Measurements of the lateral cerebellar hemispheres using near-infrared spectroscopy through comparison between autism spectrum disorder and typical development

Toshiki Nishida [1], Nao Suzumura[1], Yuto Nakanishi[2], Nao Maki[1], Hidetsugu Komeda[3], Masahiro Kawasaki[4], Yasuko Funabiki[1]*.

[1]Graduate School of Human and Environmental Studies, Kyoto University, Yoshida-nihonmatsu-cho, Sakyo-ku, Kyoto, Japan.

[2] Department of Psychiatry, Kyoto University Hospital, 54, Shogoin-kawahara-cho, Sakyo-ku, Kyoto, Japan.

[3]Department of Education, College Education, Psychology and Human Studies, Aoyama Gakuin University, 4 4 25, Shibuya, Shibuya-ku, Tokyo, Japan.

[4]Department of intelligent Interaction Technology, Graduate School of Systems and information Engineering, University of Tsukuba, 1-1-1, Tennodai, Tsukuba-shi, Ibaraki, Japan.

*Corresponding author:

Yasuko Funabiki, M.D., Ph.D.

Graduate School of Human and Environmental Studies, Kyoto University, Yoshida-nihonmatsu-cho, Sakyo-ku, Kyoto, Japan.

Tel: +81-075-753-6605

E-mail: funabiki.yasuko.8a@kyoto-u.ac.jp

Highlights

・On the cerebellar channel we captured response related to the fine motor.

・During fine motor, the response of the cerebellum differs from the occipital lobe.

・The cerebellar responses do not differ between ASD and typical development.

・NIRS enables us to capture the cerebellar activity in a way close to daily living.

Measurements of the lateral cerebellar hemispheres using near-infrared spectroscopy through comparison between autism spectrum disorder and typical development

Abstract

The cerebellum plays a vital role in cognition, communication with the cerebral cortex, and fine motor coordination. Near-infrared spectroscopy (NIRS) is a portable, less restrictive, and noninvasive functional brain imaging method that can capture brain activity during movements by measuring the relative oxyhemoglobin (oxy-Hb) concentrations in the blood. However, the feasibility of using NIRS to measure cerebellar activity requires discussion. We compared NIRS responses between areas assumed to be the cerebellum and the occipital lobe during a fine motor task (tying a bow knot) and a visual task. Our results showed that the oxy-Hb concentration increased more in the occipital lobe than in the cerebellum during the visual task (p = .034). In contrast, during the fine motor task, the oxy-Hb concentration decreased in the occipital lobe but increased significantly in the cerebellum, indicating a notable difference (p = .015). These findings suggest that we successfully captured cerebellar activity associated with processing, particularly fine motor coordination. Moreover, the observed responses did not differ between individuals with autism spectrum disorder and those with typical development. Our study demonstrates the meaningful utility of NIRS as a method for measuring cerebellar activity during movements.

Keywords

near-infrared spectroscopy; cerebellum; fine motor; autism spectrum disorder

Introduction

The cerebellum is a brain region that is involved in motor control. The cerebellar hemisphere has diverse functions other than motor function, and the lateral part of the cerebellar hemisphere is also involved in the regulation of emotions, thoughts, and cognition that are not directly related to motor planning, such as working memory [1]. Furthermore, the cerebellum exchanges information closely with the cerebrum through cerebrocerebellar association [2] and plays a role in regulating processing in the cerebrum [3,4,5]. Thus, the function of the cerebellum is believed to be more complex than previously thought, and various measurements have helped in elucidating its function.

Functional magnetic resonance imaging (fMRI) has been widely used to study cerebellar activity due to its high spatial resolution [6,7]. However, fMRI has some limitations. It requires participants to be immobilized in a supine position within a confined space, thereby restricting their movements during measurements. This limits the assessment of coordinated motor function, which necessitates more extensive body movements. In addition, fMRI measurements generate noise, making it difficult to use auditory stimuli. Moreover, for participants who are uncomfortable with confined spaces and noise, such as children and individuals with autism spectrum disorder (ASD), performing stress-free measurements may be difficult because of the singularity of the measurement space.

To address the limitations of fMRI in evaluating the cerebellum, near-infrared spectroscopy (NIRS) offers a promising alternative. NIRS is a noninvasive technique that measures changes in oxygenated hemoglobin (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb) concentrations in the cerebral blood by analyzing the absorbance of near-infrared light (700–900 nm) [8]. It is based on the neurovascular coupling hypothesis, which explains the relationship between neural activity and cerebral blood flow in specific brain regions [9]. NIRS primarily assesses the cerebral cortex, as the near-infrared light can penetrate up to 3 cm from the scalp [10]. Compared with fMRI, NIRS provides higher time–frequency resolution and allows real-time measurements. Because NIRS is a portable machine, it reduces physical constraints and enables performing studies in more natural settings. However, little is known about the application of NIRS in evaluating the cerebellum, and its feasibility for measuring cerebellar activity requires proper investigation. Although a previous study has performed noninvasive investigations of cerebellum-targeted channeling using electroencephalography (EEG) and magnetoencephalography (MEG) [11], no studies have examined NIRS responses in the cerebellum.

