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Running Head: BALANCE AND COGNITION

Evidence for the Bypass of the Response-Selection Bottleneck in Tasks with Reflexive Responses in Younger and Older Adults

A Thesis Presented

by

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Table of Contents

Abstract

This study investigated dual-task processing in younger and older adults using a psychological refractory period procedure. The first task was to name the color framing a picture; the second task was to either press a button or tilt their body in the direction of the tilt of the picture. In the body-tilt condition, electromyography was used to determine the reaction time. The stimulus-onset asynchrony (SOA) between the onset of the color and tilting of the picture varied from 50 to 1000 ms. In contrast with the response selection bottleneck model, which claims that processing of a second task cannot be completed until the first task is finished, the mode of response for the two tasks directly impacted the ability to avoid the bottleneck. In the body-tilt condition the increase in reaction time to the second task with decreasing SOA was less than in the button press condition, suggesting that processing of the second task could begin before processing of the first task was completed. This was true for both younger and older adults. Contrary to previous findings that older adults cannot engage in simultaneous processing of two tasks, evidence was found that older adults, like younger adults, could bypass the cognitive bottleneck if the second task has a reflexive component.

Evidence for the Bypass of the Response-Selection Bottleneck in Tasks with Reflexive Responses in Younger and Older Adults

Introduction

When compared with younger adults in dual-task performance, older adults commonly appear to show greater dual task interference (Maquestiaux et al, 2010; Woollacott & Shumway-Cook, 2002; Shumway-Cook et al, 1997; Maquestiaux et al, 2004). A challenge for researchers in the field of aging is to determine how to bypass the cognitive bottleneck and in turn lessen the effects of dual-task interference on older populations.

The psychological refractory period (PRP) procedure is a dual-task paradigm pioneered by Telford (1931). Two successive stimuli (*S1* and *S2,* respectively) are presented and each stimulus requires a distinct response (*R1* and *R2*, respectively). The two stimuli are separated by a stimulus onset asynchrony (SOA) that can be manipulated to be either long or short. Long SOAs (e.g., 1000 ms) result in low levels of temporal overlap whereas short SOAs (e.g., 50 ms) result in higher levels of temporal overlap. Each stimulus requires a unique response; R1 to S1 and R2 to S2. Figure 1a shows the sequence of processing stages when a short SOA separates Task 1 and Task 2. The slack time before the response selection portion of Task 2 can begin is longer than when the SOA is longer. Figure 1b illustrates the situation in which the SOA is longer; this results in a shorter slack time before the individual can respond to Task 2.

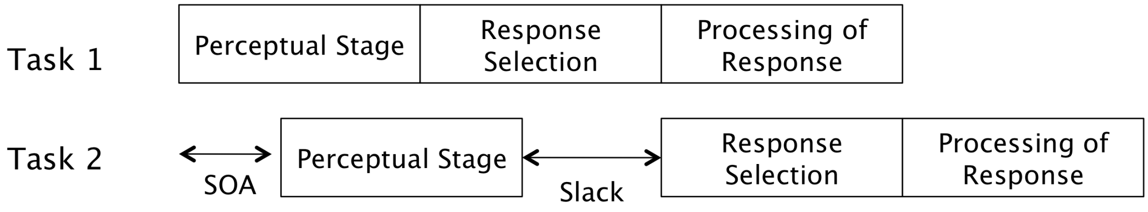

Figure 1a: Sequence of processing stages with short SOAs. Response selection for Task 2 cannot occur until response selection of Task 1 is completed.

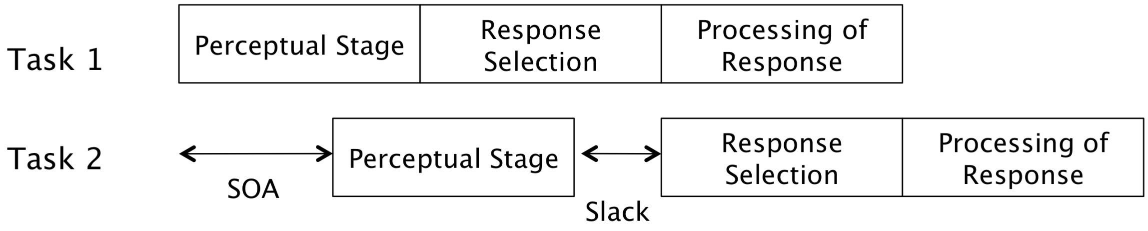

Figure 1b: Sequence of processing stages with long SOAs. Response selection for Task 2 cannot occur until response selection of Task 1 is completed.

