M* = 72.15, *SD* = 5.23) were recruited from a local community center. The two age groups did not differ in years of education (Young: *M* = 14.03, *SD* = 2.1; Old: *M* = 13.91, *SD* = 2.3, $t(68) = 0.227$, $p = 0.82$, $df=1$). All participants gave written informed consent, and the use of human subjects in this study was approved by the Kyungpook National University Institutional Review Board. No participants reported a history of neurological or psychiatric disorders. For the older participants, the scores on the Korean version of the Mini-Mental State Examination ranged from 25 – 30 (*M* = 28.58, *SD* = 1.44), demonstrating no apparent signs of dementia.

Procedure

After the participants provided informed consent and the older participants completed the Korean Mini-Mental State Examination, they performed the Eriksen flanker task. Responses were made by pressing the appropriate key with the index finger of either hand. Participants performed a practice block consisted of 20 trials before every experimental block. Every trial started with a white fixation cross displayed in the center of the screen, and it remained on the screen for 2.5∼4 s. Five arrows then appeared on-screen for 1 s. A black screen replaced the stimuli and remained for up to 3 s until the feedback image appeared (Figure 1). Responses had to be made before the feedback display and responses which were made after time limit were regarded as incorrect. The feedback pictures were presented immediately after the participants' responses and displayed for 1.5 s. The participants were encouraged to respond as fast and accurately as possible.

Every participant completed 360 trials that were divided into three blocks (block 1:. emotional feedbak, block 2: neutral feedback, block 3: monetary feedback). The order of the blocks was distributed across the participants. In the emotional feedback condition, a pleasant picture was displayed when the participant made correct response, and an unpleasant picture was displayed when the answer was either wrong or was not made within the time limit. In the neutral feedback condition, neutral pictures were displayed after the participant's response. In the monetary feedback condition, the participants were told that prize money was available in each trial and that they would receive the total money they won when the experiment ended. The maximum reward was 30,000 won or approximately 26 US dollars.

Half of the trials were congruent, and half were incongruent. The trials were further divided into two different conditions depending on the congruency of the previous trial, which resulted in four different conditions[congruent-ongruent(CC), congruent-incongruent(CI), incongruentongruent(IC), and incongruent- ncongruent (II)], with 30 trials of each condition. In order to prevent possible priming Mayr, Awh, & Laurey, 2003) and partial repetition (Hommel, Li, & Li, 2004) effects from biases in the response pattern, the same stimuli were not repeated in more than five consecutive trials, and the total number of presentations of each stimulus was equal. Response repetition was controlled by setting the percentage of repeated responses to 50% and by preventing repeated responses from exceeding four consecutive trials.

Task and Stimuli

A modified version of the Eriksen flanker task was used (Eriksen & Erkisen, 1974). The stimuli consisted of five arrows. The five arrows pointed in the same direction (left or right) in congruent condition or the center arrow pointed in the opposite direction to the others in incongruent condition, which resulted in four distinct stimuli. The participants were asked to press the button that corresponded to the direction of the center arrow while ignoring the other arrows on either side of the center one. A feedback picture was displayed immediately after participants had made a response. The pictures were from the International Affective Picture System, and they were chosen according to their ratings for valence and arousal. More specifically, in the emotional feedback condition, a picture of a smiling child (valence: 7.08, arousal: 4.46) was used to indicate a correct response, and a lacerated face (valence: 1.91, arousal: 6.76) indicated a wrong response. In the neutral condition, a mug (valence: 4.93, arousal: 3.01) or a towel (valence: 7.08, arousal: 3.16) were used (Figure 1). The feedback images in the monetary condition were pictures of coins with word label informing the amount of reward money superimposed on the center of the picture.

