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► To cite this version:

Thomas Rulleau, Lucette Toussaint. Massage can (re-)activate the lower-limb sensorimotor representation of older adult inpatients. *Psychology and Aging*, 2018, 33 (5), pp.832-840. 10.1037/pag0000264 . hal-01770433

HAL Id: hal-01770433

<https://hal.science/hal-01770433>

Submitted on 19 Apr 2018

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Massage can (re-)activate the lower-limb sensorimotor representation of older adult inpatients

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Running head: Activation of sensorimotor representation

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Abstract

Understand how changes in afferent signal processing may impact the sensorimotor processes is essential for physical therapists whose objective is to actively improve the reorganization of motor function in patients suffering from sensorimotor system disturbance. Because the sensorimotor processes are slowed with the advance in age, we examined whether a single massage session can reactivate the sensorimotor processes of older adult inpatients. Participants were randomly assigned to the experimental (with massage) or control (without massage) groups. Massage was realized on both feet with 7.30 minutes spent on each foot (Experiment 1), the right foot or the right foot and knee for 10 minutes (Experiment 2). Body and non-body mental rotation tasks were used to assess the lower-limb motor representation before (pre-test), immediately after (post-test 1) and 24 hours after the massage (post-test 2). Results showed the positive impact of massage on the body mental rotation task. The activation of the sensorimotor processes can last up to 24 hours depending on the extent of the massaged area. Importantly, the activation of the sensorimotor representation concerned not only the massaged leg but also the contralateral leg. No difference between groups appeared in the non-body mental rotation task which did not solicit the sensorimotor processes. These results highlighted that peripheral activation via a massage had a specific impact on the sensorimotor processes. Massage is an interesting technique which can help older adult inpatients cope with the slowdown of the signal processing related to advancing age.

Keywords: Massage, Sensorimotor representation, Older adult, Lower limb, Mental rotation

Plasticity is an old concept in neuroscience that led many researchers to take an interest in the structural as well as the functional reorganization of the central nervous system according to environmental demands and experiences. Pascual-Leone and collaborators (2005) wrote in their review on the plasticity of the cortex of the human brain that *"The challenge we face is to learn enough about the mechanisms of plasticity and the mapping relations between brain activity and behavior to be able to guide it, suppressing changes that may lead to undesirable behaviors while accelerating or enhancing those that result in a behavioral benefit for the subject or patient."* One topic of interest related to plasticity is understanding how changes in afferent or efferent signal processing may be observed at the behavioral level to enhance changes that can favor behavioral benefits and suppress those that can induce undesirable behaviors for the subject or the patient.

Over the past two decades, researchers in cognitive neuroscience have revealed that the human brain is rich in reorganization and changes not only in younger but also in older adults. These changes observed in various parts of the brain may affect cognitive and sensorimotor functions, aging being associated with the progressive loss of these functions. For example, sensorimotor changes with aging are highlighted by slower and less smooth movements (Diggles-Buckles, 1993; Goble, Coxon, Van Impe, Swinnen, 2009), increased spatial and temporal variability (Contreras-Vidal, Teulings, Stelmach, 1998), difficulties to perform multi-joint movements (Seidler, Alberts, Stelmach, 2002), postural instability that increases the risk for fall (Tinetti, Speechley, Ginter, 1998) and so on. The sensorimotor performance impairments with aging are likely due to changes in peripheral structures and central nervous system (see Seidler, Bernard, Burutolu, Fling, Gordon, Gwin et al., 2010, for a review on aged-related differences and motor deficits in older adults). In the present study, we will focus on the positive effects of brain plasticity in older adults, especially considering the sensorimotor function and the effects of

massage on the sensorimotor representation. This knowledge can be important for physical therapists whose objective is to actively improve the reorganization of motor function in patients suffering from sensorimotor system disturbances.