The cerebellum is believed to regulate various brain functions, including movement. Individuals with ASD often face challenges in coordinated movements [12] and fine motor skills [13], which may be related to cerebellar dysfunction [14]. Thus, it is essential to investigate cerebellar functions specific to individuals with ASD.

In the present study, we aimed to determine the feasibility of using NIRS for evaluating the cerebellum. We included participants with both typical development (TD) and ASD. Anatomically, the lateral part of the cerebellum is the region at which the near-infrared light reaches, so we aimed to investigate the response of the cerebellum using a cap covered over the cerebellar region and discuss the possibility of measuring the activity of the lateral cerebellar hemisphere via NIRS using fine motor and visual tasks. We also attempted to assess the feasibility of cerebellar measurement using NIRS by examining two points: (1) whether the responses obtained in the cerebellum differed from those in the adjacent occipital lobe and (2) whether the responses can be interpreted to be originating from the cerebellum.

Materials and methods

Participants

This study was approved by the ethics committee of our university hospital, and informed consent was obtained from all participants. We recruited 39 adults (20 men and 19 women, mean age 28 ± 6.9 years), including 20 with ASD and 19 with TD. Participant characteristics and cognitive and behavioral assessment results are presented in Table 1. The ASD group included outpatients or community-dwelling individuals without psychosis or medication diagnosed with ASD according to the criteria outlined in the Diagnostic and Statistical Manual of Mental Disorders, Fourth Revised Edition (DSM-IV-TR) [15]. The TD group consisted of mentally and physically healthy individuals who were assessed using cognitive and behavioral measures and were recruited from the local community, matching the ASD group’s age and gender distribution. Among the participants, 33 were right-handed, 5 were left-handed, and 1 was ambidextrous.

Cognitive and behavioral assessments

Each participant's intelligence quotient (IQ), verbal IQ, and performance IQ were previously assessed using the Wechsler Adult Intelligence Scale-Third Edition [16]. All participants with scores falling within the 80–120 range were included. The severity of autism was evaluated using module four of the autism diagnostic observation schedule (ADOS-2) [17], a series of semistructured interview and assessment tools. The assessment focused on communication and social interaction with standardized values. Furthermore, multidimensional scales for pervasive developmental disorders and attention-deficit hyperactivity disorder (MSPA) were employed. The MSPA encompasses four domains related to ASD: communication, group adaptability, empathy, and restricted interests/behaviors. In addition, two coordinated motor domains were evaluated: gross motor and fine motor [18]. MSPA is a comprehensive neurodevelopmental assessment conducted through interviews based on daily observations. Each domain was rated on a 9-point scale with 0.5 increments from 1 to 5.

Fine motor task

To assess fine motor skills, we employed the task of tying a bow with two loops. Practice trials were conducted to ensure that the participants could perform the task smoothly. The task comprised two phases: a rest phase and a bowknot phase. During the rest phase, the participants were instructed to refrain from actions as much as possible. In the bowknot phase, the participants were orally guided to repetitively tie a bow with two loops using a long rubber band that had been cut in one place as many times as possible. To prevent the task from being simplified using familiar methods, participants were instructed to use a specific knot-tying technique, such as the Ian knot, which is not commonly known. Each trial consisted of a 10-second rest phase, a 20-second bowknot phase, and another 10-second rest phase. This block of the task was repeated four times.

Visual task

A visual task was employed to compare brain activity in the fine motor task. This task involved a rest phase and a visual presentation phase. During the visual presentation phase, participants were instructed to observe and memorize meaningless shapes attentively. Each shape was displayed on a PC monitor for 2 seconds, followed by a 2-second black screen interval. This pairing of shape presentation and the black screen was repeated four times, and the total duration of one trial for the visual task was 16 seconds. A 20-second rest phase was provided before and after the visual task, and the trial was repeated three times.

NIRS measurement

Our measurements utilized a multiple-channel functional near-infrared spectroscopy system (LABNIRS, Shimadzu Corporation, Japan). We situated six emitter and six receiver probes in a grid pattern. The midpoint between the probes was defined as channels, representing measurable points. The occipital channels were positioned according to the extended 10-20 EEG system, whereas the cerebellum channels were placed approximately 3 cm below the most caudally located external occipital protuberance, following the extended 10-20 EEG system. Channels 1 to 15 were designated as occipital channels, and channels 16 to 17 represented the cerebellum channels (see Figure 1). We measured three types of signals: oxy-Hb, deoxy-Hb, and the sum of oxy-Hb and deoxy-Hb (total-Hb). A previous study showed that deoxy-Hb was more unstable than oxy-Hb and had various changes and that the change in oxy-Hb concentration was correlated more closely with cerebral blood flow [19]. Therefore, the relative change in oxy-Hb concentration was shown as a waveform on a monitor in real time.

Data analysis

We visually inspected the measured brain activity waveforms and removed artifacts. The occipital channels consisted of channels 3 and 6 for the left side and 5 and 7 for the right side. If any channels were rejected, the remaining channels were used. The average of the retained channels was used as the occipital channel. These channels were named O1 (left) and O2 (right). The cerebellar channels were 16 and 17 and were named as Cr1 (left) and Cr2 (right).

