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OOPS – THAT WAS A MISTAKE! HOW TODDLER BRAINS REACT TO FEEDBACK

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REVIEWED BY:

ALEX
12 YEARS OLD

Oops, I just clicked on the wrong button on my computer (mistake) and it made this error sound that you might know. This is an example of feedback. Feedback is useful information to indicate if something was correct or wrong and we can use feedback to improve something. For example, I do not want to make the same mistake again, so now, I click on the right button! This is called feedback learning. You often get feedback on what you are doing and sometimes that feedback tells your brain "Oops, that was a mistake!" From such feedback, you can learn and do things better the next time. Learning from feedback is, especially, important early in life when young children still need to learn a lot about the world. Interestingly, the brain regions that generate the feedback signal, however, take a long time to fully develop. Sometimes, they do not completely develop even until the late teenage years. How then do young children (also called toddlers) between the ages of one and three process the feedback signal in their brain? And how do they learn based on the feedback they get? These were some of the questions that we wanted to answer.

Tony was late for the game. He put on his socks in a hurry and was about to quickly put on his shoes and leave. He picked up a shoe and looked at his feet and he realized, "Oops! My socks don't match." Then he changed the white sock to the matching blue sock, slipped into his shoes and off he went. Like Tony, I mix up my socks by mistake, too. Don't you sometimes? When you put on your socks and look at them, your eyes see them and tell your brain what they see. Then the brain, when seeing socks that do not match, might think "Oops! Made a mistake." So your brain is using helpful information to indicate if what you just did was correct or wrong and whether to improve something. This sort of information is called feedback. Next time you pick up the second sock, you know to check if they match before putting them on (feedback-based learning). You learn from the feedback that you received from your earlier experience. That feedback can happen in many different ways, including the grade you get on your test at school or the sound you hear and the broken glass you see when you accidentally drop a glass of milk. You can learn from all kinds of feedback, but how does this learning from feedback actually happen? Also, as you might know if you have a little brother or sister, learning from feedback is especially important early in life when children still need to learn a lot about the world. So, we were curious to know how toddlers (young children) process feedback and learn from it.

From experiments done with adults, we have known for a while that there are different brain signals when the feedback says "Correct" compared to the feedback that says "Oops! Made a mistake" [1]. Before telling you more about it, we will explain how you can measure such brain responses:

Your brain does anything and everything that it does by passing very, very, *very* tiny bits of electricity between different brain cells called neurons. This electricity allows the neurons to communicate with each other and send information across the brain. Neuroscientists, the people who study brains, know how to measure these tiny currents using a technique called electroencephalography (Electro-En-ce-pha-lo-Gra-phy), usually shortened to **EEG**. They take a lot of extremely sensitive wires, called electrodes, and arrange them on a cap. The neuroscientists can see and measure the tiny brain signals, which look like what is shown in Figure 1A, when the cap is placed on a person's head, as in Figure 1B. This helps the neuroscientists observe the changes happening to your brain signals when you get feedback.

From the experiments with adults that we mentioned earlier, it was found that the brain generates a specific signal for feedback, called **feedback-related negativity (FRN)**. We also know that the brain regions generating this signal, called the **anterior cingulate cortex (ACC)** and the **medial frontal cortex (MFC)**, take a long time to completely develop. Figure 1C shows you that the ACC and MFC are in the middle and at the front of the brain. Sometimes, they do not completely develop even until teenage years [2]!

EEG

Electro Encephalo Graphy (this comes from "encephalon" which means the "brain" and "graphein" which means "to write") – a technique used to measure electrical brain signals

FRN

Feedback Related Negativity – this brain signal reaches its highest negative point, after getting the feedback for making a mistake

ACC

Anterior Cingulate Cortex – a brain area that is involved in processing feedback

MFC

Medial Frontal Cortex – the brain area that is in the middle, toward the front of your brain

