Title: Left/right limb judgement task performance following total knee replacement.

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Abstract

Purpose: Working body schema (WBS) of the limbs may be indirectly assessed using left/right limb judgement (LRLJ) task performance. This study aimed to investigate if: 1) Total Knee Replacement (TKR) patients perform LRLJ tasks with reference to their WBS; 2) patients have a disrupted WBS following a TKR for the replaced knee compared to the contralateral knee; and 3) lower limb-based LRLJ task performance changes following post-surgical rehabilitation using change in upper limb-based LRLJ task performance as a control.

Methods: In a convenience sample (n=18, age 69±7yrs, 12F 6M) of TKR patients <1month post-surgery, WBS was assessed using LRLJ task performance for the upper (pictures of the hand) and lower limb (pictures of the foot) before and after rehabilitation. Accuracy and response time (RT) were analysed using a series of 2x2x2 ANOVAs.

Results: LRLJ task performance for images corresponding with the operated and non-operated side were comparable for accuracy (p=0.83) and RT (p=0.28). Accuracy for hand images was comparable from baseline to post-rehabilitation (p=0.54) whereas accuracy for feet images increased significantly (p=0.03). Responses for awkward posture images were significantly slower than for more natural posture images (p=0.001).

Conclusions: LRLJ task performance data reflected the typical biomechanical constraints indicative of implicit motor imagery being performed by patients. There was no evidence of a disrupted LRLJ task performance for the replaced knee compared to the contralateral knee. Following post-surgical rehabilitation, patients' lower limb LRLJ task performance improved whilst upper limb LRLJ task performance remained unchanged. These findings are the first to show that WBS improves with rehabilitation following TKR, and this may explain some of the clinical improvements observed. Undertaking LRLJ tasks could theoretically be a useful adjunct to current post-TKR rehabilitation.

Key words: Total knee replacement; working body schema; Implicit motor imagery.

Introduction:

The total knee replacement (TKR) has become an increasingly popular surgical procedure for the treatment of knee osteoarthritis when conservative treatments have failed.[1] While patient outcomes following joint replacement are broadly positive, approximately 18% of patients report only a poor to fair outcome[2] and reports of continuing high levels of pain unrelated to mechanical structural dysfunction are not uncommon.[3] The central nervous system may present a novel therapeutic target for maximising the recovery of these patients.

The brain maps that integrate the motor cortices of different bodily regions have been referred to as working body schema (WBS).[4] An efficient WBS enables accurate planning of a coordinated movement. There is a growing body of evidence that chronic pain sufferers have a distorted WBS corresponding to the body part in pain.[5-6] It is postulated this disruption may play a role in maintaining an individual's pain state in those suffering from a range of chronic pain conditions. [7-11]

A disruption in the WBS in those with longstanding knee osteoarthritis (OA) pain has been demonstrated.[12] Using a left/right limb judgement (LRLJ) task performance, where images of feet were presented to the patients who must immediately judge whether the image is of a left or a right foot, the accuracy of left/right judgements was shown to be poorer in those with knee OA compared with healthy controls.[12] WBS disruptions have also been reported in people with hand OA.[13] This altered WBS may contribute to the maintenance of pain in patients with OA. It is possible such a disruption is present in patients following a TKR, as many will have suffered from OA knee pain for some time prior to surgical intervention. This disrupted WBS may partially explain why some patients report continuing high levels of pain and dysfunction post-surgery.

To date, no studies have investigated the integrity of the WBS of patients with a TKR or how that WBS changes following a course of rehabilitation. No studies have quantified LRLJ task performance in patients with TKR or the strategies used during the performance of such a task. This study aimed to investigate if: 1) TKR patients perform LRLJ tasks using implicit motor imagery (i.e. with reference to their WBS); 2) patients have a disrupted WBS following a TKR for the replaced knee compared to the contralateral knee; and 3) lower limb LRLJ task performance changes following post-surgical rehabilitation using change in upper limb LRLJ task performance as a control. Throughout, LRLJ task performance was assessed using pictures of the feet for the lower limb and pictures of the hand for the upper limb.

Methods:

Participants:

A convenience sample of individuals who had received a TKR and were referred to physiotherapy for post-operative rehabilitation were recruited into this study between September 2013 and August 2014. Participants were included if they were ≥18 years of age, English speaking, had the capacity to provide informed consent, and had undergone TKR surgery within the past month. Participants were excluded if they had a history of a neurological condition, a history of contralateral TKR or invasive knee surgery within the past six months, a history of foot or ankle surgery (on either limb) in the past six months, an infection of the knee, a visual impairment that would impede ability to complete the LRLJ task performance. All participants provided written informed consent prior to participation.