We applied a bandpass filter (0.01–0.05 Hz) to the NIRS raw data using MATLAB to remove baseline drift or artifacts. The baseline value was calculated as the mean of the 5-second epoch before the task. In the fine motor task, the task value was the mean of the 11-second epoch from 5 seconds after task initiation until task completion (16 seconds). In the visual task, the task value was calculated as the mean of the 11-second epochs starting from 5 seconds after the first visual presentation until task completion. Epochs with artifacts were excluded.

For the visual task, we obtained data from 31 participants in O1 (ASD = 15; TD = 16), 31 in O2 (ASD = 16, TD = 15), 35 in Cr1 (ASD = 19, TD = 16), and 30 in Cr2 (ASD = 18, TD = 12).

For the fine motor task, we obtained data from 33 participants in O1 (ASD = 17, TD = 16), 31 in O2 (ASD = 15, TD = 16), 32 in Cr1 (ASD = 17, TD = 15), 28 in Cr2 (ASD = 14, TD = 14). The obtained values were relative, and direct comparisons among participants were inappropriate due to variations in optical path lengths for the same region [20]. Therefore, we calculated the oxy-Hb response score by dividing the difference between the task and baseline values by the baseline standard deviation.

For statistical analysis, a four-way analysis of variance (ANOVA) was conducted using IBM SPSS version 19.0 (IBM Corp., Armonk, NY, USA). The factors examined were group (ASD or TD), task (visual presentation vs. fine motor), region (occipital vs. cerebellum), and laterality (right vs. left). The group factor was between participants, whereas the other factors were within participants. A significance threshold of $p < 0.05$ was adopted.

We also performed Pearson's correlation analyses to examine the relationship between developmental traits and brain activity. In particular, we explored correlations between oxy-Hb response scores in the fine motor task (O1, O2, Cr1, and Cr2 channels) and the six MSPA domains (communication, group adaptability, empathy, restricted interest/behaviors, gross motor, and fine motor) and the two ADOS domains (communication and social interaction).

Results

We calculated the means and standard errors of oxy-Hb response scores for the ASD and TD groups (Figure 2) and performed a four-factor ANOVA (Table 2). No significant three-way or two-way interaction effects or main effects were observed. We found one-way interaction effects for task × region ($F(1,15) = 12.472$, $p = .003$) and task × laterality ($F(1,15) = 5.557$, $p = .032$), which led to the identification of four subsequent simple main effects.

In the occipital region, the oxy-Hb concentration increased during the visual task but decreased during the fine motor task ($F(1,15) = 23.50$, $p < .001$). During the visual task, the oxy-Hb concentration increased significantly more in the occipital region than in the cerebellum region ($F(1,15) = 5.44$, $p = .034$). During the fine motor task, the oxy-Hb concentration increased in the cerebellum region but decreased in the occipital region ($F(1,15) = 7.58$, $p = .015$). In the right hemisphere, the oxy-Hb response was larger during the visual task than during the fine motor task

($F(1,15) = 9.60$, $p = .007$). However, this difference was not observed in the cerebellum, as depicted in Figure 2, and a significant simple interaction between task and region was found in the right hemisphere ($F(1,15) = 22.11$, $p < .001$). Further analysis revealed a significant simple main effect only in the occipital region (left: $F(1,15) = 8.07$, $p = .012$; right: $F(1,15) = 5.44$, $p < .001$), indicating a significant decrease in hemoglobin concentration in the right occipital lobe during the fine motor task. Moreover, a significant difference was found when we examined the left and right simple main effects in the occipital lobe during the fine motor task ($F(1,15) = 10.47$, $p = .006$). No significant group differences were identified between ASD and TD.

Correlation analyses were performed to assess the relationship between developmental traits and fine motor skills (Table 3). No significant correlations were found between the six MSPA domains and the oxy-Hb response score or between the two ADOS domains and the oxy-Hb response score.

Discussion

We explored whether cerebellar activity could be measured from the brain surface in real time using NIRS. To investigate this, we added cerebellar channels and compared the response of the lateral cerebellar hemispheres to NIRS light with that of the visual cortex.

In the occipital region, we observed significant effects between the visual and fine motor tasks. The oxy-Hb concentration in the occipital area increased during the visual task, which was consistent with the findings of Villringer [8], in which the oxy-Hb concentration increased in the visual cortex when participants were presented with visual stimuli. Since previous studies showed the increase in oxy-Hb concentrations in the region of interest indicated neural activity in that area [21,22,23], the occipital channels evaluated in our visual task could be identified with the visual cortex. Conversely, we observed a decrease in oxy-Hb concentration in the same area during the fine motor task. Although the physiological mechanisms of the negative shift underlying neurovascular linkage remain unclear, previous studies shed light on the deactivation of oxy-Hb. Research conducted by Devor et al. [24,25] in rats demonstrated that vasoconstriction and decreased blood oxygenation, reflected by decreased oxy-Hb signals, correspond to neuronal inhibition. Hence, in NIRS measurement, a decrease in oxy-Hb signal may indicate cortical deactivation [26]. Similarly, Sakatani [27] proposed that the decrease in oxy-Hb concentration is associated with the suppression of neural activity in the region of interest. As another discussion limited to this negative shift, the steal phenomenon, in which the oxy-Hb concentration decreases in the region of interest as it migrates to activated brain regions, explains the decreasing oxy-Hb concentration [28,29]. Considering these perspectives, the decrease in the oxy-Hb concentration during the fine motor task may indicate that the visual channels were deprived of oxy-Hb due to the activation of brain regions involved in fine motor tasks, leading to the suppression of activation.

