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THE DEVELOPMENT OF POST-ERROR SLOWING IN CHILDREN AND ADOLESCENTS

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Abstract

The current study aimed to identify the development of post-error deceleration in children and adolescents of ages (8, 11, 14, 17 years), and to identify the significance of the differences in post-error deceleration in children and adolescents according to the variables of age and gender. The current research was limited to children and adolescents of ages (8, 11, 14, and 17) years old, and for both genders attending public morning schools in the city of Baghdad, along with its two sides (Al-Karkh and Al-Rusafa). The research sample consisted of (240) children and adolescents, with (30) males and (30) females for each age, chosen by the stratified method. Randomization and the Simon test were applied to them, and the standard characteristics of the test were extracted, namely validity and reliability, as the reliability coefficient of the scale using the Cronbach equation reached (0.89), and the results of the study showed a decrease in post-error deceleration across the stages of childhood and adolescence, starting from the age of (8). years, and females show a greater slowdown after a mistake than males.

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Introduction

Post-error slowing is one of the most widely used phenomena to study the psychological, cognitive effects and recovery from errors. It has received significant attention in applied fields and clinical psychology. This phenomenon provides a unique window into understanding how children and adolescents' reaction times decrease differently in response to errors or suboptimal outcomes, which could have serious consequences (Eben, et al., 2023: 1).

Post-error slowing aims to improve behavior, as it is sometimes associated with increased behavioral accuracy. Traditionally, it is attributed to adaptive modifications in decision-making policies, employing a more cautious response approach to enhance performance in subsequent trials (Fievez et al., 2021: 2).

There is a debate regarding the development of post-error slowing. Some studies have shown a decrease in post-error slowing from 8 years to late adolescence, while others have demonstrated a reduction at 9. Additionally, studies indicate a decrease beginning at the age of 6 years (Smigasiewicz. et al., 2019, 1_2).

Keywords: Post-error slowing, Children, Adolescents.

The behavior of children and adolescents changes and becomes slower after making mistakes. Children and adolescents slow down their performance to avoid future errors. Mistakes make them more cautious and elicit emotional expressions from others. In some cases, these social expressions may lead to more cognitive processing, thus strengthening the error signal or even providing a punitive signal that facilitates further behavioral modification. This results in greater post-error slowing in children compared to adolescents (Gupta & Deak, 2015, p. 10).

De Mooij et al. (2022) argue that post-error slowing begins to decrease from the age of 9 years through adolescence, as children start using more efficient cognitive control from the age of 8 years and upwards. On the other hand, Brewer & Smith (1989) observe that post-error slowing begins to decrease from the age of 6 to 15 years (Ger & Claudia, 2023: 2).

A study by Dubreavac et al. (2022) showed that post-error slowing develops and decreases starting from the ages of 8, 10, 12 years and throughout adolescence in all age groups (Dubreavac, et al., 2022: 14). This result aligns with the findings of Compton et al. (2017), which indicated a general decrease in the development of post-error slowing at the age of 8 years, but differs from the findings of Ger and Roybers who showed that the development of post-error slowing demonstrates a decrease at the age of 7 years (Ger & Claudia, 2023: 12).

The developmental effects on post-error slowing are somewhat inconsistent. Studies by Schachar (2004), Smulders et al. (2016), and Gupta et al. (2009) have shown that post-error slowing decreases with age, from 5 years to adolescence. In contrast, a study by Dubravac et al. (2020) demonstrated a decrease in post-error slowing starting from the age of 9 years to late adolescence. However, some studies diverge in their results; for example, Wiersema et al. (2007) and Davies et al. (2004) found that post-error slowing does not decrease with age between 8 years and adolescence. More recently, Ficarella (2019) suggests that the relationship between post-error slowing and age remains controversial (Smigasiewicz. et al., 2019, 1_2).

Studies on gender differences in the development of post-error slowing have yielded inconclusive results. For instance, Thakkar et al. (2013) found that females exhibit greater post-error slowing than males. This result was attributed to decreased attentional distraction by irrelevant cues among males with age. Conversely, Themanson et al. (2011) showed opposite results, indicating that males demonstrate greater post-error slowing than females (Fischer et al., 2016: 2, 3).

