THE EUROPEAN SOCIETY OF MEDICINE
Medical Research Archives, Volume 12 Issue 7

RESEARCH ARTICLE

Characteristics of Attentional Focus of Movement among Adults who Stutter

Shinobu Murase[1]

[1] Faculty of Education, Gifu University, Japan

OPEN ACCESS

PUBLISHED
31 July 2024

CITATION
Murase, S., 2024. Characteristics of Attentional Focus of Movement among Adults who Stutter. Medical Research Archives, [online] 12(7).
https://doi.org/10.18103/mra.v12i7.5627

DOI
https://doi.org/10.18103/mra.v12i7.5627

ISSN
2375-1924

ABSTRACT

Certain conditions are known to eliminate stuttering immediately. These conditions are referred to as fluency-inducing conditions, and they infer abnormalities of attentional characteristics among people who stutter. The aims of this study were to elucidate how the motor performance of stutterers is influenced by attentional foci: external focus of attention and internal focus of attention. A typing task involving sequential key pressing was conducted under the external focus and internal focus conditions among 13 adults who stutter and 12 matched control adults who do not stutter. Typing accuracy and typing speed were analyzed. The results revealed that the typing speed was significantly lower under the internal focus condition than the external focus condition in both groups, indicating that internal focus reduces the efficiency of finger movement compared to external focus. Moreover, for adults who stutter, typing accuracy also decreased significantly under the internal focus condition. It is speculated that adults who stutter are more vulnerable to disruptions in motor control under internal focus conditions than adults who do not stutter. The clinical implications of these findings are discussed.

Keywords: stuttering, focus of attention, finger movement, motor performance

Introduction

The cause of stuttering is not known. Therefore, there is no medical treatment that targets its cause. Speech therapy is widely used to alleviate stuttering. According to recent studies on the effectiveness of speech therapy for stuttering, treatments using speech restructuring strategies have benefitted both children and adults who stutter.[1,2] However, the limitations of the treatment are evident since speech restructuring treatments require stutterers to acquire a novel speech pattern—such as easy onsets, prolonging sounds/words, and slowing down speech rate—and to use it in one's daily life. Brignell et al.[1] found that the reduction in stuttering remains only at about 50%, and Tasko et al.[3] argued that the acquired speech pattern often sounds unnatural.

Despite the difficulty in establishing natural fluency through speech therapy, certain conditions are known to eliminate stuttering immediately and almost completely. Examples of these conditions, known as fluency-inducing conditions (FCs), include speaking with someone else, following the rhythm of a metronome, speaking under delayed auditory feedback, and singing songs.[4] Although the reasons that stuttering disappears in FCs are not clearly understood, the most common explanation for this effect is "distraction."[5] Because stuttering is partly an anticipatory struggle behavior, a distraction from one's stuttering reduces fear or anxiety and, thus, may prevent stuttering. Hesse[5] argued that this cannot fully account for the complete fluency usually observed under FCs. Instead, he proposed the attention theory, which explains that FCs reduce stuttering by changing the allocation of attention in people who stutter.

The relation between motor performance and attention has been well studied. Since Wulf et al.[6] revealed that motor performance is greatly affected by the direction of the performer's attention, numerous studies have been conducted and have consistently shown that external focus of attention (EF) results in more effective performance than internal focus of attention (IF). According to Wulf,[7] EF involves directing attention to the environment, such as an apparatus or objects, while IF involves directing attention to one's own body movements. McNevin et al.[8] postulated the constrained action hypothesis to explain the different effects of these attentional focus types on motor control. The hypothesis suggests that an EF facilitates performance because it enhances automatic control of movement, while an IF induces more conscious control of movement, disrupting the process of automatic control.