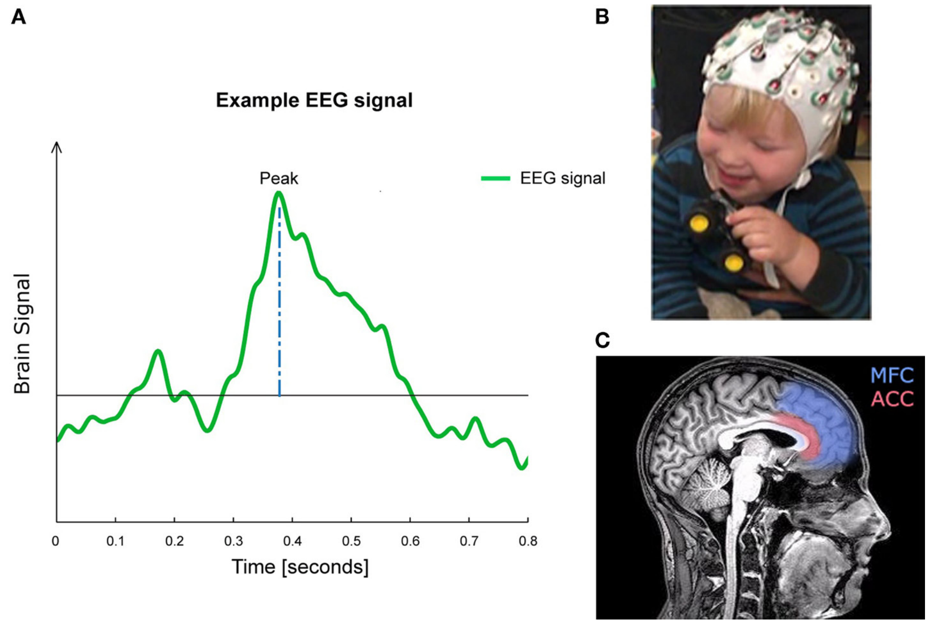

FIGURE 1

FIGURE 1

(A) This is what an EEG brain signal could look like. **(B)** Picture of a toddler wearing an EEG cap. **(C)** If you imagine splitting a brain into two halves, much like a peanut, it is the inside part of one half that you see here. Anterior cingulate cortex (ACC) and medial frontal cortex (MFC) are in color. These are some of the regions that develop during the teenage years. Figure (C) adapted from DrOONeil http://commons.wikimedia.org/wiki/File:FMRI_Brain_Scan.jpg

How then do toddlers as young as 2½ years of age, whose ACCs and MFCs are not fully developed, manage to create the feedback signal in their brain and learn from feedback? How can toddlers learn how to plan their action the next time, based on the feedback that they receive? At what age do young children start showing the specific signal for feedback, the FRN response? How different or similar are a toddler's brain signals compared with a grownup's brain signals? These were some of the questions that we wanted to answer using the EEG technique.

THE GAME

In our experiment, we gave the toddlers a fun game with animal cards to play on a touch screen similar to an iPad. The goal of the game was to find the animal card that matched the one shown in the middle of the screen. We had a lot of different animals so toddlers could play many rounds of the game.

One round could look like what is shown in Figure 2. After showing toddlers all the cards in the round (here two lions and a pig), the cards were mixed and we asked the toddlers "Where do you think the other (in this case) lion is?" When toddlers touched a card, the chosen card turned face-up and revealed its picture. Was it the matching card? Here we see that the first choice is the pig! Oops, that was a mistake. Do you recognize that this is the feedback that the toddler is getting? If we were to measure their brain responses, what do you expect to see? We expected an FRN-like brain response, similar to the feedback signal we know from adults.