Common findings in PRP experiments show that the reaction time (RT) for Task 1 is not affected by varying SOAs. This is not true for Task 2; the SOA greatly affects the RT for Task 2 with findings showing that RT for Task 2 is slower with decreasing SOA (see Telford, 1931; Pashler et al, 1993; Meyer & Kieras, 1997a, 1997b).

Theories of the PRP Effect

One of the most universally accepted ways of understanding dual-task interference is capacity sharing. This theory presupposes that processing capacity, as the name implies, is shared between tasks. As a result of the sharing, the mental resources that are dedicated to each particular task are reduced and therefore the ability to perform the task is weakened. In our day-to-day lives, people typically do multiple tasks at once. When the two tasks exceed available mental resources, then the individual delegates more capacity to the more important task (Pashler, 1994).

The central bottleneck model and the executive-process interactive control (EPIC) model are two separate models to explain the PRP effect. The central bottleneck model to explain the PRP effect was proposed by Welford (1952). The response selection bottleneck (RSB) theory is one of the most widely accepted models to account for the PRP effect. This model claims that central processing can be completed for one action at a time. When two operations need the mechanism at the same time, a bottleneck arises and this leads to either impairment or a delay in one of the tasks. This therefore implies that parallel processing may be impossible for central mental operations (Pashler, 1994; Meyer et al, 1995). The central bottleneck model claims that individuals are unable to complete more than one central mental process at once, which leads to the PRP effect. The central bottleneck model comprises three components: the precentral stage, central stage, and postcentral stage. The precentral and postcentral stages can be completed concurrently with any stage from Task 2. However, the central stage of Task 1 cannot be carried out in parallel with the Task 2 central stage (Maquestiaux et al, 2010).

The EPIC model is an alternative model of dual-task control that can be used to explain the PRP effect (Meyer & Kieras, 1997a, 1997b). This theory says that the stages of Task 1 and Task 2 can occur in parallel or sequentially and therefore an immutable, fixed central bottleneck does not exist. Bottlenecks can be inserted precentrally, centrally or postcentrally. Thus the insertion of a bottleneck centrally results in the central bottleneck model (Maquestiaux et al, 2004).

Effects of Practice

Some researchers have shown that younger adults can bypass the bottleneck with massive amounts of practice (Hartley, Maquestiaux, & Butts, 2011; Gothe et al, 2007; Maquestiaux et al., 2008). This is only the case in younger adults.

Other research has proposed that even with massive amounts of practice, older adults are still unable to bypass the bottleneck. Gothe, Oberaue, and Kliege (2007) argue that older adults cannot use parallel processing because younger and older adults approach dual-task situations differently. They classified the participants into two groups; serial processing and parallel processing. This classification was based on how well the participants met the criteria of parallel processing rather than serial processing. Their findings showed that younger adults switch from serial processing to parallel processing whereas older adults do not. After practice, young adults were able to process the two tasks in parallel without dual-task costs, while none of the older adults were able to perform two cognitive operations in parallel. Similarly, Maquestiaux, Hartley, and Bertsch (2004) examined the effects of practice and aging on the PRP effect. Massive amounts of practice led to an increase in age-related differences rather than a decrease. They attributed the increase to an extra stage before Task 2 response selection. The authors speculated that older adults used this extra stage for retrieval of response mappings for Task 2 while younger adults did not need this extra stage. Presumably, younger adults were able to retrieve the response mappings before the two stimuli were presented.

Although the existing research shows that older adults do not bypass the bottleneck even with large amounts of training (Maquestiaux et al, 2010), we hypothesized that a reflexive Task 2 response might lead to a bypass of the cognitive bottleneck. Previous research conducted by Pashler, Carrier, & Hoffman (1993) on saccadic eye movements showed that an eye movement response activates the bottleneck for a very short amount of time if at all. They argue that this is because the superior colliculus (SC), rather than the frontal cortex, is responsible for the reflexive eye movement. In their experiment, participants observed a fixation point with two digits located to the right and left of the fixation. Participants were instructed to look at the higher digit value by moving their eyes toward it. Their findings illustrate that in a comparison of manual RT and eye movement RT as a function of SOA, participants RT decreased as SOA much more rapidly with an eye movement response than with a manual response. This change, involving only the response modality, is evidence that the response selection bottleneck was at least partially bypassed. Following this logic we propose that a body-tilt, which presumable is reflexive, will lead to a bypass of the cognitive bottleneck.

Balance and Task Prioritization

Balance studies have always been at the forefront of aging research because of the frequency of falls in the elderly and the negative impact of falls on quality of life. It was first proposed that balance was primarily reflexive and therefore did not necessitate the use of cognitive processes for maintenance, as was the case for eye movement responses in younger adults. This is not true. Findings show that there is a greater need for cognitive control, or attentional resources with aging to maintain balance (Woollacott & Shumway-Cook, 2002). Research shows that falls in the elderly typically occur when the individual is performing two tasks concurrently, i.e., a motor and a cognitive task (see Shumway-Cook et al, 1997). This was found in memorization and walking experiments conducted by Li et al (2001). Their research suggests that older adults utilize different models of task emphasis and prioritize walking over memorization while younger adults prioritize memorization over walking.