In cognitive neuroscience, some studies that focused on the plasticity of the sensorimotor system mainly used two approaches that were based on either a stimulating or impoverished environment to assess the continuous and rapid changes in sensorimotor representation. Some researchers using brain mapping techniques have revealed a decrease in motor cortex excitability (Avanzino, Pelosin, Abbruzzese, Bassolino, Pozzo, Bove, 2013; Facchini, Romani, Tinazzi, Aglioti, 2002) as well as a disruption in motor performance (Bassolino, Bove, Jacono, Fadiga, Pozzo, 2012; Huber, Ghilardi, Massimini, Ferrarelli, Reidner, Peterson, Tononi, 2006) following 10-12 hours to 4 days of immobilization of the fingers or an arm. Recently, to examine the central and functional effects of non-use of a limb, some researchers based their reasoning on the simulation theory (Jeannerod, 2001), which states that physical and simulated actions share the same sensorimotor representations and rely on similar mechanisms. The authors specifically examined whether internal sensorimotor representations are affected by the input/output restriction of signal processing following a short delay of upper-limb non-use (24 or 48 hours; Meugnot, Agbangla, Almecija, Toussaint, 2015; Meugnot, Almecija, Toussaint, 2014) by asking participants to solve mental rotation tasks using body or non-body stimuli that depended respectively on motor and visual imagery strategies, respectively. Based on a motor imagery strategy, the mental rotation tasks used body images (i.e., hand or foot) to assess the efficiency of specific internal sensorimotor representation (i.e., the upper-limb or the lower-limb representation, respectively). The results showed that immobilized participants took more time than controls (i.e., non-immobilized participants) to solve the body (hand) mental rotation task (i.e., to identify whether the stimulus corresponds to either a left or a right hand), whereas no

differences were detected between the two groups when solving the non-body mental rotation task (i.e., to identify whether the stimulus corresponds to the number "2" or its mirror image). Moreover, a short period of sensorimotor restriction did not lead to a general slowdown in the sensorimotor processes. A somatotopic effect induced by 24 hours of left-hand immobilization have been reported, as revealed by longer response times for the stimuli depicting the immobilized hand compared to the non-immobilized hand (Meugnot et al, 2014; 2015). In contrast, 48 hours of left-hand non-use affected both the immobilized and the non-immobilized hand (Toussaint & Meugnot, 2013). Moreover, if 48 hours of left-hand immobilization impairs the effector- system corresponding to the restricted limb (i.e., the upper-limb system), it does not extend to another effector-system (i.e. the lower-limb system) (Meugnot, Agbangla, Toussaint, 2016).

Other researchers that have focused more on the effect of a stimulating environment on sensorimotor representations confirmed its central consequences. Neuroimaging studies have shown that enhancing sensory input by proprio-tactile stimulations (vibrations on muscles) modulates the excitability of the motor cortical projections to a specific limb and to the opposite limb (Kossev, Siggelkow, Kapels, Dengler, Rollnik, 2001; Rosenkranz & Rothwell, 2004) and can reduce the decrease in motor cortex excitability due to limb non-use (Avanzino et al., 2013; Roll, Kavounoudias, Legre, Gay, Fabre, Roll, 2012). From a behavioral point of view, the functional relevance of a stimulating environment has been demonstrated by experiments showing the effect of augmented sensory feedback on movement control in patients. For example, adding or enhancing proprioceptive information by muscle vibrations improved head and trunk movements in patients with torticollis (Karnath, Konczak, Dichgans, 2000), finger movements in pianists with musician's dystonia (Rosenkranz, Butler, Williamon, Rothwell, 2009) and gait control in Parkinson's disease patients following vibrations on lower limb muscles

(El-Tamawy, Darwish, Khallaf, 2012). Somatosensory stimulation can also be performed by physical therapists with a massage procedure. In particular, massage therapy is known to reduce pain and increase the range of motion in patients with knee arthritis pain (30 minutes/week for 4 weeks), improve active knee flexion after knee arthroplasty following one week of treatment (20 minutes/day) (Field, Diego, Hernandez-Reif, 2007), and improve physical fitness (strength, flexibility, agility, speed) in healthy soccer players (30 minutes every 3 days for 10 days) (Hongsuwan, Eungpinichpong, Chatchawan, Yamauchi, 2015). Sensory stimulation for 3 hours has been shown to enhance tactile acuity, haptic object exploration and fine motor control in the older adults (Kalisch, Tengenthoff, Dinse, 2008). Moreover, some authors have shown that a 20-minute "over-activation" of somatosensory information (by manual massage and mobilization of both the feet and ankles joints) allows the older adults to compensate for the absence of vision for regulate their postural sway (Vaillant, Vuillerme, Janvey, Louis, Braujou, Juvin, Nougier, 2008) as well as to improve functional balance performances (assessed by means of the One Leg Balance test and the Time Up and Go test) (Vaillant et al., 2008; Vaillant, Rouland, Martigne, Braujou, Nissen, Caillat-Miousse, Vuillerme, Nougier, Juvin, 2009). Even if these later experiments clearly showed that such a therapeutic intervention plays a major role in postural control, nothing is known about the importance of massage taken in isolation.