Rong-Na et al.[9] implemented speech therapy for adults who stutter using shadowing, a task during which subjects listen to a spoken passage and repeat it simultaneously. They reported that some subjects with pronounced symptoms showed a markedly reduced frequency of stuttering through speech therapy with shadowing. They speculated that stuttering was reduced because the subjects distracted their attention from their stuttering to the model speech. Considering this result from the perspective of the constrained action hypothesis, it can be inferred that stutterers pay too much attention to their articulatory movements (IF condition) and become fluent with shadowing because they alter their attention to their environment (EF condition). However, there is little information about the characteristics of attentional focus and motor performance in people who stutter.

This study aimed to clarify the characteristics of the motor control of people who stutter. A typing task under EF and IF conditions was used to investigate how these conditions affect motor performance among people who stutter and those who do not.

Methods

SUBJECTS

Subjects were 13 adults who stutter (AWS; M=26.6; SD=±5.3) and 12 matched control adults who do not stutter (ANS; M=21.7; SD=±1.7). The AWS were recruited from university student bodies or self-help groups in Japan, while the ANS were all graduate or undergraduate university students. All subjects were male with normal hearing and no self-reported neurological conditions affecting finger movement. Although one participant in the AWS had a history of social anxiety disorder, no one was currently taking any medication.

Among the AWS, the stuttering severity during informal conversations with the experimenter, assessed using the Standardized Test for Stuttering Second Edition,[10] ranged from very mild to very severe as follows: two very mild, six mild, four moderate, and one severe. The ANS did not show any signs of stuttering. According to the FLANDERS handedness questionnaire, Japanese translation version,[11] all subjects were right-handed except for three AWS. The average typing time per day over the past month was surveyed and recorded as 3.3±2.8 hours (range: 0–8 hours) for the AWS and 1.1±0.5 hours (range: 0.5–2 hours) for the ANS. A t-test indicated no significant difference in typing time between the AWS and the ANS ($t=2.181$, $p=.052$).

The experiment received approval from the Ethics Review Committee of the Special Needs Education Division, Graduate School of Education, Gifu University. Additionally, all subjects were provided with written and verbal explanations of the purpose and content of the experiment, and written informed consent was obtained from all subjects.

EQUIPMENT

The experiment was conducted in a quiet room where subjects were comfortably seated in a chair. A desk was set in front of the subject, and a computer keyboard (ELECOM TK-FCM062) connected to a PC (Panasonic CF-SZ5) and a monitor (BENQ GL2760B) was placed on the desk in an easy-to-reach position for typing. The F, T, Y, U, and K keys on the keyboard were labeled with stickers with the numbers 1, 2, 3, 4, and 5, respectively. For later analysis, characters that subjects input with the keyboard were recorded. Subjects' finger movements were also recorded using an external webcam (Logicool HD720p) attached to the computer.

TYPING TASK

The typing task involved sequential key pressing using all five fingers of the dominant hand in two attentional conditions: EF and IF. Each of the five fingers was paired with a single numbered key. Right-handed subjects were required to use the thumb for 1 (F key), index finger for 2 (T key), middle finger for 3 (Y key), ring finger for 4 (U key), and little finger for 5 (K key). Conversely, left-handed subjects were directed to use the thumb for key 5 (K key), index finger for key 4 (U key), middle finger for key 3 (Y key), ring finger for key 2 (T key), and little finger for key 1 (F key). The sequence of key presses was 1234513524543215314 2 for right-handed subjects and 54321531421234513524 for left-handed subjects. Subjects memorized the sequence in three minutes and then performed 10 trials in each condition (EF and IF).

PROCEDURE

Initially, subjects were advised to adjust their posture, chair, and keyboard position to ensure optimal comfort and efficiency in key manipulation. Following this, the task was explained to the subjects. After the explanation, subjects were presented with a document delineating the sequence of key presses. They were allotted three minutes to practice and memorize the sequence. During this practice period, subjects manipulated the keyboard freely and ensured the firm depression of keys. After the practice period, subjects received the following instructions for typing: After the experimenter says "yes" (indicating start), subjects should silently count "three, two, one" in their minds, and then begin typing. Upon completing one sequence of typing, subjects should say "yes" (indicating finish). This process is to be repeated until the 10th trial is completed. There was a five-second interval between each trial.