Components of postural control decline with age and these declines can increase the likelihood of falls (see Lindenberger et al, 2000). Previous research has also shown that postural sway increases in individuals as they age (Freitas & Duarte, 2012; Melzer et al, 2001). Healthy older adults exhibit increased postural sway and hip movement in normal stance tasks (Amiridis et al, 2003). By varying the base of support in postural sway studies, Melzer et al (2001) showed that older and younger adults approach postural control in different ways. Older adults exhibit anticipatory adjustment reactions in an attempt to limit postural sway whereas younger adults do not.

Attentional resources and task prioritization are essential in the maintenance of postural stability in older adults. Doumas, Smolder, & Krampe (2008), examined task prioritization in younger and older adults using a dual-task paradigm. The author’s findings show in older adults when their posture is fairly stable they have the ability to share attentional resources. The sharing of resources between the two tasks increases the likelihood of decreased postural stability but allows them to complete the dual-task action. In contrast, when their posture is unstable, older adults prioritize postural control over cognitive tasks. Rapp et al. (2006) and Doumas et al (2008) have found evidence that resource allocation is adaptable and as such, older adults allocate resources to postural stability to counteract their decline in sensorimotor processing.

The present study examines dual-task processing in younger and older adults using a psychological refractory period procedure. We expected, that due to the reflexive nature of a body-tilt, both younger and older adults would be able to bypass the cognitive bottleneck. We predict that an increase in RT of the second task with decreasing SOA will be less with the body-tilt condition because body-tilt is able to partially bypass the response selection bottleneck.

Method

Participants

Two age groups were tested in this study: 15 younger adults (4 men, 11 women), and 15 community-volunteer older adults (4 men, 11 women). The young adults averaged 20.2 years of age (SD = 1.57); they reported their health as 8.87 (SD = 1.06) on a 10-point scale where 10 was "excellent"; they reported 14.53 years as their average years of education (SD = 1.30 years); the participants Near Vision Acuity (measured using a Near Vision Acuity Chart) was 20/21.47 (SD = 3.89). The older adults averaged 75.67 years of age (SD = 17.74); they reported their health 8.53 (SD = 0.92) on a 10-point scale where 10 was "excellent"; they reported 15.13 years as their average years of education (SD = 2.72 years); the participants measured Near Vision Acuity was 20/30.47 (SD = 8.43). Data from four participants were excluded from analysis due to technical difficulties and participant difficulties with the required body-tilt motion. Participants received a stipend of 15 USD for their participation.

Apparatus

The experiment was conducted using programs written in E Prime (Version 1.0, Schneider, Eschman, & Zuccolotto, 2002) and run on Windows computers. Electromyographic data was collected using BioPac AcqKnowledge 4 Software & MP150/MP36R (Version 4.2, BIOPAC Systems, Inc, 1999-2001). Manual responses given by participants were made with button presses on a response box (Serial Response Box Model 200a, Psychology Software Tools).

Tasks

Single Task 1. Task 1 required a red-green discrimination. Participants sat in a chair located approximately 48 cm from a monitor. Each trial began with a solid black screen. An image of an indoor or outdoor scene appeared on the monitor for 1000 ms and then a gray frame appeared around the image. After 1000 ms the frame changed to either red or green. The participant was instructed to respond as quickly and clearly as possible to the color by saying *Red* if the frame appeared as red or by stating *Green* if the frame appeared as green. The researcher entered the color response with a keypress. The stimulus remained until a response was sensed.

Single Button press Task 2. For Task 2 the participant was seated approximately 48 cm in front of a monitor with a key press pad located directly in front of them. As in Task 1, each trial in the button press task began with a solid black screen. An image appeared on the monitor and then a gray frame appeared around the image. After 1000 ms the frame changed to either red or green. The frame would then either tilt 20 degrees to the left or to the right. The stimulus-onset asynchrony (SOA) between the change in frame color and the tilt of the image was 50 ms, 100 ms, 150 ms, 200 ms, 500 ms, or 1000 ms. The participants were instructed to ignore the color change and respond as quickly and accurately as possible to the tilt by pressing a corresponding button on the key pad. The stimulus remained until a response was sensed.