Schroder et al. (2021) believe that the development of post-error slowing remains a topic of debate. However, studies have a consensus on error correction and recovery from its effects. Individuals tend to exhibit slowing after errors when engaging in resource-intensive cognitive processes that follow cognitive flexibility in performing ongoing tasks. After a wrong response, neural processing is initiated to detect and compensate for the error. Nonetheless, post-error slowing reflects a cognitive distraction, leading to a decrease in performance accuracy in subsequent trials (Beatty et al., 2021: 1).

Upon realizing they have made a mistake, children and adolescents often halt their current motion briefly or at least slow down slightly. This helps them refocus on their task or understand why they made the error (Danielmeier & Ullsperger, 2011: 2). Making mistakes is a part of the learning process, allowing learners to improve. The ability to detect, evaluate, and adapt to these errors is essential for developing children and adolescents and constitutes an important area of research (de Mooij et al., 2022, p. 1).

Children and adolescents become more cautious in their responses after making mistakes, thus reflecting a strategic adaptive modification to prevent future errors. This adaptive behavior forms a crucial element in cognitive control. When a child or adolescent acts in a way that is not consistent with situational demands, the awareness of this discrepancy (the error) activates the initiation of adaptive cognitive control processes to change behavior, contributing to response slowing to increase the likelihood of better performance. Slowing in response often occurs when the child does not take the necessary time to ensure an accurate response. Therefore, a slow response to a trial after an error is a form of adaptive behavior (Adkins et al., 2022: 4).

Jentzsch & Dudschig (2009) suggest that post-error slowing develops over time across the stages of childhood and adolescence and aims to improve future behavior. This slowing stems from cognitive difficulties following an error, affecting the sensory processing period (Dames & Christina, 2021: 5_6).

Damaso et al. (2020) believe that post-error slowing results in children and adolescents feeling capable of manipulating the outcome; if they feel in control of the work, they slow down after errors, hoping to gather more information and thus change that outcome. Conversely, if they do not feel in control (for instance, if the error is due to an external factor like a blurred stimulus presentation), they may not slow down or might even speed up (Eben et al., 2023: 1_2).

Buzzell et al. (2017) assert that post-error slowing results from delayed processing of sensory information related to the task in the following trial. This delay is not due to a general lapse in attention or distraction but rather the error detection process itself, leading to an intentional cognitive bottleneck due to allocating limited resources to determine whether an error has occurred (Buzzell et al., 2017, p. 2896).

Hester et al. (2005) note that the duration of post-error slowing is significantly adjusted by awareness of the error; slowing increases after a conscious error compared to an unrecognized one (Masina et al., 2018). Klein et al. (2007) believe that the error signal needs to surpass a particular strength or signal-to-noise ratio (peaking between approximately 50 to 100 milliseconds after an error) to allow for awareness of the error and gathering information about its source (Mohamed et al., 2018, p. 2218).

Rabbitt pondered what a child or adolescent does after making a mistake. One answer he proposed is the occurrence of post-error slowing, resulting from increased caution in the subsequent response to errors. The error prompts the child or adolescent to gather more information before deciding. The basic idea here is the adaptive change in children and adolescents' response threshold (they become less cautious after correct responses and more cautious after incorrect ones) (Dutilh et al., 2011, p. 455).

Laming's theory is one of the earliest explicit theories of post-error adaptive processing. Its primary assumption is that post-error slowing leads to a delay in processing perceptual information. This assumption is based on the idea that children and adolescents might begin sampling information before presenting the definitive stimuli from the cognitive task. This premature information sampling could negatively impact the decision-making process triggered by the stimulus, leading to errors. Therefore, delaying the start of this information-sampling process could prevent errors arising from such early sampling (Wessel, 2018: 3).

Dubravac and others suggest that non-repetitive events shift attention towards the unexpected event, resulting in performance slowing in the subsequent trial (post-error slowing). Therefore, the substantial slowing in children in the first trial after an error likely reflects a more robust orienting response in children with more difficulties directing automatic attention toward the error.

Post-error slowing decreased with age, and this diminishing age effect suggests behavioral adjustments in adolescents become more precise after errors. This reflects the developmental trajectory of post-error slowing from the age of 8 years to adolescence (Dubravac et al., 2021, pp. 3-16).