The functional changes that probably followed massage, although still poorly documented, could reveal the impact of a massage procedure on the sensorimotor system and legitimized intervention with massage by therapists in rehabilitation programs. However, the origin of these functional changes is unknown, and an important issue for cognitive scientists is to clarify whether these functional changes resulted from peripheral (i.e., the softening of muscles and/or joints) or central effects (i.e., the activation of the sensorimotor processes/representation). Therefore, the aim of the present study was to examine the effect of a single massage session on

mental rotation tasks using either body or non-body stimuli (Experiments 1 and 2), which was also performed in the study of the immobilization-induced effects on the sensorimotor representation (Meugnot et al., 2014; 2015; Toussaint & Meugnot, 2013). Because aging disturbs the sensorimotor representation, as revealed by the slowdown in response times on mental rotation tasks with body parts (Saimpont, Malouin, Tousignant, Jackson, 2013; Saimpont, Pozzo, Papaxanthis, 2009), we chose to examine the effect of a single massage session on the mental rotation abilities of older adult participants. In Experiment 1, a physical therapist performed a massage on both feet successively for 15 minutes. In Experiment 2, the therapist performed massage for 10 minutes on either the right foot or the right foot and the right knee. We expected that the massage-induced effects on sensorimotor processes would be manifested by better performance (i.e., a decrease in response times) when solving the body mental rotation task (with foot images), such a result confirming the central effects of massage. The importance of the extent of the massage area on the activation of the sensorimotor processes was specifically investigated in Experiment 2 by comparing the effects of massage on the foot only versus the foot and the knee. In Experiment 2, we also investigated the bilateral activation of the sensorimotor system following unilateral massage (i.e., massage on one side of the body). In both experiments, no positive impact of the massage was expected in the non-body mental rotation task (with number images), which did not spontaneously elicit the use of sensorimotor processes (Dalecki, Hoffmann, Bock, 2012).

Experiment 1

Method

Participants

32 right-handed inpatients voluntarily participated in the experiment (mean age 78.5 years, SD = 7.6 years). They were hospitalized for diverse geriatric or neurogeriatric reasons (asthenia, general state alteration, falls, chronic obstructive pulmonary disease, depression, etc.) and were still at the hospital during the experiment. All participants were able to walk 10 meters in less than 30 seconds. They had normal or corrected-to-normal vision and provided written informed consent for their participation prior to their inclusion in this study. Before testing, the participants were randomly divided into 2 groups: a control group (n=16, mean age 79 ± 7.5 years, 9 males) and a massage group (n=16, mean age 78 ± 8.5 years, 8 males). The study protocol was in accordance with the ethical standards of the local ethics committee of the hospital center where the experiment occurred. All participants were naïve to the purpose of the experiment. However, they received both written and verbal descriptions of the experimental procedure and signed consent forms indicating agreement to participate in the experiment.

Tasks and material

All participants performed 2 mental rotation tasks using either body or non-body stimuli. For both tasks, participants were seated in front of a computer screen (~60 cm) and instructed to place their left and right index fingers on 2 marked keys located on the left and the right sides of the keyboard, respectively. Participants were asked to identify the images displayed on the center of the computer screen as quickly and accurately as possible. *In the body mental rotation task*, the stimuli consisted of pictures of right or left feet (created with Poser 6.0 software; sized 20.7 x

12.7 cm; Figure 1A). The participants had to determine the laterality of the foot images and answer by pressing the left-marked key for a left foot image or the right-marked key for a right foot image. *In the non-body mental rotation task*, the stimuli consisted of the number “2” or its mirror image (20.7 x 12.7 cm; Figure 1B). Participants had to determine whether the number was presented in its canonical form or its mirror image by pressing the appropriate left or right key. For both tasks, the foot and number stimuli were presented in different orientations in the plane of the images (i.e., 0°, 40°, 80° and 120° in clockwise and counterclockwise directions). A trial began when a fixation cross was displayed in the center of the screen for 500 ms. Then, a stimulus was presented and remained visible until the participant provided his/her response. The E-Prime 2.0 software package (Psychology Software Tools Inc., Pittsburgh, USA) was used to present images and record the participants’ responses (accuracy and response times).