Single Body-tilt Task 2 (Training Task). In the training task, participants were instructed to stand on a mat facing a computer monitor that was located 124.5 cm off the ground while holding onto a grab bar with both hands that was located 81.3 cm off the ground. The stimuli were identical to those in Task 2 of the Control Condition. Each trial in the calibration task began with a solid black screen. An image appeared on the monitor and then a gray frame appeared around the image. After 1000 ms the frame changed to either red or green. The frame would then either tilt 20 degrees to the left or to the right. The stimulus-onset asynchrony (SOA) between the change in color and the tilt was 50 ms, 100 ms, 150 ms, 200 ms, 500 ms, 500 ms, or 1000 ms. The participants were instructed to respond as quickly and accurately as possible to the tilt by tilting their body in the direction of the tilt by lifting their heel of their dominant leg. The researcher entered the direction of the participant’s tilt on the keyboard. The stimulus remained until a response was sensed.

Dual Button press Task (Control Condition). In the dual task conditions participants completed both Task 1 and Task 2 on each trial, responding to the color of the stimulus with a vocal response and the tilt of the stimulus by pressing a key. Participants were instructed to respond to each stimulus as quickly as possible rather than waiting and grouping the responses.

Dual Body-tilt Task (Experimental Condition). In the dual task conditions participants completed both Task 1 and Task 2 on each trial, responding to the color of the stimulus with a vocal response and the tilt of the stimulus by tilting their body and lifting their heel of their dominant leg in the direction of the tilt. Participants were instructed to respond to each stimulus as quickly as possible rather than waiting and grouping the responses.

Procedure

Written informed consent was obtained at the outset of the testing session. Information on participant's year of birth, self-rated health status, education, and near vision acuity was collected upon participant's arrival. Next the researcher placed three electrodes on the participant's self-reported dominant leg. The researcher began by abrading the participant's skin over the gastrocnemius muscle with a cotton pad. Next rubbing alcohol was placed on a cotton pad and rubbed over the skin. The first electrode was placed over the gastrocnemius muscle, 5 cm below the bend of the knee. The second electrode was placed over the belly of the gastrocnemius. The third electrode was placed right or left, 5 cm lateral to the second electrode, the placement was dependent on whether the participant was right or left leg dominant.

The Control Condition preceded the Experimental Condition for all participants. After the tasks were explained, the participant first completed a practice session. The practice session comprised 12 trials of Task 1 alone, and 12 trials of Button press Task 2 alone. Next the participant completed 10 blocks of 12 trials of the Button press Dual Task. Participants were given the option to take a break after each block. After completing the Control Condition the participants were moved to a different testing room for the Experimental Condition and the electrodes were connected to the amplifier. After the electrodes were attached the participant completed Body-tilt Task 2 alone. This task was run until the participant stated they felt comfortable with the required movement. Next the participant completed 10 blocks of 12 trials of the Experimental Dual Task. Participants were given the option to take a break after each block.

The Scripps College Institutional Review Board approved the method and procedure used in the present experiment. All treatment of participants was within the ethical guidelines of the American Psychological Association.

Results

Analyses of variance (ANOVA) were carried out on dual task reaction times (RTs). Age group (younger or older) was a between-subjects variable; Mode (button press or body-tilt) and SOA (50, 100, 150, 200, 500, 1000 ms) were within-subjects variables.

There was a significant main effect of SOA, *F*(2,67) = 74.01, $p < 0.001$, $\eta^2_{PARTIAL} = 0.73$. RTs decreased monotonically from 50 ms (*M* = 740 ms, *SE* = 23 ms) to 100 ms (*M* = 659 ms, *SE* = 22 ms) to 150 ms (*M* = 649 ms, *SE* = 21 ms) to 200 ms (*M* = 629 ms, *SE* = 22 ms) to 500 ms (*M* = 572 ms, *SE* = 20 ms) to 1000 ms (*M* = 522 ms, *SE* = 14 ms). A significant main effect was also found in age group, *F*(1,27) = 39.59, $p < 0.001$, $\eta^2_{PARTIAL} = 0.59$. RTs were shorter for younger adults (*M* = 509 ms, *SE* = 26 ms) than for older adults (*M* = 748 ms, *SE* = 27 ms).

A comparison of the button press or body-tilt task and age group showed a significant interaction effect, *F*(1,67) = 8.22, $p = 0.008$, $\eta^2_{PARTIAL} = 0.23$. Younger adults RTs were faster for the button press task (*M* = 493 ms, *SE* = 31 ms) than for the body-tilt task (*M* = 525 ms, *SE* = 29 ms). Examination of Figure 2 shows that in accordance with previous research, RT for younger adults decreases with increasing SOA. Younger adults found the button press task to be easier than the body-tilt task evidenced by the fact that their RTs for the button press task with long SOAs were faster in the button press task than in the body-tilt task.