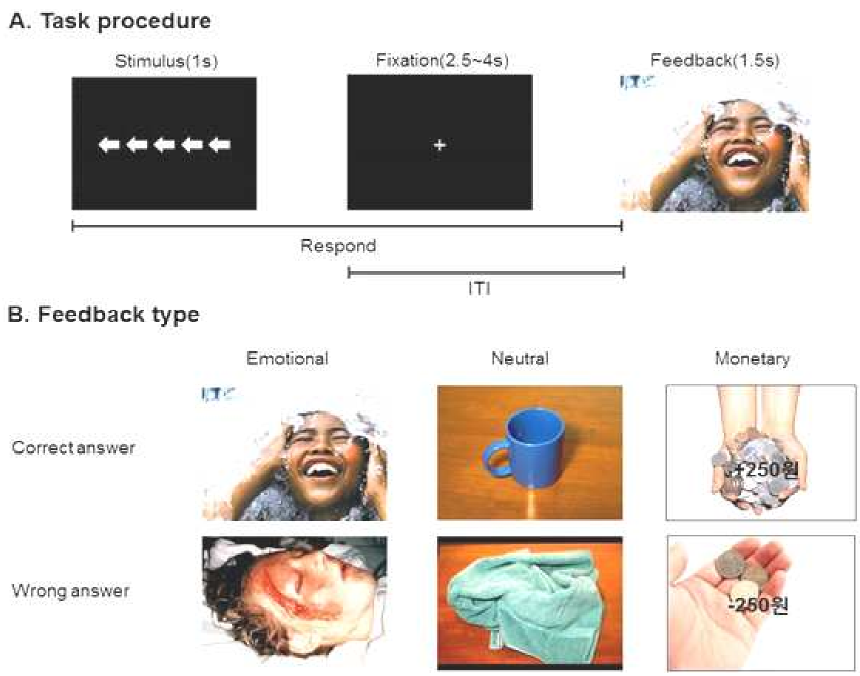

Figure 1. Task procedure and feedback images for three different feedback conditions

Analysis

All trials containing errors and data for the participants with mean response times (RT) that exceeded three SDs above or below the sample mean were removed. The data for an older adult who did not follow the task instructions because he didn't understand the fact that he can make response after the stimuli were also removed. Thus, data for five participants (three older adults and two younger adults) were excluded (6.6% of total participants).

The two independent variables were the mean RT and the conflict adaptation effect which was converted into a percentage. We converted RT data into percentage data because of the following reason. Conflict adaptation refers to both slower reaction times in congruent trials preceded by incongruent trials (IC-CC) and faster response times in incongruent trials preceded by incongruent trials (CI-II). However, a simple comparison of RT can be biased because both measures are relative delays of response time. For example, if a participant has an RT of 100 ms on a CC trial and an RT of 110 ms on an IC trial, the adaptation effect is then 10 ms. Meanwhile, if another participant has RTs of 1,100 ms on a CC trial and 1,110 ms on an IC trial, the adaptation effect is again 10 ms despite the relative delay being much smaller than that of the former participant. To avoid this, each adaptation effect (IC-CC and CI-II) was converted into a percentage score and then summed (%).

IC-CC(%) = (IC RT – CC RT) / CC RT × 100
CI-II(%) = (CI RT – II RT)/ II RT × 100

The mean RT data were analyzed in a four-way mixed-measures 3 × 2 × 2 × 2 analysis of variance (ANOVA), with the within-subject factors of feedback type (emotional, neutral, or monetary), current congruency (congruent, incongruent), previous congruency (congruent, incongruent) and a between-subject factor of age (young, old). We conducted another 3 × 2 ANOVA in order to assess the effects of age and feedback type on the conflict adaptation effect.

Results

Accuracy

A four-way mixed ANOVA of age (2) × feedback type (3) × current condition (2) × previous condition (2) revealed no significant main effect or interaction except the main effect of current congruency[$F(1, 61) = 38.43$, $p = 0.00$, $df = 1$] and interaction of previous congruency and current congruency[$F(1, 61) = 4.53$, $p = 0.04$, $df = 1$]. This indicates that the results in response time are not the effect of speed-accuracy trade off(Table 1), which is the phenomenon of sacrifice the speed to raise the accuracy or vice versa.

