BLOOD FLOW VELOCITY IN MIDDLE CEREBRAL ARTERY DURING VISUO-MOTOR TASKS USING A MIRROR: A TRANSCRANIAL DOPPLER STUDY

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SUMMARY – Mirror illusion means that standing in front of a mirror placed in sagittal plane, with the head tilted on one side and one arm stretched forward, one side of the body is reflected as if it were the other side by mirror visual feedback. The aim of this study was to monitor blood flow changes in middle cerebral artery (MCA) by use of transcranial Doppler (TCD) in individuals during motor tasks and tasks using mirror visual feedback. Eight young healthy volunteers (four male and four female) were included in the study. TCD recording in MCA was done during each task consisting of various motor and visuomotor activities using mirror illusion. Both MCA mean blow flow velocity (MBFV) was measured while the subjects were seated in a comfortable chair. The MCA MBFV recordings are presented as baseline values. During the illusion of motor hand activation, when the subject was making right hand flexions and watching its reflection in the mirror, with the left hand immobile, an increase was observed the contralateral MCA MBFV (task 3, +4.5% baseline value; P=0.017). Furthermore, when the subject made left hand flexions while watching the reflection of the immobile right hand in the mirror, there was an increase in the right MCA MBFV (+5.6% baseline value; P=0.044), which was more pronounced than during the illusion of motor hand activation (task 3) and less than during direct vision of hand flexion (task 2, +6.3% baseline value; P=0.005). Our data showed that visual illusion of action, as well as direct action observation could increase the MCA MBFV, which brings forward the possible usage of mirror illusion as a tool in motor neurorehabilitation.

Key words: *Brain – physiology; Neurons – physiology; Vision – physiology; Visual perception – physiology; Motor activity; Cerebrovascular disorders – physiopathology; Ultrasonography, Doppler – transcranial*

Introduction

Transcranial Doppler sonography (TCD) was introduced for evaluation of cerebral circulation in patients with subarachnoidal hemorrhage[1]. Since then, it has also been used in the assessment of brain hemodynamics in different clinical settings for evaluation of cerebrovascular diseases. Due to the excellent time resolution, it enables noninvasive monitoring of real-time changes in intracranial circulation. TCD has found wide clinical applications, e.g., in the evaluation of ischemic cardiovascular disease, intra- and extracranial stenosis[2], recanalization[4,5], embolus detection[6], and cerebral vasoreactivity[7-9]. TCD is also often used as a diagnostic tool in stroke[10-12], movement disorders[13,14], and cognitive impairment[15]. Functional TCD measures blood flow changes in cerebral arteries after applying different tasks like visual or motor stimulation.

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Limb movement activates motor parts of the brain. This part of the brain is supplied by the middle cerebral artery (MCA). Limb movement enhances metabolism of the motor parts of the brain, and consecutively MCA blood flow increases[16]. Ramachandran *et al.* have described the use of mirrors in patients with arm amputation and phantom limb pain in order to restore the disruption of normal interaction between the intention to move the limb and the absence of appropriate sensory feedback. A mirror is placed vertically in front of the patient to reflect the non-injured hand on the place of the injured one, so the patient gets a mirror visual feedback. Standing in front of a mirror placed in sagittal plane, with the head tilted on one side and one arm stretched forward, one can see one side of the body reflected as if it were the other side. These patients reported the sensation that they could move and relax the often-cramped phantom limb and experienced pain relief[17]. Since this initial report, successful use of mirror therapy has been reported in patients with other pain syndromes such as complex regional pain syndrome[18,19] and in sensory reeducation of severe hyperesthesia after hand injuries[20]. Altschuler *et al.* were the first to demonstrate that mirror therapy may be beneficial for motor function recovery of the paretic hand in nine stroke patients[21]. Other case reports[22-24] and one trial[25] in 40 patients confirmed this finding.

The aim of our study was to monitor blood flow changes in MCA by use of TCD in subjects during motor tasks and tasks using mirror visual feedback.

Subjects and Methods

Eight healthy volunteers (four male and four female), young physicians aged 25-35, participated in the study. Two subjects (one male and one female) were smokers. MBFV was recorded by a Sonara (Viasys Neurocare TCD system, Madison) TCD with two 2 MHz probes fixed on both temporal windows at a depth of 55 mm. Both MCAs were insonated according to the previously established criteria[26].

Both MCA MBFV was measured while the subjects were seated in a comfortable chair. The MCA MBFV recordings are presented as baseline values. After measuring baseline values, a mirror was placed in sagittal plane in front of them. All subjects performed 4 different visuomotor tasks as follows:

- on task 1, the subject made left hand flexion while looking forward;
- on task 2, the subject made left hand flexion while watching it;
- on task 3, the subject made right hand flexions while watching its reflection in the mirror, with the left hand immobile. Thus he had an illusion that the left hand was moving; and
- on task 4, the subject made left hand flexions while watching the reflection of the immobile right hand in the mirror. Thus he had an illusion that the left hand was immobile.

The MBFV increase was recorded and assessed in both MCA.