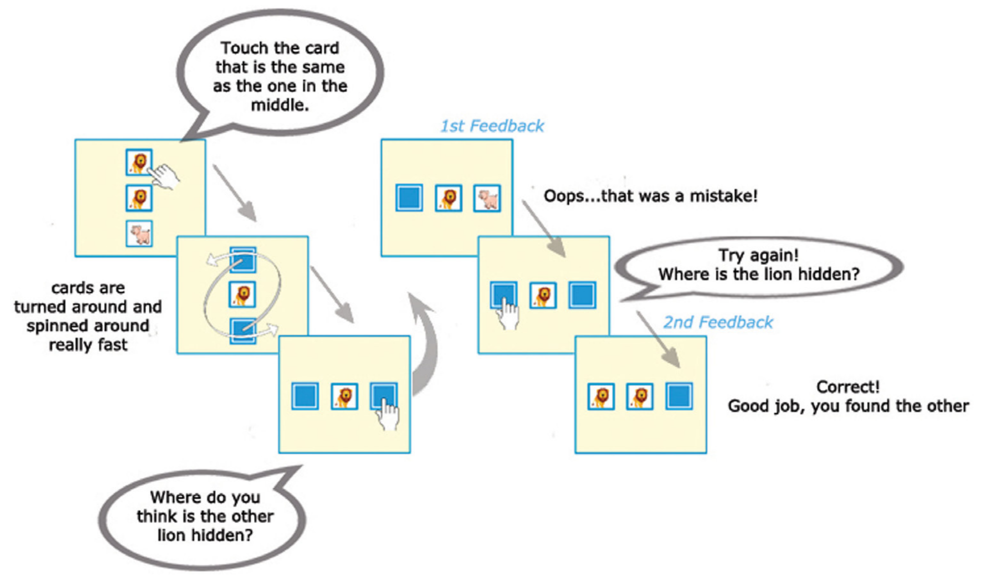

FIGURE 2

FIGURE 2

Example of one round of the game.

Next, no matter whether their first choice was right or wrong, we asked the toddlers again "Do you now know where the lion is?" and the toddler could choose again. The important difference this time was that the correct card could be found easily because of the feedback toddlers had gotten before.

You probably know by now that the most important part of this experiment is when the chosen card turns after the toddler makes the first choice, acting as the first feedback for the toddler's action. Now the fun part: this is what we found:

GAME SCORES

On average, about half of the time, the toddlers were able to give correct answers on the first choice in a round. This happens just by chance, like tossing a coin, and is expected because we designed the game such that the toddlers could not know the location of the correct card on the first turn – they had equal chances of getting the right or the wrong card. But on the second choice, they performed much better The toddlers were able to find the correct card significantly more often than they could just by chance.

BRAIN SIGNALS

What we found was that, like adults, toddlers' brain signals were different depending on the feedback they received (see Figure 3). They show a FRN-like brain response. That is, their brain signals for feedback that said "Correct" were different from the brain signals that said, "Oops! Made a mistake." This

PEAK

highest value the brain signal reaches

difference in the brain signal took 0.35 s to reach its maximum value (also called its **peak**). This is a bit slow compared to a grownup's signal, but this speed is quite common in very young children. Other studies involving babies and toddlers have shown that a peak in the signal occurs later than in adults because babies are just slower in processing all information. Also, similar to adults, these feedback signals were found near the same brain regions that generate the mistake-related signal in adults.

Before we continue, we would like to give you an example that hopefully makes it easier for you to understand the rest of the results. Imagine you play the same game for several days. Probably, the more days you play this game, the better you get at it. This concept is called positive correlation: As one thing increases (in this case the number of times you practice a game), the other increases too (for example, how good you are at the game).

Interestingly, our results showed a positive correlation between the game scores and the feedback signals from the brain. To understand what this means, take a look at two examples in Figure 4: toddler 1 and toddler 2. For toddler 1, the brain measurements were not very different for feedback that said "correct" and feedback that said "oops, mistake" (close to 0). You can imagine that if you do not really pick up the difference between being correct and wrong, that you might not be so good at the game. This was also the case for toddler 1. Now look at toddler 2. This toddler showed a much larger difference in brain signals between "correct" and "oops, mistake" feedback. And do you see the performance? Close to 100%, which is almost perfect. This creates the positive correlation: the better the brain picks up the difference between "correct" and "oops, mistake", the better the toddler can perform at the game.