Figure 1. Illustration of the stimuli used in Experiments 1 and 2 for the body mental rotation task (A) and the non-body mental rotation task (B).

Procedure

The participants were divided into 2 groups: a massage group and a control group. In the massage group, the intervention method was standardized. The massage technique consisted of effleurage and kneading and friction with moderate pressure applied under the foot (see Field et al, 2007, for a review). The massage was performed by a physical therapist with 9 years of experience. Both feet were successively massaged for 7.30 minutes each. The control group did not undergo the massage procedure, but they talked (about their family, weather, etc.) with the therapist for 15 minutes.

The body and non-body mental rotation tasks were performed during three experimental sessions: before (pretest), immediately after (posttest 1) and 24 hours after the massage (posttest 2). For each session, each task was divided into 2 phases: the familiarization phase and the experimental phase. During the first familiarization phase, participants were shown 14 randomly presented trials (illustrated in Figure 1). During the second experimental phase, participants were shown 5 blocks of 14 trials (i.e., 70 trials per participants) presented in a random order within each block. In the three experimental sessions, the body mental rotation task was performed before the non-body mental rotation task because the sensorimotor processes may be attenuated when a non-body mental rotation task is performed first (Toussaint & Meugnot, 2013).

Data analysis

Accuracy and response times were recorded and analyzed. Only data from correct responses were used to analyze response times. Separate ANOVAs were performed for the body mental rotation task and the non-body mental rotation task on accuracy (%) and response times (ms) with group (control vs. massage) as a between-subjects factor and session (pretest, posttests 1 and 2) and rotation (0° , 40° , 80° and 120°) as within-subjects factors. Preliminary analyses

revealed similar results for clockwise and counterclockwise directions for both body and non-body stimuli oriented to 40°, 80° and 120° angles, which lead us to average the data with the same rotation angles to increase reliability (for a similar procedure, see Wilson, Thomas, Maruff, Wilson, 2008). Post hoc comparisons were carried out with Newman-Keuls test. Alpha was set at .05 for all analyses.

Results

The body mental rotation task

ANOVA performed on the *percentage of correct responses* showed a mean effect of rotation only ($F_{3,90} = 27.09, p < .0001, \eta^2_p = .47$). Post hoc comparison revealed that correct responses were more frequent for the 0°, 40° and 80° foot rotations ($M = 95\%$; $SD = 8\%$) than the 120° rotation ($M = 82\%$; $SD = 15\%$; $ps < .0002$), regardless of the group and the session.

ANOVA on the *response times* showed a mean effect of session ($F_{2,60} = 5.25, p < .008, \eta^2_p = .15$) and rotation ($F_{3,90} = 51.66, p < .0001, \eta^2_p = .63$), as well as a significant session x group interaction ($F_{2,60} = 3.59, p = .034, \eta^2_p = .11$). Post hoc comparisons showed that response times increased from the 40° to 120° foot rotations (40°: $M = 1352$ ms, $SD = 149$ ms; 80°: $M = 1489$ ms, $SD = 162$ ms; 120°: $M = 1740$ ms, $SD = 190$ ms; $ps < .006$), while no significant differences were for the 0° to 40° rotations (0°: $M = 1298$ ms, $SD = 131$ ms; $p < 0.27$). As illustrated in Figure 2 and confirmed by post hoc comparisons, response times decreased from the pretest to the posttests following the massage ($ps < .015$) without a distinction between posttests 1 and 2 ($p = 0.62$). No significant differences were observed between the pretest and posttests for the control group ($ps > 0.41$). Moreover, response times were shorter in posttests 1 and 2 for the massage group than for the control group ($ps < .05$), while no significant difference appeared in pretest.

Figure 2. Mean response times (ms) for the body mental rotation task as a function of group (control vs. massage) and session (pretest, posttest 1 and posttest 2). Error bars indicate the standard error of the mean.