Regarding the cerebellum, as shown in Figure 2, we observed an increase in oxy-Hb response in both tasks without significant differences. Previous fMRI studies have demonstrated that the lateral cerebellar hemispheres are activated during tasks requiring finger tapping in fine motor tasks [30,31,32]. Considering that NIRS detects activation of the region of interest through an increase in oxy-Hb concentration, the observed increase in oxy-Hb response during the fine motor task in our study may indicate cerebellar activation. In addition, the oxy-Hb response also increased during the visual task. Previous studies implied that the lateral cerebellar hemispheres were activated during perception task [33,34], and the increase during the visual task in our study suggests the involvement of cerebellar cognitive functions.

By examining the changes in oxy-Hb concentration among different brain regions, we observed significant effects in both the visual and fine motor tasks. During the visual task, the occipital lobe exhibited a higher oxy-Hb concentration than the cerebellum, indicating its direct involvement in visual processing. In contrast, during the fine motor task, the cerebellum was activated and the occipital lobe was deactivated, as depicted in Figure 2. Considering scattering effects prevent determination of the optical path length, it is important to note that NIRS measurements represent the relative change in oxy-Hb concentration [21]. Therefore, caution must be exercised when interpreting the significant differences observed in visual tasks. However, the increase or decrease observed in the fine motor task may hold crucial significance beyond the validity of numerical comparisons between regions ,though direct numerical comparisons between regions are not inherently suitable for interpretation. The observed differences in response can be understood in terms of the steal phenomenon, where there is a shift in oxy-Hb concentration from the visual cortex to the cerebellum, resulting in the suppression of activation in the visual cortex and activation in the cerebellum.

Furthermore, we identified a left–right difference in the occipital region during the fine motor task. Krystal [35] noted that tapping tasks lack spatial accuracy constraints, making it challenging to generalize to visuomotor aiming. In our study, the participants were not specifically instructed regarding eye usage during the fine motor task. The laterality observed in the fine motor task could also be influenced by ocular dominance according to hand dominance. Previous studies have shown that the response of the occipital lobe complex is more contralateral to the dominant eye, and ocular dominance is associated with a cerebral basis [36,37]. Moreover, dominant eyes are typically aligned with dominant hands [38]. In our study, 2 participants were left-handed, 28 were right-handed, and 1 was ambidextrous, suggesting that the lower right occipital lobe reactivity was due to right-eye dominance. While drawing definitive conclusions about left–right differences falls outside the scope of this study, future investigations considering dominant eye factors will offer more conclusive insights into laterality.

This study investigated individuals with ASD as representatives of diversity. Although no significant differences were found between the ASD and TD groups, individuals with ASD tended to exhibit greater brain activation in the regions of interest: the cerebellum for the fine motor task and the occipital regions for the visual task (see Figure 2). However, it is important to consider individual differences, as there was a large variance in oxy-Hb concentration changes in this study. In complex cognitive performance, Pratusha et al. [39] have shown that individual differences in brain usage may be apparent to the extent that they can be captured by NIRS. The fine motor task performed in this study required a complex cognition, which can reflect individual differences, although as mentioned earlier, individual strategy differences in eye usage are likely to be reflected. For example, participants who showed increased brain activity in the occipital lobe during the fine motor task might have better visual attention. Further research can explore the relationship among individual differences, strategy variations, and ASD traits during the fine motor task.

One limitation of NIRS in this study was its inferior spatial resolution, which prevented detailed examination of specific areas. However, NIRS excels in simultaneous measurements. To complement its spatial resolution, integrating NIRS with large-scale equipment, such as fMRI and positron emission tomography (PET), could provide valuable insights. Alternatively, simultaneous measurements with EEG and MEG can be conducted to capture fine motor movements with minimal constraints and high temporal resolution. EEG, known for its strength in estimating signal sources [40], can contribute to a more detailed understanding by examining the origin of signals from cerebellar responses. Although this study has some issues such as left–right differences due to dominant eye and individual variations, the observed differences in response between the cerebellum and occipital regions remain significant even after accounting for these factors. In addition, the measurement of cerebellar activity in the ASD and TD groups suggests that this method holds potential for wide applicability across diverse populations. Building upon this study, we anticipate further insights into cerebellar measurements in the future, with efforts made to translate them into practical applications.

Conclusion

In this study, we established a cerebellar channel and investigated its NIRS response. We found that the response was different from that of the adjacent occipital lobe. Furthermore, the response observed in the cerebellum was clearly attributable to cerebellar function. We measured cerebellar activity in individuals with ASD, similar to typically developing individuals. These findings highlight the promising potential of NIRS for assessing the cerebellum and improving our understanding of brain function during movement.