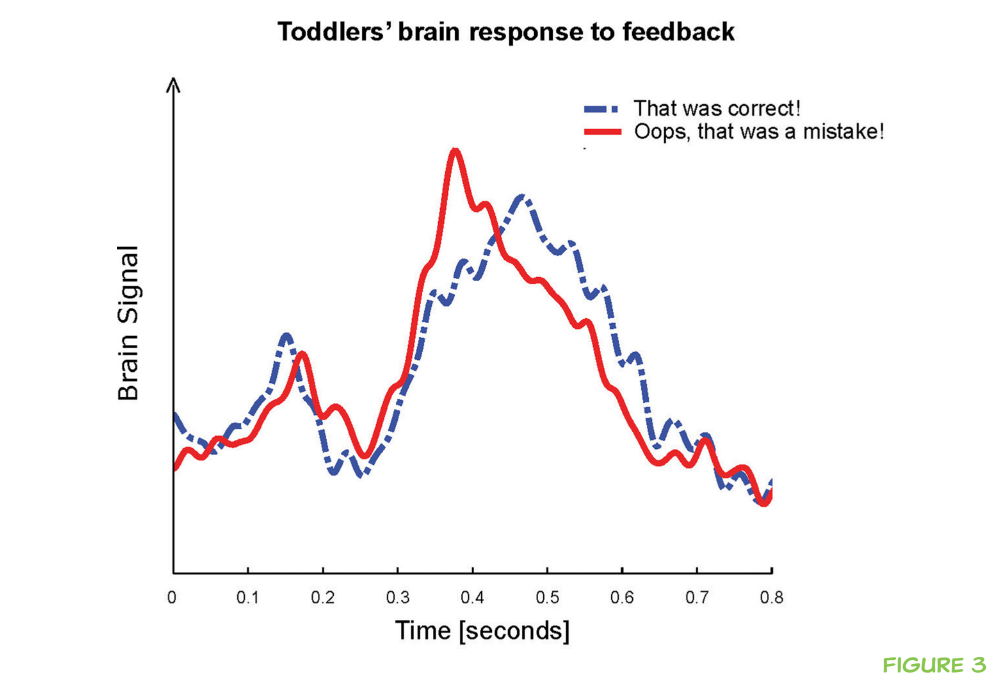

FIGURE 3

Illustration of our results: the toddlers' brain signals measured over areas known for feedback processing.

FIGURE 4

The larger the difference in brain-signal peaks for correct and incorrect trials, the better was the performance in the game.

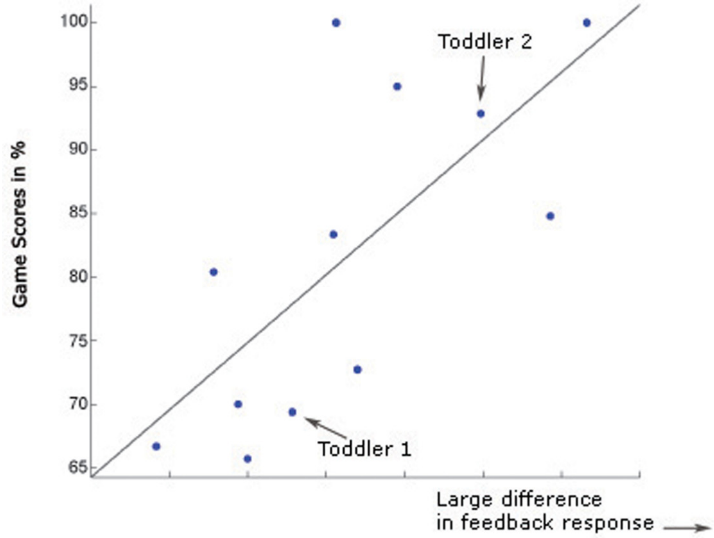

FIGURE 4

WHY IS THIS IMPORTANT?

Before we did these experiments, we had very little idea how the brains of young children deal with feedback. Now we know that even when 2½-year-old toddlers receive feedback, they show similar brain signal patterns as adults. The brain signal appears slightly slower (about 0.1 s later than in adults), which is expected and may represent slightly slower processing in a toddler's brain [3].

As mentioned above, the larger the difference between the toddlers' brain signals for correct and incorrect feedback, the better the toddlers performed in the second turn. This shows that even a toddler brain takes steps to make sure that, whenever a mistake is made, it is corrected the next chance they get. But why do some toddlers show stronger brain signals in response to feedback when compared with other toddlers? Well, there could be several reasons for this:

1. Remember we mentioned that some brain regions take a lot of time to develop? So in some toddlers who show larger differences, these brain regions might already be more developed than in others [4].
2. Some toddlers who show weaker signals might just be less sensitive to feedback in general [5]. For these toddlers, socks have to be very, *very* different in order for them to see that they do not match.
3. Or, it is possible that toddlers are sensitive to feedback, but might just not pay attention or might not be motivated to learn the game. We know from other studies that attention plays an important role in learning from feedback [1]. So, those toddlers who show lower feedback peaks might just not be interested in the task. They are able to play the game, but are not excited enough or paying enough attention to learn from the feedback they receive. To use the example of Tony

and the socks, these toddlers are thinking about something else already and do not pay attention to their socks, so they do not realize that they are different colors.

However, more research is needed to fully understand all of the factors that affect these brain signals to help learning in general. But for now, to summarize, this study is the first of its kind to show that toddlers as young as 2½ years show a specific brain signal when they receive feedback, and that the larger the difference in the brain signals between correct and incorrect responses, the better they are at playing the game next time. So, the way the toddlers' brains process the feedback influences their performance. But we still need to do more research to figure out exactly how this happens. Maybe you can help us find answers to these questions. Will you?