After the practice period, all subjects completed 10 trials of typing in the EF condition and 10 trials in the IF condition. Since a within-subject design was employed, all subjects performed both EF and IF conditions. The order of EF and IF conditions was counterbalanced. In the EF condition, subjects were instructed to focus on the numbers on the keys. In contrast, in the IF condition, they were instructed to focus on the movement of their fingers with their eyes closed. Upon the execution of each condition, the following instructions were given to each subject.

EF Condition: "Please type as quickly and accurately as possible. When typing, make sure to pay attention to the number of the key you are pressing."

IF Condition: "Please type as quickly and accurately as possible. When typing, close your eyes and pay attention to the movement of your fingers."

Subjects in the IF condition were allowed to open their eyes between trials to check their fingers' positions on the keyboard. During the trials, the computer screen was positioned facing away from the subjects and toward the experimenter to prevent subjects from monitoring their typing. Subjects were instructed to continue typing even if they made a mistake and not to verbalize the numbers while typing.

Measurement

ATTENTION OUTCOME

The self-evaluation of focus of attention was measured. Subjects were asked about their compliance with instructions on attentional focus at the end of the experiment. The questionnaire employed a 7-point scale ranging from 7 (very well) to 1 (not at all). Subjects were asked whether they had focused on the numbers on the keys in the EF condition and whether they had focused on their finger movements in the IF condition. They marked the most applicable number.

TYPING OUTCOMES

Regarding typing errors, the keystrokes of the subjects were recorded on the PC as strings. After the experiment, the characters pressed by the subjects were compared to the instructed string to detect errors and the number of errors was counted in each trial. The average number of errors per trial was analyzed for each subject. Typing errors included "substitution," "insertion," "omission," and "repetition." The definitions of each error are as follows: Substitution: Typing the wrong key instead of the correct one.

Insertion: Typing unnecessary keys in addition to the required ones.
Omission: Failing to type the required key.
Repetition: Continuously pressing the same key.

Even if one key was typed more than twice, it was counted as one error. For example, in the sequence FTY, typing FTTY would result in one insertion, and typing FTYYYYYYYY would result in one repetition. The total number of errors for each condition was counted per subject, and a group average was calculated.

Regarding typing time, video-recorded data were used to analyze the duration of typing. The duration of typing was defined as the time it took a subject to finish one trial. The time between the first key press and the last key press was measured with a visual inspection of the video-recorded data. The average duration of typing per trial was calculated for each subject, and a group average was obtained.

STATISTICAL ANALYSIS

The subjective evaluation of attentional focus, the number of errors, and the duration of typing were analyzed using repeated-measures ANOVA with group (AWS, ANS) as a between-group factor and condition (EF, IF) as a within-group factor.

Results

SELF-EVALUATION OF FOCUS OF ATTENTION

The average scores of self-evaluation of attentional focus for AWS were 5.7 (±1.2) for EF and 5.8 (±1.0) for IF. For ANS, these scores were 5.8 (±0.6) for EF and 5.8 (±1.0) for IF. Repeated-measures ANOVA with group and condition did not reveal any statistical differences. The results indicate that both groups were able to adopt attentional focus as instructed.

TYPING ERRORS

Figure 1 shows the average error of AWS and ANS in EF and IF. Repeated-measures ANOVA with factors of Group(AWS, ANS) and Condition(EF, IF) revealed a significant Group and Condition interaction, $F(1,20)=8.353$, $p=.005$. Follow-up analysis by simple main effect showed a main effect of condition in AWS, $F(1,20)=18.28$, $p=.001$, and a main effect of group in IF, $F(1,20)=6.06$, $p=.023$. The results indicate that AWS made significantly more errors in IF than in EF. Moreover, in IF, AWS made significantly more errors than ANS.