Notebaert believes that post-error slowing reflects a response directed at an unexpected event. Since errors are rare, they represent prominent, motivationally significant, unexpected events that automatically attract attention, diverting a child's attention from the task. This results in both post-error slowing and a decrease in post-error accuracy. According to this theory, it is not the error that causes slowing but rather the redirection of attention towards this event (Ceccarini & Umberto, 2018: 2).

Wessel's theory offers three main assumptions explaining post-error slowing and its psychological and cognitive effects, as follows:

First, Errors are specific instances of a broader category of task-related, unexpected psychological events. Wessel (2012) posits that an error usually results from a specifically unexpected action. An error involves either a mismatch between the planned action and the action that was executed or between the completed action and its outcomes. Neurophysiological investigations support the assertion that post-error processing in the brain is associated with the anticipation of action outcomes by comparing children’s responses during easy and complex tasks. Errors evoke several automatic attentional processes to detect the effects of unexpected actions (or, more generally, any unexpected task-related events) (Wessel et al., 2012, p. 4).

Second: Task-related unexpected events lead to a typical, rapid sequence of automatic processing. Wessel (2018) assumes that all unexpected events, including errors, are followed by an automatic sequence of two rapid, successive processes (inhibition – attention orientation). Both are aimed at interrupting ongoing processing and redirecting attention to the source of the unexpected event. This initial automatic processing sequence is not specific to errors but occurs after any unexpected task-related event (Figure 7) (Wessel & Aron., 2017: 3).

Third: If the unexpected event is an error, the automatic sequence is followed by conscious cognitive processing. Wessel believes that if the expectation violation is identified as resulting from an error, the automatic sequence is followed by another set of error-specific processing (however, if the expectation violation results from something other than an error, a different set of controlled processes may be needed and may be necessary appropriately depending on the situation).

These controlled processes have the following characteristics:

- The automatic sequence preceding these controlled processes is beneficial for their execution.
- These controlled processes are specific to the type and nature of the error.
- These adaptive processes are deliberate, relatively slower, and controlled (may involve awareness) (Wessel, 2018:11, 13).

Method

Achieving the objectives of the current research requires a quantitative description of the development of post-error deceleration in children and adolescents (8, 11, 14, 17) years. For this reason, the descriptive research method was used, which is designed to identify and describe the facts related to the current situation (Odeh and Malkawi, 1992: 113), including cross-sectional studies that fall under the types of developmental studies that study a single physical or behavioral manifestation in a cross-section of time in the developmental ladder, and in this Method: The sample consists of groups of individuals distributed over ages (Al-Alusi and Khan, 1983: 76).

The method is a valued, important approach to undertake studies in health and social care settings (Arnout, Abdel Rahman, Elprince, Abada, & Jasim, 2020: 32).

Test description:

Dobrivac and others confirm that post-error slowdown abilities emerge and are derived from its psychological and cognitive causes and effects, as each test task consists of a group of mental abilities that are considered potential causes of post-error slowdown, which leads to a cognitive conflict that the child is likely to commit. Or the teenager made a mistake, and these abilities are considered complementary and one of them may be the cause of the slowdown, the most important of which are the following:

1. Delayed processing of sensory information.
2. The sudden event.
3. Distraction.
4. Committing two mistakes in a row.
5. Delayed accumulation of cognitive evidence.
6. Awareness of error.
7. Executive functions (transfer - switching, updating, and restraining dominant or automatic responses) (Dubravac, et al., 2020: 2_4)

The Simon test consists of two types of tasks:

• The harmonious task group: It consists of (24) trials, (12) yellow starfish and (12) blue starfish appear in random order on either side of the harmonious response, and presenting this group of harmonious (pure) trials before the group of mixed trials is for training. Children and adolescents on consistent trials, to create a response pattern alongside the stimulus with the aim of increasing error rates on the mixed trial set, and also to obtain a baseline for differences in reaction speed and pure deceleration between children and adolescents (Dubravac, et al., 2020: 7).

• Mixed task set: consists of (120) mixed trials (consistent and inconsistent) in a random order, including (96) consistent trials, and (24) inconsistent trials in every fifth trial (see Appendix 5).