ORIGINAL SOURCE ARTICLE

Neural Correlates of Feedback Processing in Toddlers (Journal of Cognitive Neuroscience, 2014, http://www.mitpressjournals.org/doi/abs/10.1162/jocn_a_00560#.U_0saPmSx6B)

REFERENCES

1. Walsh, M. M., and Anderson, J. R. 2012. Learning from experience: event-related potential correlates of reward processing, neural adaptation, and behavioral choice. *Neurosci. Biobehav. Rev.* 36(8):1870–84. doi: 10.1016/j.neubiorev.2012.05.008
2. Crone, E. A., Zanolie, K., Leijenhorst, L., Westenberg, P. M., and Rombouts, S. A. 2008. Neural mechanisms supporting flexible performance adjustment during development. *Cogn. Affect Behav. Neurosci.* 8(2):165–77. doi: 10.3758/CABN.8.2.165
3. Csibra, G., Kushnerenko, E., and Grossmann, T. 2008. Electrophysiological methods in studying infant cognitive development. 2nd ed. In *Handbook of developmental cognitive neuroscience,* eds. C. A. Nelson and M. Luciana, (Cambridge, MA: MIT Press), 247–62.
4. Gogtay, N., Giedd, J. N., Lusk, L., Hayashi, K. M., Greenstein, D., Vaituzis, A. C., et al. 2004. Dynamic mapping of human cortical development during childhood through early adulthood. *Proc. Natl. Acad. Sci. U.S.A.* 101(21):8174–9. doi: 10.1073/pnas.0402680101
5. Santesso, D. L., Dzyundzyak, A., and Segalowitz, S. J. 2011. Age, sex and individual differences in punishment sensitivity: factors influencing the feedback-related negativity. *Psychophysiology* 48(11):1481–9. doi: 10.1111/j.1469-8986.2011.01229.x

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REVIEWED BY

ALEX, 12 YEARS OLD

I am a 7th-grade student at the Next Generation School in Champaign (IL). I was born in North Carolina and before coming to Illinois, I also lived in Alberta, Canada. I love school, and some of my favorite topics include math, computers, physics, chemistry, engineering, and neuroscience. I am also interested in sports. I started ice skating when I was 4 and have been playing hockey for several years. I have also competed in basketball, track and field, and karate.

AUTHORS

MARLENE MEYER

I am a researcher in the field of Developmental Cognitive Neuroscience. In other words, I am fascinated by how we develop from a newborn baby into a grownup, and how this development shows in our brain and behavior. It is a great pleasure to investigate babies and young children in my research to find out more about children's behavior and their brain processes. Besides the developing brain in action, I love meeting friends, playing sports, and traveling.

SUHAS HASSAN VIJAYAKUMAR

It all started when I began to wonder how does my brain, being something you can touch and feel and smell, create these memories, emotions, and thoughts? They also exist, but only inside my brain! I am only beginning to study how this mysterious grey blob between our ears is organized. And when I am not thinking about the awesomeness of the brain, I am reading about the awesomeness of our universe, making art, or trying to keep up with cool new tech.

HAROLD BEKKERING

I am a professor in Psychology and in my research, I want to find out how our brain makes sense of and predicts the world around us. In my free time, I enjoy playing chess. I also love squash, soccer and – like many Dutch people – cycling.

DENISE J. C. JANSSEN

My research is about our reactions to feedback. I would like to find out more about the feedback signal in the brain, how feedback helps us learn new things, and how it makes us feel. In my spare time, I like to go swimming, make designs on my computer, and go on trips to take photos.

ELLEN R. A. DE BRUIJN

We all make mistakes, but we can usually detect them very quickly. I want to know how we do this and what happens in our brain. I also want to understand why some people hate making errors while others do not mind a mistake that much. People who are depressed or sad, for example, react differently to errors than people who are happy. So, I hope that my research will also help us understand better why people sometimes feel unhappy.

SABINE HUNNIUS

I am interested in how children, and especially babies, develop. I always found it amazing how quickly babies learn and change into toddlers who can move around and talk. Isn't it crazy that nobody can remember what it was like being a baby, although we have all been a baby once? This is why I study how babies and children perceive the world and how they start to make sense of the things they experience as they grow older.