Response time

Response time of each 16 condition is presented in Table 2. A four-way mixed ANOVA of age (2) × feedback type (3) × current condition (2) × previous condition (2)

Table 1. Mean Accuracy And Standard Deviation Of The Two Age Groups In 16 Condition Depending On Feedback Type, Congruency Of Previous Trial And Congruency Of Current Trial

Feedback Type	Age	Previous C				Previous I			
		Current C		Current I		Current C		Current I	
		M	*Sd*	*M*	*Sd*	*M*	*Sd*	*M*	*Sd*
Emotional	Oa	1.00	0.01	0.99	0.02	1.00	0.01	0.99	0.02
	Ya	1.00	0.01	0.99	0.02	1.00	0.01	0.99	0.03
Neutral	Oa	1.00	0.01	0.98	0.03	0.99	0.03	0.98	0.03
	Ya	0.99	0.03	0.98	0.05	0.99	0.02	0.99	0.23
Monetary	Oa	0.99	0.02	0.97	0.07	0.99	0.04	0.99	0.02
	Ya	1.00	0.01	0.99	0.02	0.99	0.02	0.99	0.01

Table 2. Mean response time(ms) and standard deviation of the two age groups in 16 condition depending on feedback type, congruency of previous trial and congrency of current trial

Feedback type	Age	Previous C				Previous I			
		Current C		Current I		Current C		Current I	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Emotional	OA	656.10	125.69	724.68	135.37	662.54	129.75	702.69	129.23
	YA	432.38	86.73	464.11	72.27	426.64	68.82	464.96	80.98
Neutral	OA	687.49	139.10	745.48	137.64	683.65	135.44	733.31	135.92
	YA	425.25	92.89	460.77	73.92	426.29	80.20	461.90	67.45
Monetary	OA	699.14	159.31	754.15	162.59	700.23	162.33	745.85	160.79
	YA	421.49	64.71	469.04	67.75	424.06	66.62	454.88	64.20

revealed a main effect of age [$F(1, 61) = 96.24$, $p < 0.00$, $df=1$]. The mean RT of the older adults (mean = 707.94, SD = 141.60) was longer than that of the younger adults (M = 445.87, SD = 68.52). The main effect of current congruency was significant [$F(1, 62) = 376.95$, $p = 0.00$, $df=1$], which revealed a congruency effect.

The interaction of age and feedback type was significant [$F(2, 122) = 3.50$, $p = 0.03$, $df=2$]. To further explore this interaction, a one-way repeated-measures ANOVA was conducted with feedback type as the within-subject factor in each age group. The main effect of feedback type was significant in the older adults [$F(2, 62) = 3.7$, $p = 0.03$, $df=2$]. A planned comparison showed that the older adults responded faster in the emotional condition compared with the neutral ($p = 0.03$) and monetary condition ($p = 0.04$). In the younger adults, however, there was no main effect of feedback type [$F(2, 60) = 0.19$, $p = 0.83$, $df=2$]. A planned comparison of younger adults showed that they didn't respond any faster in monetary condition than bothe emotional condition(p = 0.50) and neutral condition(p = 0.85). Based on the fact that the effect of feedback type on the converted conflict adaptation effect was significant and that the interaction of the previous congruency and current congruency was found only in the monetary condition in younger adults, we presumed that this is because the task might have been too easy and that a ceiling effect might have hindered the impact of motivation on RT.

The ANOVA revealed an interaction of age and current congruency [$F(1, 122) = 12.43$, $p = 0.00$, $df=1$], which indicated an age difference in the flanker effect. The flanker effect was larger in older adults [$F(1, 61) = 376.92$,

p = 0.00, df=1]. The conflict adaptation effect was revealed by the significant current congruency (2) × previous congruency (2) interaction [F(1, 61) = 10.63, p = 0.00, df=1], which indicated that the current congruency effect was modulated by the previous congruency. This interaction was evident in older adults [F(1, 31) = 20.5, p = 0.00, df=1], but not in younger adults [F(1, 31) = 0.4, p = 0.53, df=1].