The procedure for implementing the test is the same for children and adolescents, individually, provided that the child or adolescent sits at arm's length from the laptop screen, and responds quickly by pressing either the left mouse button with the index finger of the left hand for the yellow starfish, or the right mouse button with the index finger of the right hand for the blue starfish.

Each trial is preceded by a fixation cross (the time between the response and the presentation of the next stimulus) lasting (250) milliseconds in the middle of the screen, followed by a yellow or blue starfish on a sky-colored background, which appears on the left or right side, and remains on the screen until the response. This has been adopted. The duration of the fixation interval (250 milliseconds) is considered appropriate for performing the cognitive processes that are activated when committing errors that aim to recover from the error and to increase post-error deceleration, according to the belief of Dobrivac and others, as well as confirmations from the theoretical literature in this context that shortening the duration of inhibition increases the duration of deceleration. Beyond the error (Dubravac, et al., 2020: 7).

Preparing the computerized program (post-fault hysteresis test):

To design a post-error slowdown test program and link it to Excel, the following was done:

The test experiments (stimuli) were designed in the image editor program (Picsart). The size of the starfish on the computer screen (laptop) was (9cm) the distance between the ends of the ends of the starfish’s arms and (3.5cm) the size of the body of the starfish (yellow and blue) (Dubravac , et al., 2020: 7).

“The Microsoft Visual Studio 2015 program was used to present the post-error slowdown test trials (stimuli) according to the sequence of the trials in the test structure and on an 18.1-inch display screen.

I used a database (Microsoft Office Excel 2013) and linked it to the program (Microsoft Visual Studio) to automatically transcribe the data, including (age (8, 11, 14, 17), gender (male, female)), answer score (0, 1), and answer time (in milliseconds)), and supports the results of neuroscience studies about the speed of transmission of electrical signals through nerve axons in proportion to the speed of the fixation interval in the current test and its data discharge in milliseconds (Overbye, 2018: 10), as the speed of transmission of a nerve flash in the sensory nerves is The movement that makes up the spinal nerves is (90) meters per second, of which the diameter capacity is (11-20) microns (micron = 1/1000 mm) (Al-Bayati, 2000: 44).

Four trials were presented before the start of the test (two consistent trials, two inconsistent trials) for the purpose of training and to clarify the test instructions for children and adolescents and were not included in the data analysis (Dubravac, et al., 2020: 7).

Results

The results indicated that sample members of ages (8, 11, 14, 17 years) slow down after committing errors, after a classic equation was used to extract pure post-error slowdown, which consists of subtracting the average reaction times in the experiments after the incorrect response from Reaction time in the trial that precedes the correct response (Dutilh, et al., 2014: 3), and it became clear from the results of this goal that the sample members slowed down and that there was a decrease in the averages of post-error slowdown across ages (8, 11, 14, 17), This is based on the traditional comparison process that is usually conducted in previous literature to identify the decrease in hysteresis on average scores by logically comparing the average (Balogh & Czobor., 2014: 1).

When observing the developmental path of post-error slowdown, we find that the calculated averages of pure slowdown decrease as children and adolescents age. This is consistent with the evolutionary perspective of (Dobrevac et al., 2020), which indicates a decrease in post-error slowdown with age across the stages of childhood and adolescence. The reason for the significantly lower post-error slowdown in adolescents and its higher rate in children is due to their slow processing of information and their high distraction factors, which may then incapacitate the less developed performance modification abilities of children to produce effective effects in preventing distraction and greater speed in the processing process. As a result of attention being occupied with correcting the error and recovering from its negative effects.

Dubravac and others confirm that errors are followed by a cognitive conflict that attracts attention towards the source of the error and preoccupies it with recovering from the effects of this error, and that these abilities require prevention of ongoing behavior. Given that the processes of preventing ongoing behavior are not fully mature in children, this may explain the stronger slowdown in children compared to adolescents (Dubravac , et al., 2020: 12).

Dobrivac et al. (2020) suggest that the adaptive nature of post-error slowing (PES) across tasks is not simply a response strategy to maintain an optimal balance of regular behavior. One explanation may be that errors do not merely lead to a strategically cautious slow reaction on the next trial. This does not mean that a single mechanism should explain the cause of the PES phenomenon, but it is likely that there are several mechanisms at play simultaneously in shaping post-deceleration. error and that the different accounts that attempt to explain this phenomenon are complementary rather than competing (Ger & Claudia, 2023: 14).