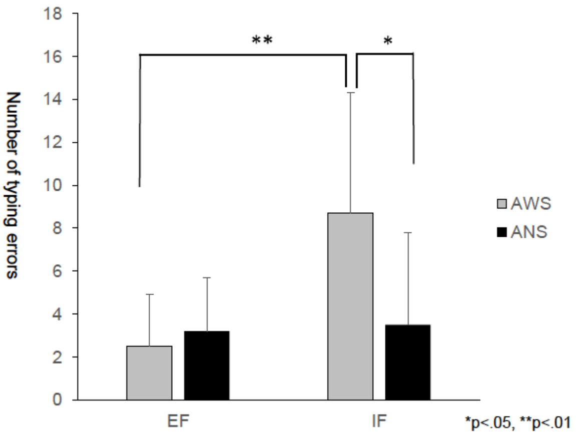

Fig.1. Mean numbers of typing erros in EF and IF for AWS and ANS

TYPING DURATION

Figure 2 shows the average duration of typing of AWS and ANS in EF and IF. Repeated-measures ANOVA with factors of Group(AWS, ANS) and Condition(EF, IF) revealed a significant main effect of condition, indicating that the average duration in EF was significantly shorter than in IF, $F(1,22)=12.611$, $p=.002$. However, no significant main effect of groups, $F(1,22)=0.928$, $p=.346$, or interaction effect, $F(1,22)=0.305$, $p=.587$, was observed.

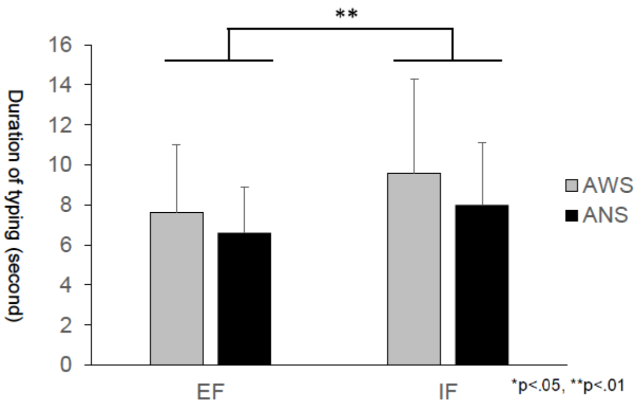

Fig.2. Mean duration of typing in EF and IF for AWS and ANS

Discussion

MAIN FINDINGS

As focusing attention is a highly cognitive task, it is not possible to observe objectively whether subjects comply with attentional instructions. Therefore, this study used self-evaluation to assess whether participants directed their attention following the experimenter's instructions. The results showed that the subjects' self-evaluation rates were high for both the EF and IF conditions, suggesting that they could focus their attention internally or externally as instructed. Furthermore, both the AWS and ANS groups performed similarly; no difference in the rate was observed between them. Therefore, both groups were regarded as equally capable of directing their attention correctly. The characteristics of the motor performance of the AWS are discussed based on this interpretation.

First, no significant difference in typing speed between the AWS and ANS was found. However, the typing speed was slower under the IF condition than under the EF condition in both groups. Previous studies investigating limb movements have shown that movements performed under EF conditions are more efficient than those performed under IF conditions.[12-15] To the best of our knowledge, no studies on sequential finger movements like typing have been conducted. However, studies on leg movements among runners have reported that the efficiency of runners' leg movements improves under EF conditions, resulting in increased running speed.[16-18] The current study demonstrated that the speed of sequential finger movements also increased under EF conditions. However, no difference was evident between the AWS and ANS.