Acknowledgments

The authors are grateful to all participants who cooperated in the study, and all staff who helped us with assessments and NIRS measurement. We also thank Enago (www.enago.jp) for the English language review.

Funding

This research was supported by Grant-in-Aid for Scientific Research (A) (17H00883) and on Innovative areas (24119004), Grant-in-Aid for Challenging Exploratory Research (15K15223) and Research Institute of Science and Technology for Society, Japan Science and Technology Agency.

Conflict of interest

None

Declaration of Generative AI and AI-assisted technologies in the writing process

None

References

[1] Eric R. Kandel, James H. Schwartz, Thomas M. Jessell, Steven A. Siegelbaum, A.J. Hudspeth, Principles of Neural Science, fifth ed., McGraw-Hill, New York, 2012.

[2] S Kakei, DS Hoffman, PL Strick, 2003. Sensorimotor transformations in cortical motor areas. NEUROSCIENCE RESEARCH. 46(1) 1-10. https://doi.org/10.1016/s0168-0102(03)00031-2.

[3] Roberta M. Kelly, Peter L. Strick, 2003. Cerebellar Loops with Motor Cortex and Prefrontal Cortex of a Nonhuman Primate. The Journal of Neuroscience. 23(23) 8432-8444. https://doi.org/10.1523/JNEUROSCI.23-23-08432.2003.

[4] Peter L. Strick, Richard P. Dum, Julie A. Fiez. Cerebellum and Nonmotor Function. Annual Reviews. 32(2009) 413-34. https://doi.org/10.1146/annurev.neuro.31.060407.125606.

[5] Jeremy D. Schmahmann. The cerebellum and cognition. Neuroscience Letters. 688(2019) 62-75. https://doi.org/10.1016/j.neulet.2018.07.005.

[6] Nitschke, F.M., Kleinschmidt, A., Wessel, K., Frahm, J. Somatotopic motor representation in the human anterior cerebellum. A high-resolution functional MRI study. Brain 119(1996) 1023-1029. https://doi.org/10.1093/brain/119.3.1023.

[7] Batson, M.a., Petridou, N., Klomp, D.W.J., Frens, M.a., Neggers, S.F.W., 2015. Single session imaging of cerebellum at 7 Tesla: obtaining structure and function of multiple motor subsystems in individual subjects. PloS One. 10(8), e0134933. https://doi.org/10.1371/journal.pone.0134933.

[8] A.Villringer, J. Planck, C. Hock, L. Schleinkofer, U. Dirnagl, Near infrared spectroscopy (NIRS): a new tool to study hemodynamic changes during activation of brain function in human adults. Neuroscience Letters. 154(1993) 101-104. https://doi.org/10.1016/0304-3940(93)90181-j.

[9] C. S. Roy and C. S. Sherrington, 1890. On the Regulation of the Blood-supply of the Brain. J Physiol. 11(1-2): [85]-108, 158-7-158-17. https://doi.org/10.1113/jphysiol.1890.sp000321.

[10] Eiju Watanabe, Yuichi Yamashita, Atsushi Maki, Yoshitoshi Ito, Hideaki Koizumi, Non-invasive functional mapping with multi-channel near infra-red spectroscopic topography in humans. Neuroscience Letters. 205(1996) 41-44. https://doi.org/10.1016/0304-3940(96)12376-4.

[11] Lau M Andersen, Karim Jerbi, Sarang S Dalal, Can EEG and MEG detect signals from the human cerebellum? Neuroimage. 215(2020).116817. https://doi.org/10.1016/j.neuroimage.2020.116817.

[12] Maninderjit Kaur, Sudha Srinivasan, and Anjana Bhata, Comparing motor performance, praxis, coordination, and interpersonal synchrony between children with and without Autism Spectrum Disorder (ASD). Research in Developmental Disabilities: 72(2017) 79-95. https://doi.org/10.1016/j.ridd.2017.10.025.

[13] Green, D., Baird, G., Barnett, A.L., Henderson, L., Huber, J., & Henderson, S.E., 2002. The severity and nature of motor impairment in asperger's syndrome: A comparison with specific developmental disorder of motor function. Journal of Child Psychology and Psychiatr. 43(5) 655-668. https://doi.org/10.1111/1469-7610.00054.

[14] Greg Allen, Eric Courchesne, Differential Effects of Developmental Cerebellar Abnormality on Cognitive and Motor Functions in the Cerebellum: An fMRI Study of Autism Am J Psychiatry. 160(2003) 262–273. https://doi.org/10.1176/appi.ajp.160.2.262.

[15] American Psychiatric Association [APA]. (2013). Diagnostic and statistical manual on mental disorders-fourth edition-text revision (DSM-IV-TR). American Psychiatric Press.

[16] Wechsler, D. (1997). Manual for the Wechsler Adult Intelligence Scale III. New York: Psychological Corporation (Fujita, K., Maekawa, H., Dairoku, K., Yamanaka, K., 2006. Japanese Wechsler Adult Intelligence Scale- III. Tokyo, Nihon Bunka Kagakusha.)

[17] Lord, C., Risi, S., Lambrecht, L., Cook, E. H., Leventhal, B. L., DiLavore, P.C., … Rutter, M, 2000. The Autism Diagnostic Observation Schedule-Generic: Standard measure of social and communication deficits associated with the spectrum of autism. Journal of autism and developmental disorders. 30(3) 205–223.

