Reaching for Words and Non-Words: Isolating Stages in the Response Dynamics of Younger and Older Adults

Leon Tsa0, 2010

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When our brains receive information from the outside world, how do we process this information and break it down? One of the goals of cognitive neuroscience is to isolate stages of information processing. This can be rather difficult because most cognitive operations are multifaceted. We have developed a novel paradigm to explore the differences in information processing between older and younger adults. In a classic paper, Sternberg developed a procedure to isolate stages of cognition. To illustrate an experiment that isolates these stages, I can take a string of letters (such as the word GREEN, or the non-word FLERP), and degrade it (in other words, mask it with dots—see example in “Stimulus Degradation” step in Figure 1). If a subject is flashed this degraded stimulus on a computer screen and has to decide as fast as possible whether the string of letters comprises a word or a non-word, there are two variables involved in processing this stimulus; the brain first has to eliminate the mask of dots and then decide whether the string of letters make up a word. In Sternberg’s procedure for isolating stages of cognition, when there is more than one variable involved in processing a stimulus, these variables are additive. According to Sternberg, these variables are additive because the time it takes to process the degraded string of letters equals the time it takes to eliminate the mask plus the time it takes to decide whether the string of letters make up a word. The speed of this decision is influenced by word frequency (e.g. frequent words like DOG are processed faster than rare words, e.g., CELO). Since the variables are additive, they are not interactive. “Interactive” means these two variables are dependent on each other; the time it takes for the brain to deal with one variable in this word/non-word decision task influences the time it takes to deal with the other variable. According to Sternberg, the brain works with one variable first, and then works with the other in a completely separate stage of processing.

The proposal of the diffusion model by Ratcliff et al. motivated our research into differences in information processing between older and younger adults. They postulated a theory of how age-related differences can occur in a word/non-word decision task, and we wished to investigate the validity of their claims. According to the diffusion model, word/non-word decisions are made as informational criteria for word or non-word from a stimulus that accumulates across time. For instance, I may see a stimulus (the masked GREEN as shown in the “Stimulus Degradation” step in Figure 1), and my brain has to figure out whether I am seeing a word. In order to make a decision, I gather information from the stimulus to decide if it fits the word or non-word criteria. When information meets the criteria boundary for either word or non-word, a response is executed. I may finally decide the degraded stimulus GREEN makes up a word, and I would then press the “1” key on a keyboard (the “1” key signifies word, and the “2” key signifies non-word). In the diffusion model, age-related differences in lexical decision have been explained by differences in setting of the response criteria, with older adults setting more conservative criteria than younger adults. This means that they wait for more criteria from the stimulus before making a decision (Figure 2).

We used a novel arm-reaching response paradigm in which a subject (an older or younger adult) sees a letter string (clear or degraded), and reaches across a computer screen with his or her arm to select “word” or “non-word” as a response (Figure 4). This is different from previous studies that used a simple key-press (key “1” on a keyboard for word, and “2” for non-word), and therefore could only track responses and response times (see Figure 3). The current study is the first to explore age-related changes in movement dynamics of lexical decision responses. The advantage is that not only can it track responses and response times, but it can track the onset of the arm movement and the trajectory of the movement made. For instance, in a trial, a subject may initially move his or her arm towards one response circle but end up selecting another response circle with it. If older adults set a more conservative response criterion, one may expect the effects of word frequency and stimulus degradation to occur primarily in the time before movement onset, whereas, for younger adults, there may be less of an influence in movement onset latency and more of an influence of these variables in movement dynamics.

Figure 2. Diffusion model. The plotted line represents criteria/information accrual over time. The vertical lines represent where older and younger adults (OA and YA) set their criteria for initiating word and non-word responses. Older adults set more conservative (farther) boundaries. In this diagram, the perception of the stimulus is initially biased towards Non-Word. Once a boundary is crossed, the subject may press a key to indicate a response. Older and younger adults may have different responses due to their boundary-setting differences.

Figure 3. Plot of additive effects on a button press. The red line is for low-frequency words, and the blue line is for high-frequency words. Yap and Balota gave young adults a word/non-word decision task in which strings of letters were either clear or degraded. The additive effect is apparent since the lines are nearly parallel, with ~50ms difference between them for clear word and degraded word conditions. This means that stimulus degradation and word frequency do not interact and occur in separate stages of processing. Since this is a button press experiment, we can record response and response times of subjects but not their response dynamics.