Finally, a four-way interaction of feedback type, age, current congruency, and previous congruency was found [F(2, 122) = 5.07, p = 0.01, df=2](See Figure 2). The ANOVAs were conducted separately for each group, and a significant current congruency (2) × previous congruency (2) × feedback type (3) interaction was found in the older age group [F(2, 62) = 3.2, p = 0.05, df=2] but not in the younger group [F(2, 60) = 2.84, p = 0.06, df=2]. In the older adults, the current congruency (2) × previous congruency (2) interaction was significant only in the emotional feedback condition [F(1, 31) = 22.0, p = 0.00, df=1] and not in the neutral [F(1, 31) = 1.5, p = 0.23, df=1] or monetary feedback condition [F(1, 31) = 2.7, p = 0.11, df=1] (Figure 2). In the younger adults, the two-way interaction

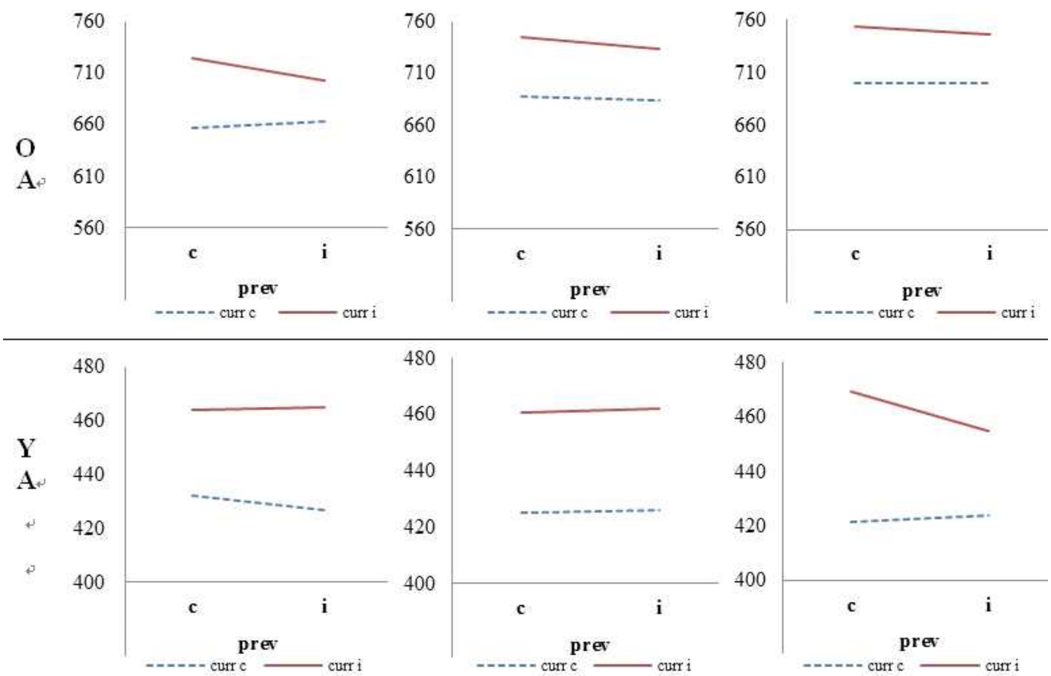

Figure 2. Interaction of the congruency of the current trial and the congruency of the previous trial in the feedback conditions in each age group(C:congruent, I: incongruent, curr: current, prev: previous)

of current congruency (2) × previous congruency (2) was significant only in the monetary condition [$F(1, 30) = 19.60$, $p = 0.00$, $df=1$] and not in the emotional [$F(1, 30) = 0.32$, $p = 0.57$, $df=1$] or neutral condition [$F(1, 30) = 0.01$, $p = 0.98$, $df=1$].

Conflict adaptation effect (%)

Mean conflict adaptation effect(%) and SDs of each age group in three different feedback conditions are presented in table 3. In order to explore the interaction of age and feedback type on the conflict adaptation effect, a two-way ANOVA was conducted on the converted conflict adaptation effect. The main effects of age [$F(1, 68) = 1.7$, $p = 0.20$] and feedback type [$F(1, 136) = 1.2$, $p = 0.30$] were not significant. However, the interaction of age and feedback type was significant [$F(2, 136) = 3.5$, $p = 0.03$]. We conducted a one-way ANONA on the adaptation effect (%) in each age group (Figure 3). In the older adults, the main effect of feedback type was significant [$F(2, 62) = 3.08$, $p = 0.05$]. A planned comparison analysis revealed that the adaptation effect was larger in

Table 3. Mean conflict adaptation effect(%) and SDs of each age group in three different feedback conditions