The non-body mental rotation task

ANOVA performed on the *percentage of correct responses* showed only mean effects of rotation ($F_{3,90} = 15.11, p < .0001, \eta^2_p = .33$) and session ($F_{2,60} = 3.53, p < .035, \eta^2_p = .11$). Post hoc comparisons revealed that correct responses were more frequent for the 0°, 40° and 80° number rotations ($M = 93\%$; $SD = 11\%$) than the 120° rotation ($M = 86\%$; $SD = 14\%$; $ps < .0002$), regardless of the group and the experimental session. Correct responses were also less frequent in the pretest ($M = 90\%$; $SD = 14\%$) than in posttest 1 ($M = 92\%$; $SD = 12\%$) and posttest 2 ($M = 92\%$; $SD = 12\%$), without any differences between the posttests ($p > .69$).

ANOVA performed on the *response times* showed only mean effects of session ($F_{2,60} = 4.02, p < .023, \eta^2_p = .12$) and rotation ($F_{3,90} = 16.58, p < .0001, \eta^2_p = .36$). Post hoc comparisons showed that the reaction times increased with rotation of the stimuli (0°: $M = 1128$ ms, $SD = 143$

ms; 40°: M = 1151 ms, SD = 138 ms; 80°: M = 1225ms, SD = 148 ms; 120°: M = 1369 ms, SD = 160 ms) and decreased from pretest (M = 1326ms, SD = 175 ms) to posttest 1 (M = 1148 ms, SD = 130 ms) and posttest 2 (M = 1181ms, SD = 135 ms) ($p < .022$), without any differences between posttests 1 and 2 ($p = 0.87$).

Discussion

The aim of the first experiment was to investigate the influence of massage on the mental rotation of body stimuli as an indicator of the efficiency of the sensorimotor processes. We expected that enhancing sensory input by means of a massage procedure performed by a physical therapist would activate the sensorimotor processes in older adult participants. For this purpose, we evaluated participants at pretest (i.e., before massage), posttest 1 (i.e., immediately after massage) and posttest 2 (i.e., 24 hours later). A similar pretest/posttest procedure was used for the control participants who did not undergo the massage procedure. The main results of Experiment 1 showed that the response times in the body mental rotation task significantly decreased after 15 minutes of a foot massage, while no significant differences were detected in the non-body mental rotation task between the pretest and posttests. The changes in response times reported for the body mental rotation task cannot be explained by a trade-off with response accuracy, as the percentage of correct responses did not differ between the groups regardless of the session and the rotation angles of the foot images. Importantly, the improvement in response times following the massage was maintained in the posttest performed after a 24-hour delay (in posttest 2).

These findings revealed that visual imagery performance, which was evaluated with the non-body mental rotation task, did not show any effect related to the limb-massage procedure. In contrast, motor imagery performance, which was evaluated with the body mental rotation task, was improved by a single and brief massage session (15 minutes) performed by a physical

therapist with 9 years of experience. The performance improvement was not manifested by an increase in the success of the task (i.e., the percentage of correct responses) but by the activation of the sensorimotor processes required to solve the task. Therefore, unlike the immobilization procedure which showed the negative effect of an impoverished environment on the sensorimotor representation with the slowing of the sensorimotor processes induced by input/output restriction (Meugnot et al, 2014; Toussaint & Meugnot, 2013), the present experiment highlighted the positive effect of a stimulating environment. Enhancing sensory input by massage led to rapid updates to the sensorimotor representation that may be more effective or easier to access due to an increase in proprioceptive signals. Similar observations were previously reported specifically with a vibratory stimulation procedure that activates the sensorimotor-related area (Naito, & Ehrsson, 2001; Romaiguere, Anton, Roth, Casini, Roll, 2003). The present experiment does not cast doubt on the peripheral effects of massage (on muscle stiffness and peripheral blood flow; Liu, Qi, Li et al., 2015) but shows, for the first time in the literature, the cognitive (or central) effects of a massage procedure that activates the sensorimotor processes. Further experiments will be carried out to determine whether the positive effect of massage on the processing of sensorimotor information is accompanied by a significant improvement in functional balance performances.

Importantly, the comparison between posttests 1 and 2 in the body mental rotation task revealed that the positive effect of massage on the sensorimotor processes was also found 24 hours after the intervention. These findings are interesting because they showed that a single and brief massage session performed by a physical therapist improved the functioning of the sensorimotor system and revealed that the massage is still effective one day later. However, the present experiment did not provide information on the importance of the extent of the massage area on the activation of sensorimotor processes or the duration of the massage-effect as a

function of the extent of the massage area. These points were specifically investigated in the following experiment.