Figure 1. Two-stage processing model. In the “Stimulus Degradation” step, the brain has to eliminate the mask. In the “Frequency” step, the time it takes to decide whether the letter string is a word depends on the frequency of the word (GREEN would be a relatively frequent word). Clear stimuli (one without a dotted mask) would be processed faster than degraded stimuli, since only one step is involved (the “Frequency” step). If variables are interactive, the two-stage model does not apply, since it is non-additive.

Methods
- 27 older adults (10 males/17 females), mean age = 77.8 ± 8 years
- 20 younger adults (8 males/12 females), mean age = 19.7 ± 1 years

Participants were seated on a tall chair about 1 foot from a screen-facing-upwards computer monitor upon which stimuli were presented. A glove on their right hand had an Ascension Flock of Birds magnetic sensor attached to the right index finger. A detector tracked the location of the sensor in 3 dimensions (up/down, left/right, forward/backward); while participants made reaching movements (see Figure 4).

- 480 experimental trials, half of which were degraded with a random dot mask.
  - 100 High-Frequency (HF) words
  - 100 Low-Frequency (LF) words
  - 200 Pronounceable Non-Words (NW) words

- Dependent variables:
  - Movement Onset Time - time from stimulus appearance to movement initiation
  - Accuracy
  - Positional variables:
    - X position - horizontal position of finger throughout movement in cm
    - Y position - vertical position of finger throughout movement in cm
  - Change in position over time
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In a classic paper, Sternberg developed a procedure to isolate stages of cognition.7 To illustrate an experiment that isolates these stages, I can take a string of letters (e.g., the word GREEN, or the non-word FLERP) and degrade it (in other words, mask it with dots—a common example in “Stimulus Degradation” step in Figure 1). If a subject is flashed this degraded stimulus on a computer screen and has to decide as fast as possible whether the string of letters comprises a word or a non-word, there are two variables involved in processing this stimulus; the brain first has to eliminate the mask of dots and then decide whether the string of letters make up a word. In Sternberg’s procedure for isolating stages of cognition, when there is more than one variable involved in processing a stimulus, these variables are additive. According to Sternberg, these variables are addictive because the time it takes to process the degraded string of letters equals the time it takes to eliminate the mask plus the time it takes to decide whether the string of letters make up a word. The speed of this decision is influenced by word frequency (e.g., frequent words like DOG are processed faster than rare words, e.g., MLQ). Since the variables are additive, they are not interactive. “Interactive” means these two variables are dependent on each other; the time it takes for the brain to decide one variable in this word/non-word decision task influences the time it takes to deal with the other variable. According to Sternberg, the brain works with one variable first, and then works with the other in a completely separate stage of processing.

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Table 1. Overview of the study.

<table>
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<tr>
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<td>- Participants were seated on a tall chair about 1 foot from a screen-facing-upwards computer monitor upon which stimuli were presented. A glove on their right hand had an Ascension Flock of Birds® magnetic sensor attached to the right index finger. A detector tracked the location of the sensor in 3 dimensions (up/down, left/right, forward/ backward) while participants made reaching movements (see Figure 4).</td>
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- 400 experimental trials, half of which were degraded with a random dot mask.
  - 0 High-Frequency (HF) words
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  - 0 Pronounceable Non-Words (NB)

- Dependent variables:
  - Movement Onset Time - time from stimulus appearance to movement initiation
  - Accuracy
  - Positional variables:
    - X position - horizontal position of finger throughout movement in cm
    - Y position - vertical position of finger throughout movement in cm
  - Change in position over time
Results

The results shown in Figure 5 suggest that younger adults set a more liberal criterion and initiate their responses before full analysis of the stimulus. An interactive effect is apparent in Figure 5 for younger adults because the lines in the graph for this group are not parallel. Older adults wait for a full analysis before initiating movement, which is apparent from the parallel lines in the graph similar to that in the younger adults of Figure 3. Keep in mind that the y-axis for Figure 3 is reaction time, and the y-axis for Figure 5 is movement onset-latency, which can only be measured with a movement paradigm. Given the ability to move towards a target rather than a simple button press, younger adults employ a different strategy from older adults, as evident in the fact that their effects are now interactive instead of additive.