	YA		OA	
	M	*SD*	*M*	*SD*
Emotional	-0.45	9.57	4.09	5.23
Neutral	0.66	6.10	1.34	5.21
Monetary	3.72	4.72	1.32	4.36

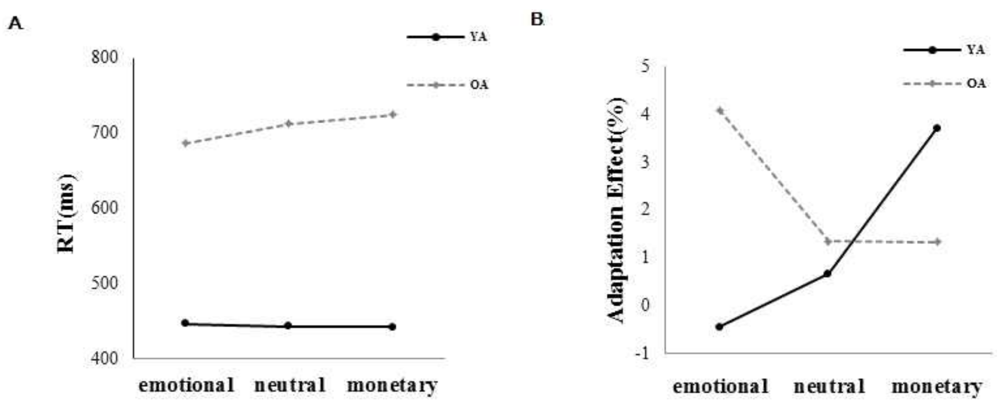

Figure 3. A. Mean response times by age group and feedback type. B. Mean adaptation effect (%) by age group and feedback type

the emotional feedback condition than in the neutral (p = 0.46) or monetary (p = 0.44) conditions. The main effect of feedback type was also significant in the younger adults [$F(2, 60) = 3.12$, $p = 0.05$]. The conflict adaptation effect was larger in the monetary condition than in the emotional (p = 0.02) or neutral (p = 0.04) condition.

Lastly, however, we could not find any age effect in neutral feedback condition[$F(1, 61) = 8.76$, $p = 0.21$], which is not consistent with previous findings.

Discussion

The goal of this study was to examine the effect of the subjective value of expected reward on cognitive control and the ability to modulate control intensity in later life. By using a revised version of the flanker task, we obtained two main findings.

First, the interaction of age and feedback type on response time and the adaptation effect revealed that control intensity was modulated by the significance of the reward for each age group. It is noteworthy that there was an age difference in the feedback condition where the strongest control was implemented. This result raises the possibility that the intensity of the control signal can vary depending on age difference in value system. However, previous models of cognitive control have posited that the signal intensity should reach a certain level in order to resolve a conflict. The signal that is not strong enough would result in a failure of the control process from this point of view. However, the current results suggest that the optimal control intensities can differ by how highly motivated the individual is to achieve the goal. This finding provides a novel perspective in interpreting previous findings regarding individual differences in cognitive control.

One of the research areas where the current result could shed light is individual differences of cognitive control in clinical populations. Studies on this area have found that the patients with a mood disorder lack top-down control capabilities (Comte et al., 2015; Demeyer, De Lissnyder, Koster, & De Raedt, 2012; Etkin, Prater, Hoeft, Menon, & Schatzberg, 2010; Vanderhasselt et al., 2012). However, some researchers reported that there is a content-specific deficit in cognitive control depending upon the valence of the distractor stimuli. Depression symptoms were related to poorer performance and weaker neural signals when an attentional shift was needed to draw the focus away from sad stimuli. However, the performance deficits in the clinical group disappeared when the irrelevant stimuli were neutral ones (Beevers, Clasen, Stice, & Schnyer, 2010; Fales et al., 2008; Goeleven, De Raedt, Baert, & Koster, 2006; Hertel & Gerstle, 2003; Joormann & Gotlib, 2008, 2010; Vanderhasselt, Baeken, Van Schuerbeek, Luypaert, & De Raedt, 2013; Vanderhasselt et al., 2014; Vanderhasselt et al., 2012). There also was no group difference when patients with depression were asked to suppress attention to neutral or positive stimuli (Beevers et al., 2010; Clawson, Clayson, & Larson, 2013; Goeleven et al., 2006; Power, Dalgleish, Claudio, Tata, & Kentish, 2000; Saunders & Jentzsch, 2014). These results suggest that the failure of inhibiting irrelevant information in the depression group was not because of an abnormality in the top-down mechanism itself but rather because the participants were strongly motivated to pay attention to negative information.