Ethical approval for the study was granted by Teesside University's School of Health and Social Care Governance and Research Ethics committee [086/13] and The NHS NRES committee North East – Newcastle and North Tyneside 2 [13/NE/0244]. The study was conducted in line with the Declaration of Helsinki.

Procedure:

Participants referred for post-operative rehabilitation were invited to participate in the study within one month of their operation. Baseline data were collected prior to receiving any post-operative rehabilitation. Demographic information was initially collected (age, gender, body mass index, hand/foot dominance, side of TKR, number of days' post-surgery, length of time of knee pain prior to surgery, any current pain in the contralateral knee or upper limbs). Limb dominance was assessed by asking participants which foot they would kick a ball with and which hand they write with. Two knee-specific standardised physical function tests were carried out to assess active range of motion (AROM) of the operated knee in sitting and the ability to do an active straight leg raise (ASLR) in supine.[14-16] Three self-reported questionnaires were completed; knee pain (average pain in the last 24h, 100mm pain Visual Analogue Scale (VAS) with 0 = no pain and 100 = worst pain imaginable)[17] Knee-Injury Osteoarthritis Score Short-Form (KOOS-PS)[18] and the Euro-Qol 5D-5L (EQ-5D-5L).[19] Each participant then completed a LRLJ task for the upper and lower limb. Following a course of rehabilitation (involving exercise in both a one-to-one and group setting focusing upon active range of motion, strength, balance, and flexibility) participants were invited back for a follow up assessment. All the baseline data was collected again at this point.

Left Right Limb Judgement task:

In the LRLJ task images of the upper limb (hands) and lower limb (feet) were presented to the participant on a computer screen. The participants were required to identify whether the image was a left or right image i.e. left/right judgement. The accuracy and response time (RT) of identification were recorded. The left/right judgements used line drawings presented to the participants via a computer based program (E-Prime® 2.0 Psychology Software Tools, Inc.). The drawings were replicated by permission from the study by Parsons et al[20] and consisted of 48 images each depicting a foot in varying laterality (left or right), view (big toe, dorsum, sole or heel) or rotation (0, 60, 120, 180, 240, 300°) of the lower limb. Upper limb images were displayed in five different views of each hand (front, back, little finger, thumb and wrist) and twelve different degrees of rotation (0-330° each separated by 30°).

Participants were seated on a chair with a monitor positioned on a table at eye level (60cm distance) and hands positioned palm down on the table with the index finger of each hand resting on the keyboard (left hand on 'V', right hand on 'N'). A practice run of eight images was performed (four hands, four feet) to familiarise with the task followed by a further 48 hand images and 48 foot images. This was performed once for lower limb images and once for upper limb images. Each image was presented in the centre of the screen followed by a small fixation cross for a random period between 1,000 and 1,500 ms, images remained on the screen until a response was made. Participants were prompted to keep their head, upper limbs and lower limbs motionless during the task apart from the responding finger.

Data analysis:

Accuracy for each trial reflected the correct or incorrect laterality judgment (i.e. left or right) for each image presented. Response time (RT) was the period in milliseconds from the onset of each image to when a response (key press) was made. Response times faster than 500ms and slower than 10000ms were excluded from the RT analysis; this accounted for less than 1% of all responses. Also, only correct responses were entered for the RT calculations. The median RT for each participant in line with the factors of interest (see below) was then entered for statistical analysis. Accuracy and RT data were analysed using a series of analyses of variance (ANOVA). To address aim 1 a 2x2x2 ANOVA with repeated measures was conducted to explore biomechanical constraints across accuracy and RT data; here the factors were Limb (hand, foot), Time (Time 1, Time 2) and Awkwardness (natural, awkward). Biomechanical constraints refer to the established finding in hand and foot-based LRLJ task performance, where the time to recognise the laterality of the limb presented is closely associated with the time it takes to actually move the limb from its current position to the position pictured.[21] Accordingly, regardless of the degree of rotation away from neutral, response times are slower (and accuracy poorer) for images reflecting more awkward limb positions from a biomechanical perspective.[22-25] These awkwardness effects provide confidence that individuals are mentally rotating their own limb and are therefore considered confirmatory of implicit motor imagery. For these analyses, only images where biomechanical constraints have previously been clearly identified were included. This included all views for images of hands (back, palm, thumb, wrist) but only half the views (sole, big toe) for images of feet.[24-25] Neutral images of left hands (fingers pointing upwards) reflect more natural (medial) postures when rotated clockwise and more awkward (lateral) postures when rotated anti-clockwise, with the reverse pattern for images of right hands. For images of feet, the categorisation of images is based on the same principles though the neutral positions are not always ‘toes up’. The categorisation of images followed the influential approach taken by Parsons. [24] To address aims 2 and 3, a 2x2x2 ANOVA with repeated measures, the factors being Limb (hand, foot), Time (Time 1, Time 2) and Side (affected, unaffected), was conducted for Accuracy and RT.