Older adult data, shown in Figure 3 for mean RT in the button press and body-tilt task, shows that RT for older adults also decreases with increasing SOA. Older adults RTs were faster for the body-tilt task (*M* = 700 ms, *SE* = 30 ms) than for the button press task (*M*

= 795, *SE* = 32). Older adults found the body-tilt condition to be easier than the button press conditions as evidence by the fact that their RT for the body-tilt with increasing SOA were faster.

A significant interaction was found between mode and SOA, *F*(2.7,67) = 18.72, $p < 0.001$, $\eta^2_{PARTIAL} = 0.41$. In the body-tilt task, RTs decreased with SOA from 50 ms (*M* = 694 ms, *SE* = 24 ms) to 1000 ms (*M* = 549 ms, *SE* = 21 ms). The PRP effect ($RT_{50} - RT_{1000}$) was 145 ms. In the button press task RTs decreased with SOA from 50 ms (*M* = 786 ms, *SE* = 29 ms) to 1000 ms (*M* = 495 ms, *SE* = 17 ms). The PRP effect was 291 ms. From a different perspective, at 50 ms and 100 ms the body-tilt task was significantly faster than the button press task (respectively, t(28) = -3.12, p = 0.004 and t(28) = -2.40, p = 0.23). The body-tilt task and button press task did not differ significantly for 150 ms, 200 ms, and 500 ms but the body-tilt task was significantly slower for 1000 ms (t(28) = 2.107, p = 0.44).

A significant interaction was also found between SOA and age group, *F*(2,67) = 10.34, $p < 0.001$, $\eta^2_{PARTIAL} = 0.28$. Younger adults RTs decreased with SOA from 50 ms (*M* = 590 ms, *SE* = 32 ms) to 1000 ms (*M* = 453 ms, *SE* = 20 ms), a PRP effect of 137 ms. Overall, younger adults had faster RT at long SOA than did older adults (Figure 4, Figure 5). Older adults RTs decreased with SOA from 50 ms (*M* = 890 ms, *SE* = 33 ms) to 1000 ms (*M* = 591 ms, *SE* = 21 ms), a PRP effect of 299 ms. Alternatively, the difference between younger and older adults increases as the SOA got shorter with a difference of 293 ms at a 50 ms SOA reducing to a difference of 137 ms at an SOA of 1000. Table 1 shows that in the button press task, younger adults had a smaller PRP effect than did the older adults. Similarly, in the body-tilt task, younger adults had a smaller PRP effect than did the older adults.

There was no significant difference as a function of age group, mode, and SOA, $F(2.7,67) = 0.778$, $p = 0.500$, $\eta^2_{PARTIAL} = 0.03$. For younger adults, the body-tilt task resulted in a PRP effect of 75 ms, and a PRP effect of 199 ms in the button press task. For older adults, the body-tilt task resulted in a PRP effect of 215 ms, and a PRP effect of 383 ms in the button press task.

In an examination of Task 1 alone, Figure 6 shows mean RT for younger and older adult. Younger adults had faster RT than did older adults at each SOA.

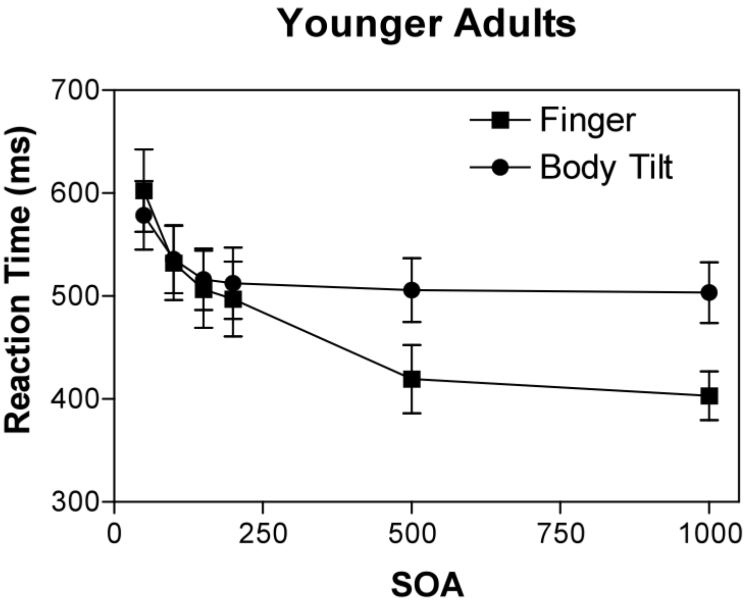

Figure 2: Effect of mode, button press or body-tilt, on RT at each stimulus onset asynchrony (SOA) in younger adults. Bars show standard errors.