[18] Yasuko Funabiki, Hisaya Kawagishi, Teruhisa Uwatoko, Sayaka Yoshimura, Toshiya Murai, 2011. Development of a multi-dimensional scale for PDD and ADHD. Research in Developmental Disabilities. 32(3) 995–1003. https://doi.org/10.1016/j.ridd.2011.01.052.

[19] Hoshi Y, Kobayashi N, Tamura M, Interpretation of near-infrared spectroscopy signals: A study with a newly developed perfused rat brain model. J Appl Physiol. 90(2001) 1657-1662. https://doi.org/10.1152/jappl.2001.90.5.1657.

[20] Goh Matsuda, Kazuo Hiraki, 2006. Sustained decrease in oxygenated hemoglobin during video games in the dorsal prefrontal cortex: a NIRS study of children. Neuroimage. 1;29(3) 706–711. https://doi.org/10.1016/j.neuroimage.2005.08.019.

[21] Hoshi Y, Tamura M, 1993. Dynamic multichannel near-infrared optical imaging of human brain activity. Journal of applied physiology. 75(4) 1842-1846. https://doi.org/10.1152/jappl.1993.75.4.1842.

[22] Goro Maehara, Shuichiro Taya, Haruyuki Kojima, 2007. Changes in hemoglobin concentration in the lateral occipital regions during shape recognition: a near-infrared spectroscopy study. Journal of Biomedical Optics, 12(6) 062109. https://doi.org/10.1117/1.2815720.

[23] Haruyuki Kojima, Takeshi Suzuki, 2010. Hemodynamic change in occipital lobe during visual search: visual attention allocation measured with NIRS. Neuropsychologia. 48(1) 349-52. https://doi.org/10.1016/j.neuropsychologia.2009.09.028.[24] Devor, A., Hillman, E. M. C., Tian, P., Waeber, C., Teng, I. C., Ruvinskaya, L., Mark H. Shalinsky, Haihao Zhu, Robert H. Haslinger, Suresh N. Narayanan, Istvan Ulbert, Andrew K. Dunn, Eng H. Lo, Bruce R. Rosen, Anders M. Dale, David Kleinfeld, David A. Boas. Stimulus-induced changes in blood flow and 2-deoxyglucose uptake dissociate in ipsilateral somatosensory cortex. Journal of Neuroscience. 28(2008) 14347-14357. https://doi.org/10.1523/JNEUROSCI.4307-08.2008.

[25] Devor, A., Tian, P., Nishimura, N., Teng, I. C., Hillman, E. M., Narayanan, S. N., Istvan Ulbert, David A Boas, David Kleinfeld and Anders M Dale. Suppressed neuronal activity and concurrent arteriolar vasoconstriction may explain negative blood oxygenation level-dependent signal. Journal of Neuroscience. 27(2007) 4452-4459. https://doi.org/10.1523/JNEUROSCI.0134-07.

[26] Hama Watanabe, Fumitaka Homae, Gentaro Taga. Activation and deactivation in response to visual stimulation in the occipital cortex of 6-month-old human infants. Developmental Psychobiology. 54(2012) 1-15. https://doi.org/10.1002/dev.20569.

[27] Kaoru Sakatani, Daisuke Yamashita, Takeshi Yamanaka, Motoki Oda, Yutaka Yamashita, Tetsuya Hoshino, Norio Fujiwara, Yoshihiro Murata, Yoichi Katayama, Changes of cerebral blood oxygenation and optical pathlength during activation and deactivation in the prefrontal cortex measured by time-resolved near infrared spectroscopy. Life Sciences. 78(2006) 2734-2741. https://doi.org/10.1016/j.lfs.2005.10.045.

[28] Takenori Akiyama, Takayuki Ohira, Toshinori Kato, Yasuo Toda, Maaya Orii, Kenji Hiraga, Atsushi Fukunaga, Masahito Kobayashi, Satoshi Onozuka, Takeshi Kawase, Motor-Related

Intracortical Steal Phenomenon Detected by Multichannel Functional Near-Infrared Spectroscopy Imaging. Cerebrovasc Dis. 20(2005) 337-346. https://doi.org/10.1159/000087934.

[29] Vorstrup S, Engell HC, Lindewald H and Lassen NA. Hemodynamically significant stenosis of the internal carotid artery treated with endarterectomy. Case report. J Neurosurg. 60(1984) 1070-1075. https://doi.org/10.3171/jns.1984.60.5.1070.

[30] Jancke L, Loose R, Lutz K, Specht K, Shah NJ. Cortical activations during paced finger-tapping applying visual and auditory pacing stimuli. Cognit Brain Res. https://doi.org/10(2000):51–66.

[31] Dhamala M, Pagnoni G, Wiesenfeld K, Zink CF, Martin M, Berns GS. Neural correlates of the complexity of rhythmic finger tapping. Neuroimage. 20(2003):918–26. https://doi.org/10.1016/S1053-8119(03)00304-5.