Dobrivac and others hypothesize that committing two mistakes in a row causes very strong deceleration, especially in children, and since the current research adopted the classic method of calculating pure deceleration, which depends on comparing the average of several scores after committing the error, this may explain the strong deceleration in young groups, because the rate of error commission is large. In children compared to adolescents, but in contrast, the classical method of calculating pure post-error slowing made it possible to filter out errors after committing the error in the high-conflict trial in the sequence of the set of trials (Dubravac, & Meier: 2023: 7).

Previous literature generally indicates that the fixation interval has a role in increasing or decreasing the post-error slowdown, that is, the shorter the duration of the fixation interval, the longer the post-error slowdown. The reason for this may be due to memory blockage and the inability to process the information that follows the occurrence of the error (Dames, et al., 2021: 1741) Since the current study adopted a relatively short fixation interval between trials (250 milliseconds), which is optimal, according to Dobrivac and others, in measuring post-error slowing in children and adolescents, this is supported by a real explanation for why slowing occurs. The post-error rate is high among sample members, perhaps because they are unable to complete post-error processing and are preoccupied with finding out the cause of the error.

The results showed that there were statistically significant differences between the averages of both males and females for the ages (8, 11, 14, and 17 years). This result is consistent with the assertions of the theoretical literature (Dobrevac et al.), which indicates that females slow down more than males after committing mistakes. Because of their keenness to show greater accuracy in performance after committing mistakes, previous studies have not resolved the matter regarding the differences between the sexes regarding this phenomenon because they showed contradictory results with the results of the current research, as some researchers believe that the reason for this is due to the intertwined nature of the neural factors. And behavioral differences between the sexes. On the other hand, studies that showed females slowing down more than males, which is in line with the results of the current research, attributed the reason for this to females spending more time being occupied with information that is not important to the event and is not related to the error in an attempt to psychologically recover from the negative effects. Error, and the researcher believes that this result may be due to the difficulty of preventing distraction in females, and the differences that exist between the sexes in brain functions based on the results of important previous studies by (Doprivat et al.).

The results showed that post-error slowdown takes a developmental path across the ages (8, 11, 14, 17) years, and this is consistent with the theoretical insights of (Dobrevac et al.), who explained the developmental path of post-error slowdown and attributed its decrease to increased awareness of the mistake with increasing age.

Realizing that a mistake has been committed improves performance in the future, which prevents it from being repeated.

When observing the path of post-error deceleration across the ages included in the research, the positive decrease in it began to gradually decrease across the ages, and this supports the point of view of (Dobrevac et al., 2020), which believes that development is continuous and not phased, and that the time courses of post-error deceleration are comparable across the ages. Age groups (8, 11, 14, 17) years.

The result of the current research is consistent with the findings of previous studies, such as the study by Masina et al. (Masina, et al., 2018), which showed that post-error slowdown takes a continuous developmental path across life, represented by a decrease in post-error slowdown throughout the stages of childhood and adolescence (Masina, et al., 2018: 1), while the study of Ger & Claudia (2022) showed that children slowed down after committing a mistake at the age of (8) years, but it is still a developed strategy for them, meaning that it exists but can be developed (Ger & Claudia, 2022: 1), while the study by Gupta et al. (2009) showed a decrease in post-error slowdown with age, as post-hoc comparisons indicated a decrease in post-error slowdown at the age of (8) and (9-10) years, The evolutionary path of post-fault deceleration is gradual and not continuous (Gupta, et al., 2009: 1_8).

Regarding the differences between the sexes, the result of the current research is in line with what was shown by the result of the study of Thakkar and others (Thakkar, et al., 2013) that females show a greater slowdown after the error compared to males, approximately (60) milliseconds after committing the error, and the authors of the study attribute this result To a decrease in distraction in males by irrelevant signs or other distractions with age, while the study of Themanson et al. (Themanson, et al., 2011) showed the opposite results, namely that males show greater slowing down after an error compared to females. The authors of the study attribute this The result is gender differences in the activity of brain regions associated with error (Fischer, et al., 2016: 2).

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