In addition we undertook a secondary analysis of our data to explore the potential relationship between pain and WBS. Specifically, we carried out correlations between: A) the change in pain (averaged between both legs) and the change in LRLJ task accuracy (for both legs) B) the change in pain for the affected leg and the change in LRLJ task accuracy for the affected leg and C) the change in pain for the unaffected leg and the change in LRLJ task accuracy for the unaffected leg.

Results:

Eighteen individual's provided baseline data [age 68.9±7.3yrs (mean±SD); gender 12F, 6M; BMI 30±6kg.m^{-2}; duration of knee pain 42months (24-51months) [median (Interquartile Range)]]. The average length of time post-operation at baseline was 25days (18-29days) [median (Interquartile Range)]. All participants were right hand and right leg dominant. Four participants reported upper limb pain. Fifteen participants provided follow-up data on completion of their post-operative rehabilitation on average 89days (73-97days) [median (Interquartile Range)] post-surgery. From pre to post post-surgical rehabilitation, on average, there was decreased pain in the operated knee, increased pain in the contralateral knee, improved knee function (operated side) and quality-of-life. The participant characteristics are presented in table 1.

Insert table 1 here

Limb x Time x Awkwardness

The LRLJ task performance data for the hand and the feet at pre and post rehabilitation are shown in table 2. Comparing performance for natural vs. awkward images suggested participants demonstrated the typical biomechanical constraints that are a hallmark of implicit motor imagery for limb laterality recognition tasks (See table 3). The related ANOVA for RTs revealed an awkwardness effect [F(1,14) =16.63, p=0.001] with responses for images showing more awkward postures (mean = 2455ms) being significantly slower than responses for more natural postures (mean = 1986ms). There was also a significant main effect for Limb [F(1,14)=20.32, p= 0.0005), but there were no other significant main effects or interactions (*Time*, F(1,14)=3.83, p=0.07; *Limb*Time*, F(1,14)=0.43, p=0.52; *Limb*Awkwardness*, F(1,14)=0.54, p=0.48; *Time*Awkwardness*, F(1,14)=0.22, p=0.65; *Limb*Time*Awkwardness*, F(1,14)=0.26, p=0.62) suggesting participants consistently used implicit motor imagery to complete the task for images of both hands and feet across both time points (Figure 1). The corresponding ANOVA for accuracy data again showed a significant main effect for *Limb,* F(1,14)=29.79, p=0.0008; participants were more accurate in responding to images of hands (mean = 0.9) than feet (mean = 0.69). Accuracy data revealed no other significant main effects or interactions (*Time*, F(1,14)=0.30, p=0.59; *Awkwardness,* F(1,14)=1.76, p=0.21; *Limb*Time*, F(1,14)=0.03, p=0.87; *Limb*Awkwardness*, F(1,14)=1.02, p=0.33; *Time*Awkwardness* = F(1,14)=0.72, p=0.41; *Limb*Time*Awkwardness*, F(1,14)=0.03, p=0.87).

Insert figure 1 here

Insert table 2 and 3 here

Limb x Time x Side

The accuracy ANOVA again revealed a significant main effect of Limb [$F(1,14)=22.26$, $p<0.0003$) but also here a Limb x Time interaction [$F(1,14)=4.54$, $p=0.05$). There were no other significant main effects or interactions (Time, $F(1,14)=3.34$, $p=0.09$; Side, $F(1,14)=0.06$, $p=0.82$; Limb*Side, $F(1,14)=0.04$, $p=0.85$; Time*Side, $F(1,14)=0.41$, $p=0.53$; Limb*Time*Side, $F(1,14)=2.06$, $p=0.17$). The simple effects of the interaction showed that accuracy for images of hands was comparable across the two time points (Time 1 = 0.87, Time 2 = 0.88, $F(1,14)=0.40$, $p=0.54$) whereas accuracy for images of feet increased significantly between the pre and post testing sessions (Time 1 = 0.68, Time 2 = 0.76, $F(1,14)=5.77$, $p=0.03$) (Figure 2).