Experiment 2

The second experiment aimed to replicate the positive effects of massage on sensorimotor processes, which were shown in Experiment 1, and investigate the importance of the extent of the massage area on the activation of sensorimotor processes, as well as the possibility that these peripheral activations can activate not only the sensorimotor representation of the massaged limb but also of the opposite limb. It is particularly important at the theoretical level but also at the practical level to know whether contralateral activation of the sensorimotor system could be observed following the massage of a specific limb. For example, a positive massage-induced effect on the contralateral limb could aid in the rehabilitation of an immobilized limb that is still in a cast because of a fracture by regularly reactivating the sensorimotor processes of the non-used limb.

Method

Participants

34 right-handed inpatients voluntarily participated in the experiment (mean age = 77 years, SD = 8.8 years). None of them participated in experiment 1. They were hospitalized for diverse geriatric or neurogeriatric reasons (asthenia, general state alteration, falls, chronic obstructive pulmonary disease, depression, etc.) and were still at the hospital during the experiment. All inpatients were able to walk 10 meters in less than 30 seconds. They had normal or corrected to normal vision and provided written informed consent prior to their participation

and inclusion in the study. Before testing, participants were randomly divided into 2 groups: a foot massage group ($n = 17$, mean age = 75 years, $SD = 9.2$ years, 6 males) and a foot-knee massage group ($n = 17$, mean age = 79 years, $SD = 8.1$ years, 7 males). The study protocol was in accordance with the ethical standards of the local ethics committee of the hospital center where the experiment occurred. All participants were naïve to the purpose of the experiment. However, they received written and verbal descriptions of the experimental procedure and signed consent forms indicating agreement to participate in the experiment.

Tasks and material

Participants performed 2 mental rotation tasks using either body or non-body stimuli. Both tasks were similar to those used in Experiment 1.

Procedure

The participants were divided into 2 groups: a foot massage group and a foot-knee massage group. In the foot massage group, the massage was performed for 10 minutes on the right foot of each participant. In the foot-knee massage group, massage was successively performed for 5 minutes on the right foot and 5 minutes on the right knee of each participant. In both groups, the massage technique was similar to that used in Experiment 1 and consisted of effleurage and kneading and friction with application of moderate pressure. Massage was performed by the same physical therapist who took part in the first experiment.

Similar to Experiment 1, the body and non-body mental rotation tasks were performed during three experimental sessions: before (pretest), immediately after (posttest 1) and 24 hours after the massage (posttest 2). For each session, participants practiced 2 phases (the familiarization and the

experimental phases), and the body mental rotation task was performed before the non-body mental rotation task.

Data analysis

Accuracy and response times were recorded and analyzed. Only data from correct responses were used to analyze response times. Separate ANOVAs were performed for the body and the non-body mental rotation tasks. For the body mental rotation task, ANOVAs were performed on accuracy (%) and response times (ms) with group (foot massage vs. foot-knee massage) as a between-subjects factor and session (pretest, posttest 1, posttest 2), foot (right vs. left) and rotation (0° , 40° , 80° and 120°) as within-subjects factors. For the non-body mental rotation task, ANOVAs were performed on accuracy (%) and response times (ms) with group (foot massage vs. foot-knee massage) as a between-subjects factor and session (pretest, posttest 1, posttest 2) and rotation (0° , 40° , 80° and 120°) as within-subjects factors. Post hoc comparisons were carried out with Newman-Keuls test. Alpha was set at .05 for all analyses.

Results

The body mental rotation task

ANOVA on the *percentage of correct responses* showed only a mean effect of rotation ($F_{3,96} = 35.78$, $p < .0001$, $\eta^2_p = .53$). Post hoc comparisons revealed that correct responses were significantly more frequent for the 0° , 40° and 80° rotations ($M = 95\%$; $SD = 8\%$) than the 120° rotation ($M = 89\%$; $SD = 13\%$, $ps < .0001$), regardless of the group, the foot and the session.

ANOVA on the *response times* showed mean effects of session ($F_{2,64} = 17.98$, $p < .0001$, $\eta^2_p = .36$) and rotation ($F_{3,96} = 39.18$, $p < .0001$, $\eta^2_p = .55$), as well as a group x session interaction ($F_{2,64} = 3.24$, $p < .04$, $\eta^2_p = .10$). As illustrated in Figure 3 and confirmed by post hoc comparisons,

response times significantly decreased from pretest to posttest 1 for both groups ($ps < .01$) and from pretest to posttest 2 (i.e., after a 24-hour delay) in the foot-knee massage group only ($p < .001$). No effect of the foot (right or massaged-foot vs. left or non-massaged foot) was reported.