The study was approved by the local Ethics Committee and an informed consent was obtained from all study subjects prior to entering the study.

The mean MCA increase was calculated for each task. Statistical analysis was done using the SPSS software (SPSS for Windows 11.0, SPSS, Chicago, IL, USA). Statistical significance of difference from baseline values was assessed for each task by Student's t-test. Statistical significance of difference was set at $P<0.05$.

Results

The men baseline MBFV and MBFV recorded during the four study tasks in both MCA are pre-

Fig. 1. Mirror visual feedback of the upper limb using mirror illusion.

Table 1. Mean blood flow velocity (MBFV) values (cm.s^{-1}) in both middle cerebral arteries

Volunteer	1	2	3	4	5	6	7	8		
MBFV in right MCA									Mean	Standard deviation (SD)
Baseline	43.22	41.79	37.31	40.52	57.62	57.00	53.50	59.99	48.87	9.04
Task 1	43.47	43.43	38.16	41.96	58.01	61.08	53.03	59.76	49.86	9.11
Task 2	44.21	45.07	38.25	43.62	64.87	62.46	55.29	61.83	51.95	10.35
Task 3	43.56	44.62	37.64	42.87	62.24	60.90	55.12	61.57	51.06	9.95
Task 4	43.73	45.14	38.11	43.55	63.23	62.93	55.061	60.92	51.58	10.09
SD	0.36	1.41	0.40	1.29	3.22	2.33	1.052	0.92	1.27	0.97
MBFV in left MCA										
Baseline	49.19	44.75	53.27	69.82	58.00	69.82	45.38	55.64	55.73	9.84
Task 1	49.64	43.93	62.29	69.40	57.54	69.40	44.81	53.90	56.36	10.11
Task 2	50.81	40.83	55.19	70.79	64.60	70.79	46.52	55.19	56.84	11.04
Task 3	50.98	45.33	59.89	73.91	64.77	73.91	42.36	56.48	58.45	12.01
Task 4	50.51	46.56	55.21	70.29	60.52	70.29	42.22	57.79	56.67	10.26
SD	0.77	2.155	3.76	1.79	3.47	1.79	1.89	1.45	1.010	

sented in Table 1 (left MCA 55.74 cm.s and right MCA 48.87 cm.s). During motor activation of the left hand, an increase was recorded in both MCA MBFV, which was more pronounced on the right side (Table 1, task 1: left MCA +1.13%, *P*=0.037; and right MCA +2.05%, *P*=0.031). This MCA MBFV increase was more pronounced during the same motor

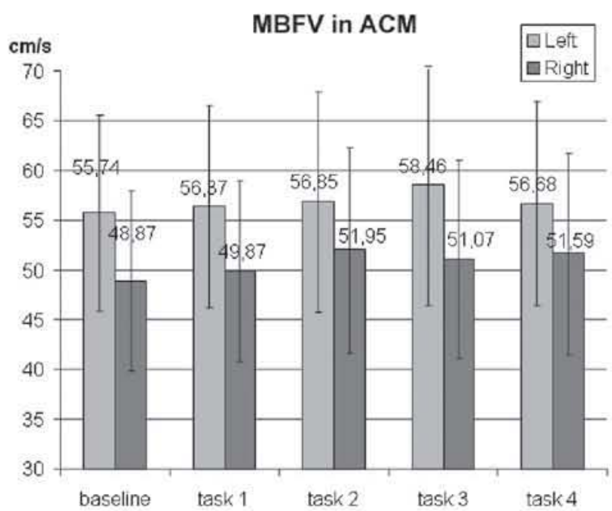

Fig. 2. Diagram of the mean blood flow velocity (MBFV) (cm.s^{-1}) in both middle cerebral arteries (MCA) during each task.

stimulation with direct visual stimulation of the moving hand (+2%, *P*=0.022) (Table 1, task 2). Therefore, the MBFV increase was greater in contralateral MCA (+6.3%, *P*=0.005). The greatest contralateral MCA MBFV increase was recorded on task 3, due to the additional subject's illusion of the ipsilateral hand movement (+4.9%, *P*=0.028) (Table 1, left MCA, task 3). A statistically significant (*P*=0.017) ipsilateral MCA MBFV increase was recorded during task 3 (+4.5%). However, this increase was less pronounced than in task 2 when the subject was not confounded by mirror illusion of the moving hand (Table 1, right MCA, task 3). Motor activation of the left hand on task 4 led to an increase in both MCA MBFV (left MCA +1.7%, *P*=0.0005 and right MCA +5.6%, *P*=0.044) but the increase was more pronounced in contralateral MCA than in task 3, where only visual illusion of movement without motor activation was present. However, the increase in contralateral MCA MBFV was less pronounced than in task 2, where there was no conflict between vision and proprioception.