Insert figure 2 here

Response times for images of hands (mean=1895ms) were faster than for images of feet (mean=2310ms) leading to a significant main effect of Limb [$F(1,14)=14.49$, $p=0.002$). The response time ANOVA revealed no other main effects or interactions (Time, $F(1,14)=0.52$, $p=0.48$; Side, $F(1,14)=0.32$,$p=0.58$; Limb*Time, $F(1,14)=1.63$, $p=0.22$; Limb*Side, $F(1,14)=1.60$, $p=0.23$; Time*Side, $F(1,14)=2.70$, $p=0.12$; Limb*Time*Side, $F(1,14)=0.76$, $p=0.40$).

Secondary exploratory analysis

There was no evidence of a relationship between: A) the change in pain (averaged between both legs) and the change in LRLJ task accuracy (for both legs) [A) Spearman's rho = 0.12, p = 0.40]   B) the change in pain for the affected leg and the change in LRLJ task accuracy for the affected leg [Spearman's rho = -0.09, p = 0.80] and C) the change in pain for the unaffected leg and the change in LRLJ task accuracy for the unaffected leg [Spearman's rho = 0.04, p = 0.90].

Discussion:

This is the first study to quantify LRLJ task performance in TKR patients. LRLJ task performance data reflected biomechanical constraints that were indicative of implicit motor imagery being performed by patients.[20,25] This finding provides confidence that participants used implicit motor imagery when making a judgement about the images with which they were presented. Response times and accuracy were comparable for images corresponding with the operated side compared to the unaffected side for the lower limb. Thus there was no evidence of a disrupted WBS for the limb where the knee was replaced compared to the contralateral knee. Finally, over the course of post-surgical rehabilitation, accuracy of judging the laterality of foot images improved from pre to post treatment while the accuracy for hands was unchanged. This suggests that improvements in WBS after lower limb rehabilitation were limb-specific (i.e., limited to the lower limb).

Performance of the LRLJ task was better for natural rather than awkward postures. Thus, patients demonstrated performance reflecting biomechanical constraints that have become the *hallmark* of implicit motor imagery when performing LRLJ tasks. It has been demonstrated that patients do not always use this strategy when completing LRLJ tasks .[25] When alternative (non-motor) imagery-based strategies are used, awkward positions are typically recognised in a similarly accurate and fast manner to natural positions. Using alternative strategies theoretically provides little insight into the patients WBS and it would likely be ineffective for enhancing WBS if the LRLJ task performance was being used for therapeutic purposes. Our data demonstrate that TKR patients' use implicit motor imagery strategies when performing LRLJ tasks.

No effect was found for images corresponding with the operated vs. contralateral side for either accuracy or RT. While some studies have shown poorer performance for an impaired or painful side for either response time [4,8,26] or accuracy[12,27] reflecting a difficulty with mental rotation of the affected limb, others have reported a more general reduction rather than it being specific to one side.[12,28-30] In all these cases, LRLJ task performance have been interpreted as patients having difficulty with implicit motor imagery consistent with the findings of the present study. If the LRLJ task performance is measuring the efficiency of the WBS should we expect to see a difference between the affected and unaffected side? The conflicting results in the literature suggest further understanding is required as to why some patient groups demonstrate slower response times compared to controls and others do not and why some studies have demonstrated asymmetric response times between the affected vs. unaffected side and others have shown no asymmetry. The presence of bilateral pain may have been a complicating factor when analysing LRLJ task performance in the present study with respect to side differences. The contralateral knee was nearly as painful pre-rehabilitation and more painful post-rehabilitation than the affected knee. Given that pain has been shown to be associated with impaired LRLJ task performance[4,8,26,27] it may be that WBS (i.e, task performance) for both knees was impaired. The absence of an age and gender matched pain free control group prohibited this possibility being explored, which is a limitation of this study.

A change over time in the accuracy scores of the LRLJ task performance was only apparent in the feet. This improvement appears consistent with self-reported function and reflects the improved ability to simulate and actually move the knee/limb post rehabilitation. Hand accuracy scores did not demonstrate a significant change over time suggesting the changes found for feet were indicative of an improvement in the WBS of the knee rather than practice effects of the test itself. Improvement in WBS has been shown to mirror improvements in pain and function in a number of clinical conditions such as phantom limb pain[7] and complex regional pain syndrome.[6] The reasons for improvement can only be speculated upon though it is likely that the large amount of physical movement of the knee associated with rehabilitation, and or the reduction in pain, resulted in improved WBS and thus LRLJ task performance. However, we tentatively investigated the potential role of pain reduction in a series of exploratory correlational analysis and found no evidence of a relationship between change in pain and change in LRLJ performance.