Figure 3. Mean response times (ms) for the body mental rotation task as a function of group (foot massage vs. foot-knee massage) and session (pretest, posttest 1 and posttest 2). Error bars indicate the standard error of the mean.

To quantify how the massage improved the response times immediately after (in posttest 1) and 24 hours later (in posttest 2), we computed the Index of Performance Improvement ($IPI = [\text{response time in posttest} - \text{response time in pretest}] / \text{response time in pretest}$, expressed as a percentage) for each participant. A positive value indicated a performance improvement (i.e., a decrease in response time in the posttest), whereas a negative value indicated a performance deterioration (i.e., an increase in response time). IPI was analyzed by ANOVA with group (foot massage vs. foot-knee massage) as a between-subjects factor and posttest (posttest 1 vs. posttest

2) as a within-subjects factor. T-tests were used to examine whether the IPI significantly differed from zero.

The ANOVA revealed only a significant group x posttest interaction ($F_{1,32} = 3.91, p < .05, \eta^2_p = .09$). Post hoc comparisons revealed that performance improvement from pretest to posttest 1 (i.e., immediately after the massage) was similar in both groups, whereas the performance improvement from pretest to posttest 2 (i.e., 24 hours after the massage) was better in the foot-knee massage group than the foot only massage group ($p < .02$; Figure 4). Moreover, in the foot massage group, the IPI was significantly smaller in posttest 2 than posttest 1 ($p < .05$). T-test analyses revealed that the IPI was significantly different from zero in posttest 1 for the foot massage group ($t_{17} = 5.30, p < .0001$) and the foot-knee massage group ($t_{17} = 5.11, p < .0001$), as well as in posttest 2 for the foot-knee massage group ($t_{17} = 5.70, p < .0001$), whereas the IPI did not differ from zero in the foot massage group ($t_{17} = 1.43, p = .17$).

Figure 4. Index of Performance Improvement (%) as a function of group (foot massage vs. foot-knee massage) and posttest (posttest 1 vs. posttest 2). Errors bars indicate the standard error of the mean.

The non-body mental rotation task

ANOVA on the *percentage of correct responses* showed only a main effect of rotation ($F_{3,96} = 19.01, p < .0001, \eta^2_p = .37$). Post hoc comparisons revealed that correct responses were significantly more frequent for the 0° and 40° rotations ($M = 93\%$; $SD = 15\%$) than the 80° ($M = 89\%$; $SD = 18\%$, $p < .001$) and 120° rotations ($M = 82\%$; $SD = 23\%$, $p < .0001$), as well as the 80° compared to 120° rotation ($p < .001$).

ANOVA on the *response times* showed only a main effect of rotation ($F_{3,96} = 11.04, p < .0001, \eta^2_p = .27$). Post hoc comparisons revealed that response times were significantly lower for the 0° and 40° rotations ($M = 1128\text{ms}$; $SD = 150\text{ ms}$) than the 80° ($M = 1263\text{ ms}$; $SD = 162\text{ ms}$, $p < .001$) and 120° rotations ($M = 1492\text{ms}$; $SD = 206\text{ ms}$, $p < .0001$), as well as for the 80° and 120° rotations ($p < .0001$), regardless of the group and the session.

Discussion

The second experiment had 2 specific aims. First, it was carried out to examine whether the extent of the massage area (i.e., massage performed on the foot only or on the foot and the knee of the right leg) differentially impacted the reactivation of the sensorimotor processes. Second, it was carried out to examine whether contralateral activation might be observed following massage performed for 10 minutes on the right leg (i.e., activation of the sensorimotor representation of the left leg not massaged by the physical therapist). With the exception of the massage, the pre/posttest experimental procedure was similar to Experiment 1. The main results of Experiment 2 revealed that, for the body mental rotation task, response times similarly decreased from pretest to posttest 1 in both groups (the foot massage group and the foot-knee massage group), but differences between groups appeared in posttest 2, with better improvement in response times following a 10-minute massage on both the foot and the knee. Importantly, the

positive effects of massage were detected for both the right foot (the massaged foot) and the left foot (the non-massaged foot) regardless of the posttest (i.e., immediately after the massage and 24 hours later). No difference between groups appeared in the non-body mental rotation task.