A similar pattern of content specificity is also found in patients with anxiety disorders. The malfunction of the control system has mainly been observed when responses to anxiety-related information are to be suppressed (Ashley, Honzel, Larsen, Justus, & Swick, 2013; Becker, Rinck, Margraf, & Roth, 2001; Kalanthroff, Henik, Derakshan, & Usher, 2015; Pergamin-Hight, Naim, Bakermans-Kranenburg, van, & Bar-Haim, 2015; Siqi Chen, 2016). Ashley and colleagues (2013) found that veterans of the Afghanistan and Iraq wars with post-traumatic stress disorder showed slower response times and lower accuracy rates when they were asked to name the font color of trauma-related words. More specifically, the control deficit was found only in the war-traumatic words condition and there was no difference among neutral, positive, or negative word conditions, indicating that the content specificity was highly sensitive. Larger event-related negativity in patients with obsessive compulsive disorder who take mistakes or errors very seriously is further evidence for this (Gehring, Himle, & Nisenson, 2000; Grundler, Cavanagh, Figueroa, Frank, & Allen, 2009; Mathews, Perez, Delucchi, & Mathalon, 2012; Nieuwenhuis, Nielen, Mol, Hajcak, & Veltman, 2005). Surprisingly, this content-specific deficit can be induced by transient states elicited by experimental manipulation, indicating that this is not limited to relatively long-term characteristics, such as mental disorders (Olvet & Hajcak, 2012).

These results suggest that the failure of the control process in patients with mood disorders might be partly due to individual differences in control intensity by motivational factor, not the malfunction of the control system itself. The fact that there was no group difference in task conditions which were not related to individual motivation further supports our assumption. We could find additional evidence from studies on the effect of individual differences in motivation on cognitive control in healthy, normal adults (Keogh, Ellery, Hunt, & Hannent, 2001; Locke & Braver, 2008; Pailing & Segalowitz, 2004; Stahl, Acharki, Kresimon, Voller, & Gibbons, 2015). Studies of motivation and cognitive control have found that the enhancement effect of reward was modulated by individual sensitivity to the reward (Jimura et al., 2010; Pailing & Segalowitz, 2004). Jimura, Locke, and Braver (2010) reported that participants showed better performance in working memory task when there was a reward and high reward sensitivity was related to greater improvement and stronger activation in lateral prefrontal cortex in rewarding context.

Second, despite the slower response time and larger flanker effect, older adults did not show deficits in adjusting control strength by different type of reward. The current results corroborated our prediction that older adults are able to change the optimal level of control engagement to meet their intrinsic motivation. These results provide a clue for reconciling divergent trajectories in research on aging and cognitive control.

Improved emotional regulation ability and the positivity effect, referring to the growing preference for positive over negative emotional information (Carstensen & Mikels, 2005; Mather & Carstensen, 2005), have been regarded as challenges in understanding cognitive aging. It is widely known that ability to regulate emotion, which requires cognitive control, improves with age (Carstensen, Pasupathi, Mayr, & Nesselroade, 2000; Carstensen et al., 2011; Charles & Almeida, 2005; Kaplan & Berman, 2010; Lawton, Kleban, Rajagopal, & Dean, 1992). The biased attention and memory for positive emotional information in older adults also require cognitive control because negative emotional stimuli arouse strong automatic responses (Baumeister, Ellen, Finkenauer, & Vohs, 2001). However, cognitive control is one of the most vulnerable functions to the effects of aging (Braver & West, 2008; Braver & Barch, 2002; Hedden & Gabrieli, 2004; Lucci et al., 2013; Raz, 2000; Themanson et al., 2006). Older adults show a decline in performing various executive control tasks including switching, selective attention, and inhibition (Verhaeghen & Cerella, 2002).