In Figure 6, there is a steeper shift in the X position relative to the Y position for older adults than younger adults. Younger adults are more likely to move their arm towards the wrong response first before landing their fingers on the correct response circle, therefore averaging a smaller X position relative to Y position. This suggests that older adults are more likely to commit to a response prior to movement onset than younger adults, thus indicating that they set a higher criterion to initiate movement.

Age-related differences in criteria-setting are also apparent in Figure 7. Older adults show a greater bias towards the X position as compared to the Y position when compared to younger adults even earlier in the movement. Again, this indicates they have made their word/non-word decision before initiation of the response and were pulled in the dimension (horizontal) that discriminates words from non-words.

Conclusions

We developed a novel reaching paradigm to explore the neural chronometry of younger and older adults’ cognitive performance in a word/non-word decision task, and their subsequent response dynamics. In contrast to the standard button press studies, younger adults showed an interactive effect of word frequency and degradation in the onset latencies, whereas older adults produced clear additivity, consistent with the standard button press studies. In other words, given the ability to move towards a response circle, the older adults followed the 2-stage model of processing as illustrated in Figure 1. For younger adults, processing between variables occurs interactively rather than in two separate stages. The reason for this contrast is that the button-press task can only record responses. The button-press forces the subject to process word degradation and frequency prior to initiating a response. Given the ability to move in our study, strategic differences are revealed between younger and older adults.

These findings reveal qualitative differences between younger and older adults’ speeded binary judgments, and are consistent with recent developments of the Ratcliff et al. diffusion model of aging and lexical decision performance. Younger adults initiated movements earlier than older adults because younger adults have more liberal criteria to initiate their response. For younger adults, the stimulus was not fully analyzed before they initiated their response. Changes in criteria were also supported by the observation that older adults were more likely to commit early on in the horizontal dimension to a target than younger adults, despite having a more delayed onset latency.

Why do older adults engage in a more complete analysis when seeing compared to younger adults? It is possible that older adults compensate their slower cognitive processing and physical movements by waiting to obtain more information about the environment before initiating movements. Younger adults can afford to act with more liberal informational criteria than older adults because they can quickly adjust the direction of their movement if they find that they made the wrong move. Older adults may have set more conservative informational criteria to minimize the cost of mistakes or injury. For example, if a young adult were to walk down a staircase, she may move her foot to the next step of the stairs without needing to process the location of the next step as thoroughly as an older adult. This is because if she did make a mistake in processing, she can change the direction of her foot more easily than an older adult can. An older adult, due to his slower movements, knows that he cannot change the direction of his foot as quickly. Therefore, he strategically spends more time processing the location of the next step prior to moving his foot in order to prevent falls. More research on the differences between younger and older adults in response to dynamics, however, is necessary to corroborate these conjectures.

References


Figure 4. Demonstration of procedure. On each trial, participants placed their right index finger at the home position. Once a letter string was presented, they moved to the appropriate word/non-word response circle. They then brought their finger back to the home position to start the next trial. Feedback about incorrect responses or problems with movement was given after each trial.

Figure 5. Plot of onset of arm movement latency by word frequency and degradation in younger and older adults. The red line is for low-frequency words and the blue line is for high-frequency words. Both groups show strong effects of frequency and degradation (all p < .001). Younger adults show an interaction between these factors (p < .01) while older adults do not (p > .40). There are no significant differences in accuracy between the two groups despite differing onset latencies (p > .30).

Figure 6. The average X position for specific distance changes of finger in the Y position (see Methods for explanation of X and Y position) for younger and older adults (YA and OA). The H in HC and HD means “high-frequency words” and the L in LC and LD means “low-frequency words.” The C in HC and LC means “clear words” and the D in HD and LD means “degraded words.” X positions for movements to the left were flipped so that all movements were evaluated in the same space. Positions further to the right indicate that movements were closer to the appropriate response circle. Younger adults show large effects of frequency (p < .005) and degradation (p < .001). Older adults show an effect of frequency (p < .05) but not degradation (p > .10). Neither group reveals a significant interaction between these variables (all p > .50).

Figure 7. Change in X position and Y position at 100, 200, and 300 ms after movement initiation (see Methods for explanation of X and Y position). The H in HC and HD means “high-frequency words” and the L in LC and LD means “low-frequency words.” X position changes for movements to the left were flipped so that all movements were evaluated in the same space.
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