In contrast, differences in the numbers of typing errors were observed between the AWS and ANS. Typing accuracy in the ANS was not influenced by focus of attention, while typing accuracy in the AWS significantly decreased under IF conditions, indicating that AWS are more vulnerable to disruptions in motor control under IF conditions. The findings of the present study regarding the typing accuracy in the ANS differ from those reported by Rossettini et al.[19] They assessed typing errors in healthy adults using a task similar to that used in the present study and demonstrated an increase in typing errors under IF conditions. Although the results appear contradictory, this discrepancy may be attributable to differences in experimental methods. Specifically, Rossettini et al.[19] employed a metronome to ensure a constant typing speed, whereas this study did not implement a metronome, but gave subjects instructions to type at their maximum speed. Therefore, the subjects in this study likely slowed their finger movements to enhance typing accuracy in the IF condition. This can be explained by the "speed-accuracy trade-off" phenomenon (for a review, see Heitz, [20]): when individuals are required to be faster, their performance becomes less accurate, and when they focus on accuracy, their speed decreases. However, in the AWS, despite a reduction in typing speed under the IF condition, there was still a significant increase in errors. This suggests that the AWS may have greater difficulty maintaining accurate motor performance under IF conditions than the ANS.

Although no neurophysiological measurements were conducted in this study, the results are discussed from a neurophysiological perspective, drawing on previous research. Zentgraf et al.[21] explored the blood oxygen level-dependent responses in a typing task under EF and IF conditions. They reported increased responses in the primary motor cortex, primary somatosensory cortex, and the insular region of the left hemisphere during EF. They suggested that sensory processing increased in the EF. Other fMRI studies, such as those by Zimmermann et al.[22] and Raisbeck et al.[23], also demonstrated augmented activation in motor- and sensory-related areas during EF. These results suggest that sensory integration plays a crucial role in motor tasks, particularly under EF conditions.[24] Regarding sensorimotor integration, some studies have pointed out that people who stutter exhibit abnormalities in sensorimotor integration.[25-27] Nevertheless, it is noteworthy that no difference in motor performance was observed under EF in the AWS. These findings challenge previous research suggesting abnormalities in sensorimotor integration in people who stutter. The studies that reported sensorimotor abnormalities in people who stutter used auditory stimuli;[28-31] however, the current study used visual stimuli to which the subjects directed their attention. Therefore, it is necessary to conduct research incorporating auditory stimuli under EF to investigate whether similar results to can be obtained.

Raisbeck et al.[23] reported increased activation in the motor regions, especially the precentral gyrus, postcentral gyrus, and cerebellum, in the IF condition. Although the mechanisms by which increased activation of the motor region disrupts movement coordination lack understanding, hyperactivation in motor-related areas has been observed in cases of yips and other forms of focal dystonia. [32-34] Parr[35] suggested that the disruption of intracortical inhibition within the primary motor cortex leads to "an overflow of activation at the cortex, which becomes reciprocated at the muscular level." Indeed, some electromyographic studies have revealed increased co-contraction of antagonist muscle pairs in the IF condition.[36,37] Therefore, it is plausible that abnormal muscle contractions occur in the AWS under IF conditions. This hyperactivity of the antagonist muscles may hinder smooth and efficient movement, as indicated by these findings.

The above possible kinematic state of the AWS in the IF condition may have important implications for speech therapy for stuttering. Speech restructuring treatments for stuttering usually incorporate instructions for clients to monitor their articulatory movements to produce a novel speech pattern,[4] which seems to be an internal focus condition. However, to ensure efficient performance, therapists should instruct their clients to focus their attention externally rather than internally. Future studies are needed to determine the specific instructions that should be given to clients and how they can be effectively implemented in speech therapy for stuttering.

Limitations

One of the limitations of this study was that articulatory movements were not observed. Since speech movements are quite automatized, different control mechanisms may be involved. So far, only one study by Lisman et al. [38] has examined the effect of foci of attention on speech motor movements. They showed the effects of the focus of attention on articulatory movements. However, their research used the experimenters' perceptual judgment to measure articulatory accuracy, which seems to be very subjective. Objective measurement methods of articulatory movement urgently need to be established to explore speech motor movement and examine speech motor control in AWS.