Studies of cognitive aging have tried to explain the asymmetric aging effects on cognitive control with motivational factors. Those studies indicated that the paradoxes of aging might arise from the fact that older adults are more motivated to regulate their emotions than younger adults (Johnson & Whiting, 2013; Kennedy, Mather, & Carstensen, 2004; Riediger, Wrzus, Schmiedek, Wagner, & Lindenberger, 2011). In line with these studies, some researchers have suggested that these paradoxes result from an adaptive strategy to compensate for the decline in cognitive functions (Hess, 2014; Morgan & Scheibe, 2014; Nashiro, Sakaki, & Mather, 2012; Verhaeghen, Martin, & Sedek, 2012). Hess (2014) argued that the costs of cognitive engagement increase as people grow old and that older adults become strategic in spending cognitive resources, suggesting that the asymmetric effect of aging on cognitive function is due to the strategy of selective engagement to save cognitive resources. However, these suggestions cannot explain how exactly the motivational factor can make the elderly overcome the deterioration caused by aging. In addition, they cannot elucidate how older adults can be superior to the younger ones when they implement top-down control to emotional information.

The current results share the idea of flexible change by motivation in explaining the selective preservation of cognitive control in older adults. However, we presume that this selectivity is the result of a general principle of control process. In other words, our study suggests that the asymmetric effect of aging on cognitive control is evidence that the ability to set the optimal level of control strength is intact in older adults, rather than an adaptive characteristic to save cognitive resources. The fact that the modulation of control intensity was found in both age groups supports this notion. The results of the current study can also explain how the elderly can be better when they deal with emotional information based on the notion of the change in prioritizing goals and values in later life.

However, we could't find age difference in neutral condition which was consistently found in many previous studies. This may result from the overall up-regulation of control caused by the other two feedback conditions(Jimura et al, 2010). However, we could't find age difference in neutral condition which was consistently found in many previous studies. This may result from the overall up-regulation of control caused by the other two feedback condition(Jimura et al, 2010). Or our results seem to support the idea that the previous findings of the age effect in executive control is certainly exaggerated (Verhaeghen, 2011).

In summary, we found that the intensity of control exertion is modulated by age difference in evaluating process, and older adults are capable of allocating the necessary amount of control resources through evaluation of the reward. Our findings provide a more parsimonious explanation for individual differences in the strength of cognitive control in various groups, including clinical populations, and elderly and healthy adults in the sense that cognitive control is a higher-level cognitive function which affects many other lower level cognitive functions such as attention, memory, and decision making.

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보상 유형이 인지적 통제에 미치는 연령차

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인지적 통제에 대한 최근 연구들은 통제적 처리과정에 동기가 미치는 고려하기 시작했다. 그러나 정확히 어떤 방식으로 동기가 인지적 통제의 과정에 개입하는지는 명확하지 않다. 최근의 인지적 통제와 보상에 대한 연구 결과들을 근거로, 본 논문은 인지적 통제의 강도가 보상에 대한 주관적 가치 기준에 따라 탄력적으로 변할 것이라고 가정하였다. 본 연구에서 우리는 이 가설을 검증하기 위하여 정서, 금전, 중성의 세 가지 유형의 보상을 제공하는 에릭슨 플랭커 과제를 청년과 노인 집단에게 수행하도록 하였다. 그 결과 각 연령 집단은 자신들에게 가장 매력적이라고 여기는 보상이 주어지는 조건에서 가장 뛰어난 수행을 나타내었다. 이는 통제적 처리과정의 개입 수준이 과제를 수행할 때 주어지는 보상이 가지는 주관적 중대성에 따라 조절된다는 것을 의미한다. 특히 통제 자원을 탄력적으로 조절하는 정도에서 연령차가 나타나지 않았다는 것은 최적 수준의 인지 자원 소비를 결정하는 기능이 노년기에도 잘 유지된다는 것을 보여준다. 이러한 발견들은 인지적 통제의 개인차를 이해하기 위한 새로운 시각을 제공한다.

주요어 : 인지적 통제, 노화, 보상, 동기, 피드백 유형