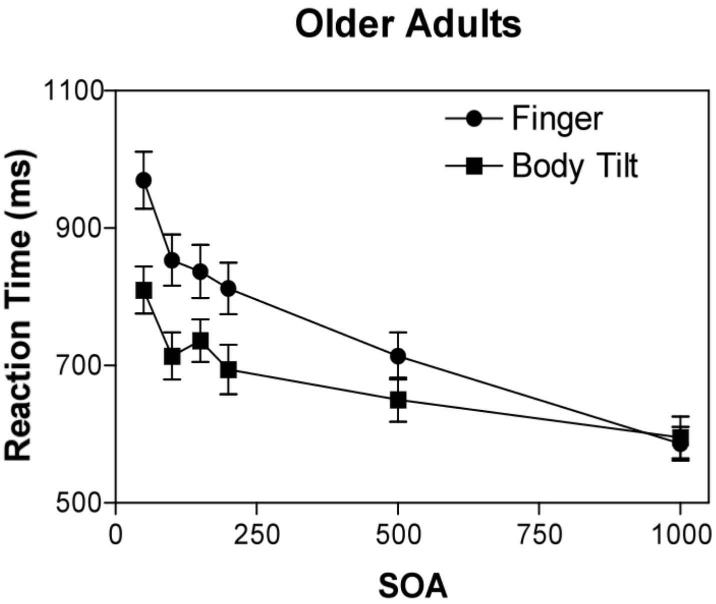

Figure 3: Effect of mode, button press or body-tilt, on RT at each stimulus onset asynchrony (SOA) in older adults. Bars indicate standard errors.

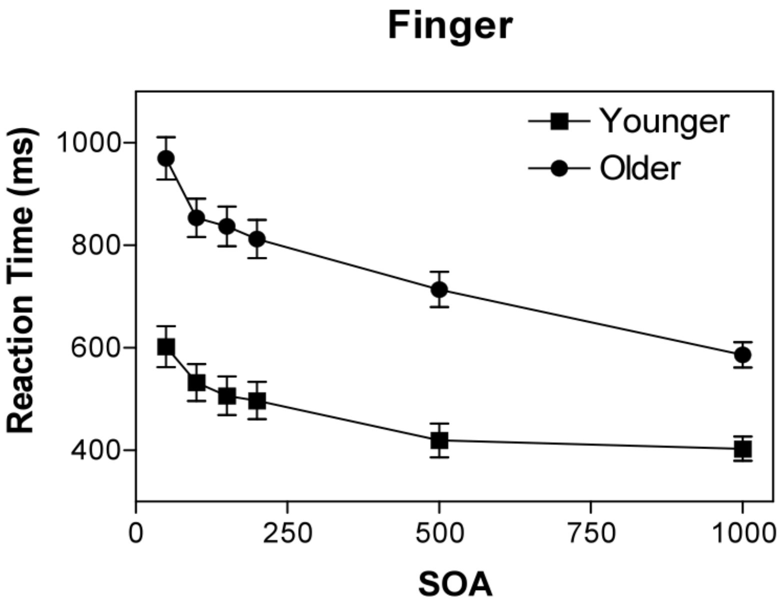

Figure 4: Effect of button press task on RT at each stimulus onset asynchrony (SOA) in younger adults and older adults. Bars indicate standard errors.

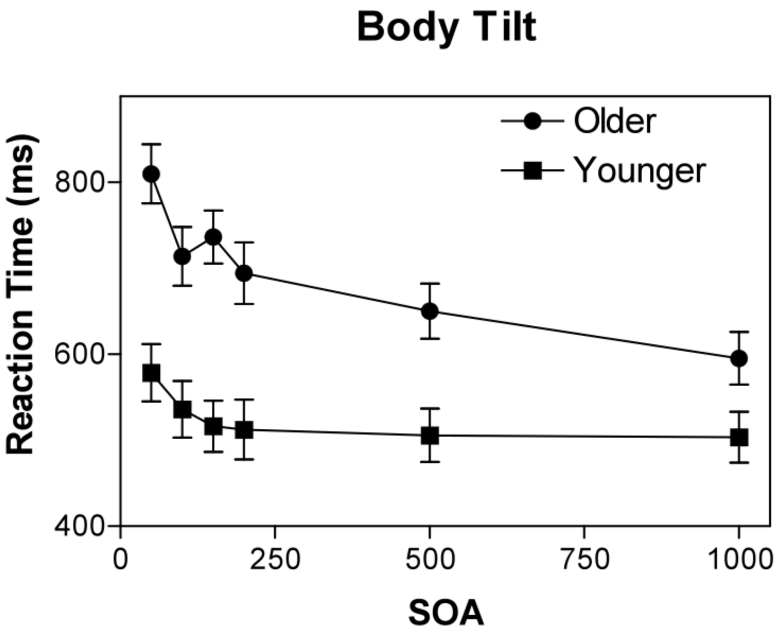

Figure 5: Effect of body-tilt task on RT at each stimulus onset asynchrony (SOA) in younger and older adults. Bars indicate standard errors.