Another limitation is that no reports of neural activation or kinematic information were available in this study. Hence, the assumption of the kinematic state of the AWS in the IF condition is very speculative. Brain activity or muscle activity needs to be measured to verify the assumption.

This study was limited by the small number of participants and the restriction to males, making it challenging to draw robust conclusions. Future studies with larger sample sizes must validate the results of this study. Given that the findings of Rong-Na et al. [9] strongly suggest that differences in motor control characteristics depend on the severity of stuttering, a study with a larger sample size would allow for the exploration of potential subgroups within the AWS.

Conclusions

To the best of the researcher's knowledge, this is the first study to clarify the effect of attentional foci on movement control among people who stutter. According to the results, people who stutter exhibited significantly slower and more inaccurate movement of fingers under the IF condition compared to people who do not stutter. Since the present results are of clinical relevance, future research on speech motor control among people who stutter is promising.

Conflict of Interest Statement

The author declares no conflict of interest regarding the publication of this paper.

Acknowledgments

The author wants to thank Ryo Shimizu, a graduate student, for helping with the experiment and data analysis.

References

1. Brignell, A., Krahe, M., Downes, M., Kefalianos, E., Reilly, S., & Morgan, A. T. (2020). A systematic review of interventions for adults who stutter. *Journal of Fluency Disorders*, *64*, 105766. https://doi.org/10.1016/j.jfludis.2020.105766
2. Kohmäscher, A., Primaßin, A., Heiler, S., Avelar, P. D. C., Franken, M. C., & Heim, S. (2023). Effectiveness of stuttering modification treatment in school-age children who stutter: A randomized clinical trial. *Journal. of Speech, Language, and Hearing Research*, *66*(11), 4191–4205. https://doi.org/10.1044/2023_JSLHR-23-00224
3. Tasko, S. M., McClean, M. D., & Runyan, C. M. (2007). Speech motor correlates of treatment-related changes in stuttering severity and speech naturalness. *Journal of Communication Disorders*, *40*(1), 42–65. https://dx.doi.org/10.1016/j.jcomdis.2006.04.002
4. Bloodstein, O., Ratner, N. B., & Brundage, S. B. (2021). *A handbook on stuttering*. Plural Publishing.
5. Hesse, T. (2022). *Overview of conditions that immediately reduce stuttering and a unifying account for their effect*. Preprints 2022, 2022070132. https://doi.org/10.20944/preprints202207.0132.v1
6. Wulf, G., Höß, M., & Prinz, W. (1998). Instructions for motor learning: Differential effects of internal versus external focus of attention. *Journal of Motor Behavior*, *30*(2), 169–179. https://doi.org/10.1080/00222899809601334
7. Wulf, G. (2013). Attentional focus and motor learning: A review of 15 years. *International Review of Sport and Exercise Psychology*, *6*(1), 77–104. https://doi.org/10.1080/1750984X.2012.723728
8. McNevin, N. H., Shea, C. H., & Wulf, G. (2003). Increasing the distance of an external focus of attention enhances learning. *Psychological Research*, *67*, 22–29. https://doi.org/10.1007/s00426-002-0093-6
9. Rong-Na, A., Mori, K., & Sakai, N. (2015). Latency analysis of speech shadowing reveals processing differences in Japanese adults who do and do not stutter. *Japan Journal of Logopedics and Phoniatrics*, *56*(4), 326–334. https://doi.org/10.5112/jjlp.56.326
10. Ozawa E., Hara Y., Suzuki N., et al. (2013). *Standardized test for stuttering second edition*. Tokyo: Gakuensha