[32] Witt ST, Laird AR, Meyerand ME. Functional neuroimaging correlates of finger-tapping task variations: An ALE meta-analysis. Neuroimage. 42(2008)343–56. https://doi.org/10.1016/j.neuroimage.2008.04.025.

[33] L.M. Vaina, J.W. Belliveau, E.B. des Roziers, T.A. Zeffiro. Neural systems underlying learning and representation of global motion. Proceedings of the National Academy of Sciences of the United States of America. 95(1998). 12657-12662. https://doi.org/10.1073/pnas.95.21.12657.

[34] Cristina Deluca, Ashkan Golzar, Elisa Santandrea, Emanuele Lo Gerfo, Jana Eštočinová, Giuseppe Moretto, Antonio Fiaschi, Marta Panzeri, Caterina Mariotti, Michele Tinazzi, Leonardo Chelazzi, The cerebellum and visual perceptual learning: Evidence from a motion extrapolation task. Cortex. 58(2014):52-71. https://doi.org/10.1016/j.cortex.2014.04.017.

[35] Krystal M. Kirby, Sreekrishna Ramakrishna Pillai, Owen T. Carmichael, Arend W. A. Van Gemmert. Brain functional differences in visuo-motor task adaptation between dominant and non-dominant hand training. Experimental Brain Research. 237(2019) 3109–3121. https://doi.org/10.1007/s00221-019-05653-5.

[36] D.C. Bourassa, I.C. McManus, M.P. Bryden, 1996. Handedness and eye-dominance: a meta-analysis of their relationship. Laterality. 1 (1) 5-34. https://doi.org/10.1080/713754206.

[37] Jensen, Bettina H. Hougaard, Anders, Amin, Faisal M., Larsson, Henrik B.W., Ashina, Messoud, 2015. Structural asymmetry of cortical visual areas is related to ocular dominance. NeuroReport. 26(17) 1071-1076. https://doi.org/10.1097/WNR.0000000000000470.
[38] Masato Taira. Function of the parietal cortex (1). Clinical Electroencephalography. 51(8). 507-515.2009.
[39] Pratusha Reddy, Patricia A. Shewokis, Kurtulus Izzetoglu, 2022. Individual differences in skill acquisition and transfer assessed by dual task training performance and brain activity. Brain Inform. 9(1) 9. https://doi.org/10.1186/s40708-022-00157-5.
[40] Ramesh Srinivasan, William R Winter, Paul L Nunez, Source analysis of EEG oscillations using high-resolution EEG and MEG. Progress in brain research;159(2006) 29-42. https://doi.org/10.1016/S0079-6123(06)59003-X.

Tables

Table 1

Distributions of Age, Gender, IQ, and scores of domains of the MSPA and ADOS.

		ASD(n=20) (male:female = 10:10)			TD(n=19) (male:female = 10:9)		
		Mean	SD	Range	Mean	SD	Range
	Age	29.2	6.2	21–41	26.1	7.5	21–48
WAIS	IQ	111.5	11.9	86–134	114.9	11.0	85–129
	VIQ	114.1	14.0	84–140	117.3	14.1	85–141
	PIQ	105.7	12.7	82–129	108.6	10.9	87–128
MSPA	Communication	3.26	0.64	2.5–4.5	1.71	0.50	1–2.5
	Group adaptability	3.28	0.55	2.5–4.5	1.47	0.41	1–2.5
	Empathy	3.08	0.67	2–4	1.53	0.54	1–2.5
	Restricted interest/behaviors	3.35	0.65	2–4.5	1.88	0.45	1–2.5
	Gross motor	2.15	0.92	1–4	1.32	0.43	1–2
	Fine motor	1.68	0.78	1–3.5	1.50	0.56	1–2.5
ADOS	Communication	1.00	2.50	0–5	0.00	0.00	0–2
	Social interaction	1.00	2.50	1–13	0.00	0.00	0–4

ADOS, autism diagnostic observation schedule; ASD, autism spectrum disorder; IQ, intelligence quotient; VIQ, verbal IQ; PIQ, performance IQ; MSPA, multidimensional scale for pervasive developmental disorders and attention-deficit hyperactivity disorder; TD, typical development; WAIS, Wechsler Adult Intelligence Scale

Table.2
Interactions, main effects and simple main effects of four-way ANOVA

	factor	*F*-value	*p*-value
three-way interaction	task × region × laterality × group	0.991	.335
two-way interaction	task × region × group	1.709	.211
	task × laterality × group	0.001	.972
	region × laterality × group	0.262	.616
	task × region × laterality	1.172	.296
one-way interaction	task × group	0.002	.963
	region × group	0.317	.582
	laterality × group	1.694	.213
	task × region	12.472	.003
	task × laterality	5.557	.032
	region × laterality	0.348	.564
main effect	group	0.015	.904
	task	2.466	.137
	region	2.944	.107
	laterality	2.136	.165

simple main effect	condition		*F*-value	*p*-value
task	region	occipital	23.5	.000
		cerebellum	0.64	.435
region	task	visual	5.44	.034
		fine motor	7.58	.015
task	laterality	left	0.22	.649
		right	9.6	.007
laterality	task	visual	2.34	.147
		fine motor	4.36	.540

Group, participants with autism spectrum disorder or typical development; task, visual or fine motor task; region, the occipital or cerebellum; laterality, left or right of the brain.