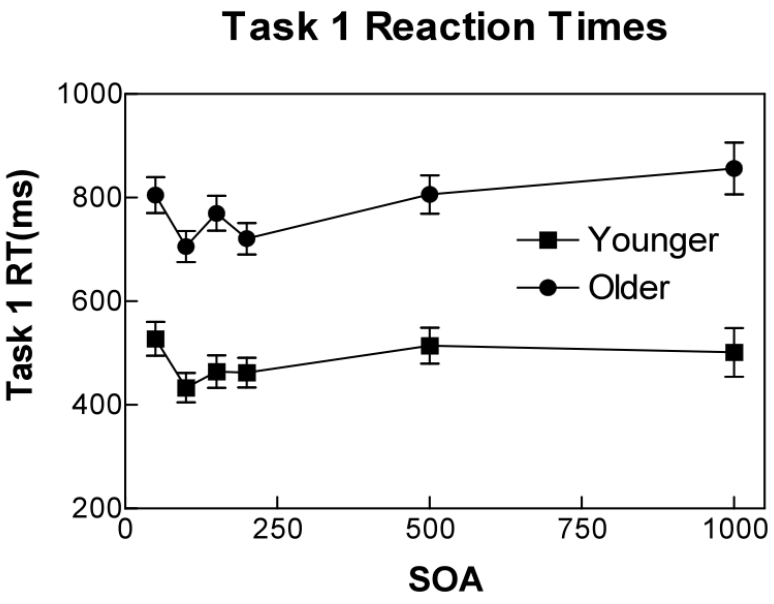

Figure 6: A comparison of Task 1 RT in younger and older adults at each stimulus onset asynchrony (SOA). Bars indicate standard errors.

Table 1
PRP effects (RT $_{Short\ SOA}$ – RT $_{Long\ SOA}$) for Younger and Older Adults in the Button press and Body-Tilt Tasks

	Button press (ms)	Body-Tilt (ms)
Younger Adult	200	75
Older Adult	383	214

Discussion

The main goal of this research was to determine whether older adults would be able to bypass the cognitive bottleneck in tasks with a reflexive component. Previous research has shown older adults are unable to bypass the cognitive bottleneck even with massive amounts of practice. Contrary to previous research, this study indicates that both older and younger adults were able to bypass the cognitive bottleneck in tasks that contain a reflexive component.

The PRP effect was found to be smaller for the body-tilt task than for the button press task in both populations. This result shows a clear bypass of the cognitive bottleneck in tasks with reflexive components. This finding has not been shown previously in the literature.

Examination of Figure 7, which shows the prediction interaction for Task 1 and Task 2, under three conditions; if the tilt were longer, shorter, or the same. This is helpful in understanding Figure 2 and Figure 3. A comparison of Figure 7 and Figure 2 shows that for the younger adult population, they found the button press, or finger, task to be easier than the body-tilt task at long SOAs. Younger adults had a faster RT for the button press condition than for the body-tilt condition. If we look specifically at the red line (tilt slower than color) and the black line (showing the finger RTs) we see that the lines intersect at very short SOAs and are significantly different at longer SOAs. That is, younger adults were overall slower at the tilt task than the color task. Nevertheless, the PRP effect was significantly greater in the button press condition than in the body-tilt condition. If we next compare Figure 7 and Figure 3, we observe that older adults found the body-tilt condition to be easier than the button press condition at shorter SOAs and approximately the same at longer SOAs. Older adults had faster RT for the body-tilt condition than for the button press condition. This is shown in both the interaction prediction figure and Figure 3. The blue line (tilt and button-press equally fast) and the black line (again showing the button press RTs) illustrate this same phenomenon.