11. Okubo, M., Suzuki, H., & Nicholls, M. E. (2014). A Japanese version of the FLANDERS handedness questionnaire. Shinrigaku Kenkyu: *Japanese Journal of Psychology*, *85*(5), 474–481. https://doi.org/10.4992/jjpsy.85.13235
12. Wulf, G., Lauterbach, B., & Toole, T. (1999). The learning advantages of an external focus of attention in golf. *Research quarterly for exercise and sport*, *70*(2), 120-126. https://doi.org/10.1080/02701367.1999.10608029
13. Wulf, G., & Prinz, W. (2001). Directing attention to movement effects enhances learning: A review. *Psychonomic bulletin & review*, 8(4), 648-660. https://doi.org/10.3758/BF03196201
14. Wulf, G., & Lewthwaite, R. (2016). Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. *Psychonomic bulletin & review*, *23*, 1382-1414. https://doi.org/10.3758/s13423-015-0999-9
15. Pompa, D., Carson, H. J., Beato, M., di Fronso, S., & Bertollo, M. (2024). Attentional focus effects on lower-limb muscular strength in athletes: A systematic review. *Journal of Strength & Conditioning Research*, *38*(2), 419–434. https://doi.org/10.1519/JSC.0000000000004714
16. Schücker, L., Hagemann, N., Strauss, B., & Völker, K. (2009). The effect of attentional focus on running economy. *Journal of sports sciences*, *27*(12), 1241-1248. https://doi.org/10.1080/02640410903150467
17. Ziv, G., Meckel, Y., Lidor, R., & Rotstein, A. (2012). The effects of external and internal focus of attention on physiological responses during running. *Journal of Human Sport and Exercise*, *7*(3), 608-616. https://www.redalyc.org/pdf/3010/301025319001.pdf
18. Skammer, S., Halvorson, J., & Becker, J. (2023). Using an external focus of attention for gait retraining in runners: A case report. *Physiotherapy Theory and Practice*, *39*(5), 1083-1094. https://doi.org/10.1080/09593985.2022.2035032
19. Rossettini, G, Testa, M., Vicentini, M., & Manganotti, P. (2017). The effect of different attentional focus instructions during finger movement tasks in healthy subjects: An exploratory study (20147). *Biomed Research International*: e2946465:2946465. https://doi.org/10.1155/2017/2946465
20. Heitz, R. P. (2014). The speed-accuracy tradeoff: history, physiology, methodology, and behavior. *Frontiers in neuroscience*, *8*, 86875. https://doi.org/10.3389/fnins.2014.00150
21. Zentgraf, K., Lorey, B., Bischoff, M., Zimmermann, K., Stark, R., & Munzert, J. (2009). Neural correlates of attentional focusing during finger movements: A fMRI study. *Journal of Motor Behavior*, *41*(6), 535–541. https://doi.org/10.3200/35-08-091
22. Zimmermann, K. M., Bischoff, M., Lorey, B., Stark, R., Munzert, J., & Zentgraf, K. (2012). Neural correlates of switching attentional focus during finger movements: an fMRI study. *Frontiers in psychology*, *3*, 555. https://doi.org/10.3389/fpsyg.2012.00555
23. Raisbeck, L. D., Diekfuss, J. A., Grooms, D. R., & Schmitz, R. (2020). The effects of attentional focus on brain function during a gross motor task. *Journal of Sport Rehabilitation*, *29*, 441–447 https://doi.org/10.1123/jsr.2018-0026
24. Sakurada, T., Yoshida, M., & Nagai, K. (2022). Individual optimal attentional strategy in motor learning tasks characterized by steady-state somatosensory and visual evoked potentials. *Frontiers in Human Neuroscience*, *15*, 784292. https://doi.org/10.3389/fnhum.2021.784292
25. Smits-Bandstra, S. De Nil, L., & Rochon, E. (2006). The transition to increased automaticity during finger sequence learning in adult males who stutter. *Journal of Fluency Disorders*, *31*(1), 22–40. https://doi.org/10.1016/j.jfludis.2005.11.004