Discussion

Our results showed increased MBFV in the MCA contralateral to motor hand activation as the result of coupled metabolic activity of the brain supplied by MCA. During the illusion of motor hand activation, an increase in MBFV was observed in both ipsilateral and contralateral MCA. These results indicated that both visual illusion of action and direct action observation could lead to an increase in contralateral MCA MBFV. It has already been shown that visual stimulation by activating primary and secondary visual cortex in the occipital lobe enhances MBFV in posterior cerebral artery[27-29]. Our results showed that visual input of action observation enhanced MBFV in MCA, which is known to be the main artery for premotor and parietal cortex. Following the information generated by the illusion of the arm in the mirror, it seems likely that this illusion enhances activation of the premotor and motor cortex in a similar way to action observation or motor imagery. Indeed, our results are in line with other studies that have shown that mirror illusion, as well as motor imagery and action observation increases cortical and spinal motor excitability. Trans-magnetic stimulation (TMS) studies have shown an increase in the motor evoked potential (MEP) responses during motor tasks using mirror illusion[30-33]. This effect can be explained by the activation of so-called mirror-neuron system. Mirror neurons are neurons that fire when the subject performs a movement, but also during observation of the same movement by someone else, and they seem to play a central role in the process of motor (re-)learning by action observation[34]. Rizzolati *et al.* were the first to describe this phenomenon in monkeys[34], followed by reports on the evidence of the existence of a mirror-neuron system in humans provided by TMS study demonstrating that observation of a movement results in motor facilitation[35]. During mirror illusion, mirror neurons of the contralateral hemisphere may be involved.

Furthermore, visual feedback seems to be stronger than somatosensory feedback for cortical proprioceptive representation. The positions of our hands are specified by proprioceptive, kinesthetic, tactile, visual, and vestibular information. While looking in the mirror so that the visually specified location of the right arm differs from its proprioceptively specified position, visual information is brought into conflict with all other positional clues. It results in the perception of hand location shifted towards its visually specified location[36,37]. In the same way, visual input can also enhance tactile sensitivity, and some authors report on sensory experiences evoked on the basis of visual information alone[38,39]. These findings imply modulation of tactile processing upstream from primary somatosensory cortex by parietal cortex.

Earlier single-neuron studies have also shown the existence of bimodal visuotactile neurons in the parietal cortex, cells that are more active when visual stimuli are administered close to the hand, in peripersonal space[40-42]. This neurophysiological evidence is consistent with the absence of visuotactile facilitation, found when visual stimulus was presented far from the hand, at the level of the patient's eyes or far from the face[43,44]. These findings as well as our preliminary results (our pilot study was limited by the small number of study subjects) provide a strong neurophysiological background for the use of visual perception in motor rehabilitation of the upper limb.

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Sažetak

BRZINA PROTOKA KRVI U SREDNJOJ MOŽDANOJ ARTERIJI TIJEKOM VIZUALNO-MOTORIČKIH ZADATAKA S UPOTREBOM ZRCALA: ISPITIVANJE POMOĆU TRANSKRANIJSKOG DOPLERA

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Iluzija zrcala očituje se time da stojeći ispred zrcala položenog u sagitalnu ravninu, gledajući na jednu stranu gdje nam je ispružena i jedna ruka, vidimo odraz kao da se radi o drugoj strani tijela zahvaljujući vizualnom zrcalnom povratu. Cilj ove studije bio je pokazati promjene brzine protoka krvi u srednjoj moždanoj arteriji (ACM) pomoću transkranijskog doplera (TCD) tijekom različitih motoričkih zadataka i zadataka s upotrebom zrcala. Osmoro mladih, zdravih dobrovoljaca (četiri muškarca i četiri žene) sudjelovalo je u ovom istraživanju. Pomoću TCD bilježile su se vrijednosti brzine protoka te promjene brzine u obje ACM, dok su ispitanici obavljali zadatke sjedeći u stolici. Snimljene vrijednosti prikazane su kao srednje vrijednosti. Tijekom iluzije o motoričkoj aktivnosti lijeve ruke pri pomicanju samo desne te gledanju njenog odraza u zrcalu zabilježeno je povećanje srednje brzine strujanja krvi u kontralateralnoj ACM (3. zadatak, porast za 4,5% u odnosu na bazalnu vrijednost, P=0,017). Nadalje, pri pomicanju lijeve ruke dok ispitanik promatra odraz nepomične desne također je došlo do porasta brzine u desnoj ACM (porast za 5,6% u odnosu na bazalnu vrijednost, P=0,044), koji je bio veći nego pri samoj iluziji motoričke aktivnosti (3. zadatak), a manji od porasta tijekom gledanja izravno u ruku koja se pomiče (2. zadatak, porast za 6,3%, P=0,005). Rezultati ovoga istraživanja pokazali su kako vizualna iluzija kretanja, kao i izravno promatranje aktivnosti povećava brzinu protoka krvi u ACM, što upućuje na mogućnost primjene iluzije zrcala u motoričkoj neurorehabilitaciji.

Ključne riječi: *Mozak – fiziologija; Neuroni – fiziologija; Vid – fiziologija; Vidna percepcija – fiziologija; Motorička aktivnost; Cerebrovaskularne bolesti – patofiziologija; Ultrazvuk, doppler – transkranijski*