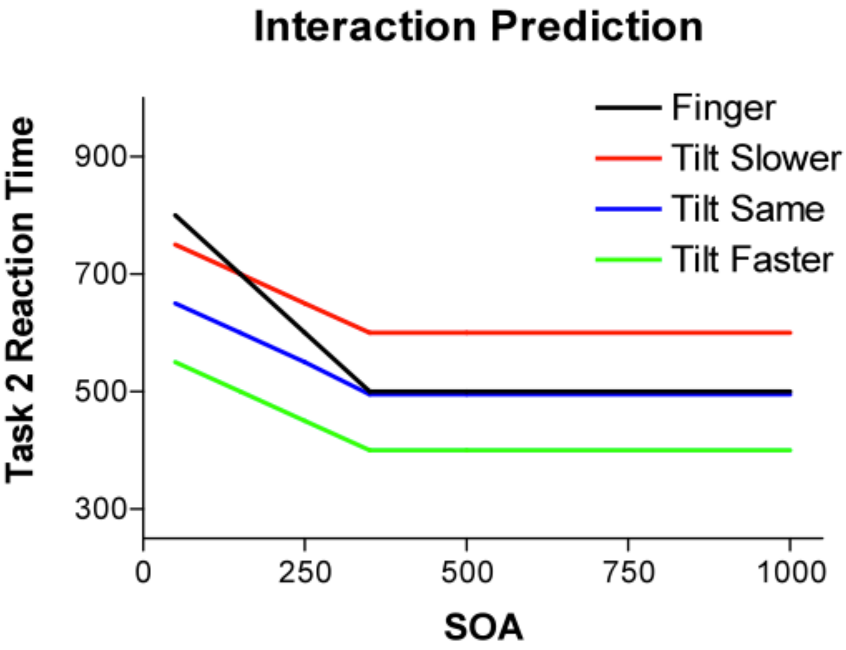

Figure 7: A comparison of Task 2 RTs and the button press task, if the body-tilt was slower, the same, or faster.

The PRP effect was found to be smaller in the body-tilt condition than for the button press condition for both younger and older adults. This finding provides clear evidence of greater bypass in the body-tilt condition than the button-press condition. Our results, however, are not indicative of resource sharing. If a sharing of resources had occurred we would have seen the RT to both Task 1 and Task 2 go up at short SOAs. This did not occur. Task 1 RT was largely independent of SOA. Instead our results point to parallel processing. Both younger and older adults were able to process the response selection portion of Task 2 in parallel with the response selection portion of Task 1. For older adults and younger adults, the PRP effect is much smaller for body-tilt than for button press condition. The RTs did not increase at the same rate as the SOA decreased. This finding shows that body tilt is being processed in parallel with Task 1, color discrimination, without any dual-task cost to Task 1. Furthermore, parallel processing occurred at the same time in both populations.

The younger adults' faster responses to the button press task with decreasing SOA could potentially be attributed to cultural experience. Our younger adult population with a mean age of 20.2 years is the product of the technological world. Today's young adults were raised in an environment that uses technology on a daily basis with finger, or button presses as the predominant mode of responding. From interacting with friends on social media, to texting, playing video games, or even typing school papers, young adults have extensive experience with button processing tasks. This may result in an improved ability to respond in the button press task, simply through practice. In contrast to younger adults, older adults found the button press to be more difficult than the body-tilt task. This difference could be the reverse effect for older adults. Older adults were not raised in the world of cellular telephones and personal computers; instead they adjusted or failed to adjust to these technological advancements as they came. Our older adult population with a mean age of 75.67 years probably does not have differential experience between the body-tilt and button press tasks.

Our speculation is that the body-tilt induces a reflexive shift. This reflexive component allows parallel processing to occur on both tasks at the same time. This implies that the processing of Task 2 can occur before processing of Task 1 is complete. Therefore, parallel processing can occur between the two tasks without a decline in processing.

The present research implies that reflexive actions can bypass the bottleneck effect in dual-task processing. We are conducting a follow-up study to determine if an even more reflexive action, namely eye-movement, can increase the processing speed in older adults and in turn result in a bypass of the bottleneck effect. It was previously shown in research conducted on saccadic eye movements that the mechanism behind eye movement utilizes the bottleneck for a very short period of time if at all (Pashler, Carrier, & Hoffman, 1993). Their findings showed that in a comparison of manual RT and eye movement RT vs. SOA, participants RT decreased a greater amount with increasing SOA with manual RT than with eye movement RT. Their results imply that eye-movement allowed participants to work through the bottleneck more quickly if indeed, it was even present at all. In our experiment we would like to see if parallel processing is possible instead of merely a faster processing of the bottleneck.

A second follow-up study that could be performed is to conduct this same study using balance board technology. Instead of the participant standing on the floor and tilting their weight, a balance board would be calibrated to tilt at prescribed angles and the reaction time to adjust the center of mass could be measure with no explicit task. This technology would allow researchers to determine if the tilt was due to a reflexive action, i.e. before the brain had processed the information.

Similarly, this experiment could be conducted using virtual reality technology alone or in conjunction with a balance board to see if a perceptual shift would result in a preemptory balance shift. By using virtual reality technology we would be able to ensure that the participant’s sole focus was on the present stimuli and that any response was therefore a direct result of the stimuli.

This study showed that younger adults and older adults were able to bypass the cognitive bottleneck in tasks that contain a reflexive component. This finding is evidenced by a PRP effect that is smaller for the body-tilt task than for the button press task in both populations. Therefore, a clear bypass of the cognitive bottleneck in tasks with reflexive components was found.

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