26. Smits-Bandstra, S., & De Nil, L. F. (2007). Sequence skill learning in persons who stutter: Implications for cortico-striato-thalamo-cortical dysfunction. *Journal of Fluency Disorders*, *32*(4), 251–278. https://doi.org/10.1016/j.jfludis.2007.06.001
27. Kim, K. S., Daliri, A., Flanagan, J. R., & Max, L. (2020). Dissociated development of speech and limb sensorimotor learning in stuttering: Speech auditory-motor learning is impaired in both children and adults who stutter. *Neuroscience*, *451*, 1–21. https://doi.org/10.1016/j.neuroscience.2020.10.014
28. Sares, A. G., Deroche, M. L., Shiller, D. M., & Gracco, V. L. (2018). Timing variability of sensorimotor integration during vocalization in individuals who stutter. *Scientific Reports*, *8*(1), 16340. https://doi.org/10.1038/s41598-018-34517-1
29. Cai, S., Beal, D. S., Ghosh, S. S., Tiede, M. K., Guenther, F. H., & Perkell, J. S. (2012). Weak responses to auditory feedback perturbation during articulation in persons who stutter: evidence for abnormal auditory-motor transformation. PloS one, *7*(7), e41830. https://doi.org/10.1371/journal.pone.0041830
30. Cai, S., Beal, D. S., Ghosh, S. S., Guenther, F. H., & Perkell, J. S. (2014). Impaired timing adjustments in response to time-varying auditory perturbation during connected speech production in persons who stutter. *Brain and language*, *129*, 24-29. https://doi.org/10.1016/j.bandl.2014.01.002
31. Kim, K. S., Daliri, A., Flanagan, J. R., & Max, L. (2020). Dissociated development of speech and limb sensorimotor learning in stuttering: Speech auditory-motor learning is impaired in both children and adults who stutter. Neuroscience, 451, 1-21. https://doi.org/10.1016/j.neuroscience.2020.10.014
32. Tanaka, M., Ohyagi, Y., Kawajiri, M., Taniwaki, T., Tobimatsu, S., Furuya, H., & Kira, J. (2005). A patient with focal dystonia induced by golf and presenting a decrease in activity of cerebral motor cortex on task. *Rinsho Shinkeigaku=Clinical Neurology*, *45*(4), 304-307. https://europepmc.org/article/med/15912799
33. Kadota, H., Nakajima, Y., Miyazaki, M., Sekiguchi, H., Kohno, Y., Amako, M., & Sakai, N. (2010). An fMRI study of musicians with focal dystonia during tapping tasks. *Journal of neurology*, *257*, 1092-1098. https://doi.org/10.1007/s00415-010-5468-9
34. Chen, M., Summers, R.L.S., Prudente, C.N., Goding, G.S., Samargia-Grivette, S., Ludlow, C.L., Kimberley, T.J.（2020）Transcranial magnetic stimulation and functional magnet resonance imaging evaluation of adductor spasmodic dysphonia during phonation. *Brain Stimulation, 13* (3), 908-915. https://doi.org/10.1016/j.brs.2020.03.003
35. Parr, J. V., Gallicchio, G., Canales-Johnson, A., Uiga, L., & Wood, G. (2023). Cortical, muscular, and kinetic activity underpinning attentional focus strategies during visuomotor control. *Psychophysiology*, *60*(6), e14249. https://doi.org/10.1111/psyp.14249
36. Lohse, K. R., Sherwood, D. E., & Healy, A. F. (2011). Neuromuscular effects of shifting the focus of attention in a simple force production task. *Journal of Motor Behavior*, *43*(2), 173–184. https://doi.org/10.1080/00222895.2011.555436
37. Lohse, K. R., & Sherwood, D. E. (2012). Thinking about muscles: The neuromuscular effects of attentional focus on accuracy and fatigue. *Acta Psychologica*, *140*(3), 236–245. https://doi.org/10.1016/j.actpsy.2012.05.009
38. Lisman, A. L., & Sadagopan, N. (2013). Focus of attention and speech motor performance. *Journal of Communication Disorders*, *46*(3), 281-293. https://doi.org/10.1016/j.jcomdis.2013.02.002