Simple main effects were analyzed only if the one-way interaction was significant.

F-values indicate the ratio of the unbiased variance of the group to the unbiased variance of the residuals.

Table 3.
Correlations between behavioral assessment and oxy-Hb response scores by NIRS

		O1	O2	Cr1	Cr2
MSPA	Gross motor	0.23	0.24	−0.07	0.08
	Fine motor	−0.05	−0.03	−0.06	−0.10
	Communication	−0.12	−0.02	−0.08	0.08
	Group adaptability	−0.12	0.02	0.01	0.02
	Empathy	−0.20	−0.05	0.04	0.02
	Restricted interest/behaviors	−0.15	0.13	0.13	−0.01
ADOS	Communication	−0.25	−0.12	−0.10	−0.19
	Social interaction	0.01	0.10	−0.13	−0.11

ADOS, autism diagnostic observation schedule; MSPA, multidimensional scale for pervasive developmental disorders and attention-deficit hyperactivity disorder; NIRS, near-infrared spectroscopy; O1 and O2, left and right occipital channels, respectively, according to the international 10–20 EEG system; Cr1 and Cr2, left and right cerebellum, respectively, located 6 cm below O1 and O2. We had no significant correlation.

Figure captions

Figure 1. Arrangement of the electrodes.

Left: location of each channel. The black circles indicate emitter probes and the white circles show receive probes. Numbers denote measurable NIRS channels. Center: Channel positions in the caudal plane. Right: Channel positions in the sagittal plane.

Figure 2. Oxy-Hb response scores in different channels.

Mean values and standard errors of oxy-Hb response scores for all participants in each channel. Vertical bars represent standard errors. O1 and O2 correspond to the left and right occipital channels, respectively, based on the international 10–20 system. Cr1 and Cr2 indicate the left and right cerebellum channels located 6 cm below O1 and O2, respectively. ASD, autism spectrum disorder; TD, typical development.

Figure 1

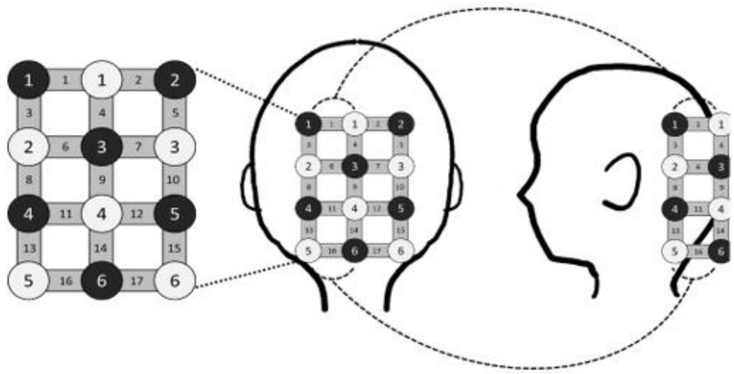
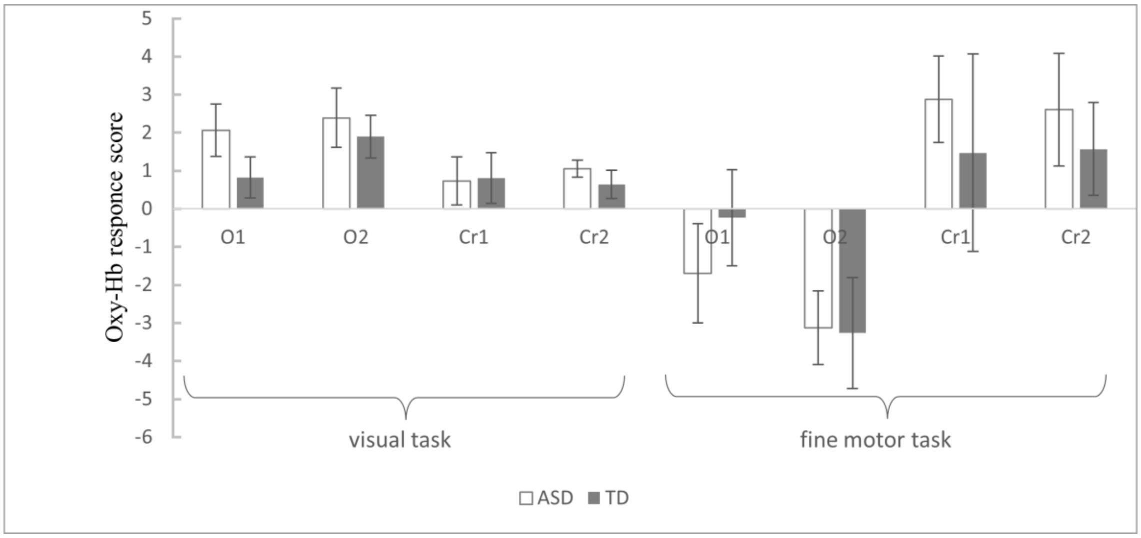


Figure 2



Oxy-Hb responce score
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
O1
O2
Cr1
Cr2
O1
O2
Cr1
Cr2
visual task
fine motor task
ASD
TD