The results of Experiment 2 confirmed those of Experiment 1, in particular the positive effect of a single and brief (10 minutes) massage session performed by an experienced physical therapist on the activation of the sensorimotor processes. Moreover, when the massage-induced effects were evaluated immediately after the massage session, no difference appeared as a function of the extent of the massage area. The participants actually took less time to identify the laterality of foot images when the task was performed after the massage in both groups (foot massage and foot-knee massage). However, the present experiment showed that the extent of the massage area was important when the effects of massage were assessed 24 hours later. In that case, the activation of the sensorimotor processes lasted longer when the massage area was more extensive. Therefore, activating a larger body representation via a massage procedure on both the foot and the knee during a brief session is better than concentrating the massage on a specific area (the foot only) during the same period. This suggests the need to diversify the location of the massage to stimulate the sensorimotor system in a sustainable manner.

In Experiment 2, massage performed on the right leg alone activated not only the sensorimotor representation of the right leg but also that of the opposite leg. The results showed that improvement in response times following the massage was similar regardless the laterality of the foot that needed to be identified. These findings revealed that, for a given effector system (the lower-limb in the present experiment), massage on one side of the body activated the sensorimotor representation of the opposite side. Similar results were previously observed following the restriction of input/output of signal processing via an immobilization procedure (Meugnot et al., 2016; Toussaint & Meugnot, 2013), which resulted in a slowdown of the

sensorimotor processes for both the immobilized and the non-immobilized effectors. In the same vein, other studies have reported a positive transfer of a learned task to the contralateral side of the body (Vangheluwe, Wenderoth, Swinnen, 2005). In all cases, it may be that the interhemispheric exchange of sensorimotor information was made possible by the corpus callosum, which is considered a central structure in hemisphere interconnection processes (Franz, Eliassen, Ivry, Gazzaniga, 1996). In the present experiment, we clearly showed that the central consequence of the enhancement of sensory input by unilateral massage was the induction of both ipsilateral and contralateral activation of the sensorimotor system, which supports the existence of an effector-independent sensorimotor representation (Vangheluwe et al., 2005). For physical therapists, the bilateral activation reported in the present experiment is very interesting because it demonstrates the possibility of using massage on one side of the body alone in case of contraindications, e.g., when an older adult is wearing a cast due to a fracture (of the hand, of the foot) or when he experiences severe pain with touch, limb manipulation on one specific side of his body.

Conclusion

The present 2 experiments offer support for the hypothesis that a single and brief massage session performed by an experienced therapist has functional effects. Massage activates the sensorimotor receptors that favor the functioning of the related sensorimotor system. The positive impact of massage is not only immediate but lasts up to 24 hours later. Importantly, the activation of the sensorimotor representation may partially depend on the extent of the area and may concern not only the massaged leg but also the contralateral leg.

Overall, these findings confirmed that peripheral activation via a massage had a specific impact on the sensorimotor processes and can help patients cope with the slowdown of the signal

processing related to advancing age (Saimpont et al., 2009; 2013). These findings highlighted the impact that massage therapies could have on geriatric care, in particular during programs for the prevention of falling or rehabilitation of autonomy. However, further studies should be carried out to examine whether the possibility of modulating the sensorimotor cortex activity by manipulating sensory inputs via massage is accompanied by improvements in motor function or produces specific improvements in rehabilitation (i.e., better motor performance for inpatients or quicker improvements). It may be that unlike immobilization, which induces a slowdown of sensorimotor processes and a deterioration in motor performance (Bassolino et al., 2012; Hubert et al., 2006), the massage-induced effect (i.e., activation of sensorimotor processes) is accompanied by an improvement in motor performance for older adults.

Finally, in the context of evidence-based practice, the present experiment showed that using body mental rotation tasks can be an adequate tool to objectively assess the central improvement of motor function following various rehabilitation programs in patients experiencing from sensorimotor system disturbances. Examining response times when identifying body-parts stimuli allows the physical therapist to objectively know the central effects of rehabilitation, i.e., whether specific sensorimotor representations of patients have improved or not, or whether other rehabilitation sessions or techniques are required to maximize the activation of the sensorimotor processes. Although further studies are needed, it is possible that the activation of the sensorimotor processes favors motor control in older adults inpatients.

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