Limitations section

The images used to investigate LRLJ knee performance used pictures of the feet. The use of foot images in the LRLJ task performance to reflect the WBS of the knee/whole limb has been adopted in previous studies.[12] It is proposed the mental rotation of the foot will also involve the associated mental rotation of the knee. Key strengths of this study was the use of standardised images[20] and software (E-Prime 2.0) that allowed millisecond precision. Additionally, the experimenter was present for all testing, ensuring that participants all responded in the same way and maintained the same position throughout testing. Variation in these aspects can modulate data from LRLJ task performance considerably and are a limitation of studies using LRLJ task performance via online data collection. Furthermore, this study identified better LRLJ task performance for hands than feet for both accuracy and response time which is in line with previous literature,[31-32] providing confidence in our data. As this is an observational study no claims of cause and effect can be made. Additionally, the inclusion of a control group of non-TKR patients would have been beneficial.

Clinical implications

Implicit motor imagery could potentially be used in clinical rehabilitation to improve recovery. The underlying mechanisms of implicit motor imagery is such that it activates similar areas in the brain to those activated during actual movement.[33] The associated aim is therefore to elicit this activation without the person experiencing pain. By doing so, implicit motor imagery aims to un-pair the typically strong temporal association between movement and pain. It has been tentatively suggested that implicit motor imagery could be used as an intervention for TKR patients who have significant pain post-surgery.[34] Our data suggest that the WBS may be impaired post-surgery and it has the capacity to improve with standard rehabilitation. Our data also suggest that TKR patients can utilise implicit motor imagery strategies when undertaking LRLJ task performance. Further research is required to fully investigate the presence and extent of any WBS deficit in TKR patients, the potential clinical implications associated with WBS deficit in this patient group and the potential clinical utility of implicit motor imagery as an adjunct to care.

Conclusions

In conclusion, this study provides the first evidence to suggest that WBS of the lower limb in people after TKR selectively improves following rehabilitation (i.e., no improvement in LRLJ task performance for upper limb images). Importantly, the LRLJ lower limb task is valid in this population - demonstrating typical RT and accuracy hallmarks of implicit motor imagery performance. Given the small sample and observational nature of the study, no firm clinical recommendations can be made. Further studies should evaluate whether implicit motor imagery training via LRLJ tasks may be a useful adjunct to current post-TKR rehabilitation given the positive effect of this training in other chronic pain conditions.

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Conflicts of interest

CGR has a patent under submission for a sensory discrimination training class II medical device which has the potential to improve Working Body Schema. Neither TDP nor CR have any conflicts of interest to declare. This was an unfunded study.

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Table 1: Participant characteristics

	Pre-rehabilitation (n=18)	Post-rehabilitation (n=15)	p-value
AROM flexion (degrees)	90 (12)	107 (6)	0.001*
AROM extension (degrees)	6 (5)	2 (3)	0.006*
ASLR (yes)	17	15	
Knee pain VAS operated side (100mm)	38.9 (25.2)	22.9 (20.6)	0.057
Knee pain VAS contralateral side (100mm)	11.5 (14.7)	25.7 (26.2)	0.075
Current knee pain contralateral side (yes)	12	12	
KOOS-PS (%)	37.4 (11.2)	28.4 (13.3)	0.043*
EQ-5D-5L (0-1)	0.64 (0.16)	0.72 (0.11)	0.136

Table Legend: Data presented as mean (1SD). AROM = Active range of motion. ASLR = Active straight leg raise. VAS = Visual analogue scale. KOOS-PS = Knee-Injury Osteoarthritis Score Short-Form (KOOS-PS). EQ-5D-5L = Euro-Qol 5D-5L (EQ-5D-5L). Post rehabilitation AROM data was only available for 13 participants

Table 2: Response time and accuracy pre and post rehabilitation

	Pre rehabilitation		Post rehabilitation	
	Replacement/ Non dominant	Contralateral/ Dominant	Replacement/ Non dominant	Contralateral/ Dominant
<u>Feet</u>				
RT (ms)	2276 (666)	2232 (674)	2239 (823)	2416 (912)
Accuracy (%)	0.70 (0.16)	0.68 (0.18)	0.77 (0.18)	0.75 (0.18)
<u>Hands</u>				
RT (ms)	2003 (529)	1967 (692)	1794 (432)	1796 (537)
Accuracy (%)	0.86 (0.12)	0.85 (0.13)	0.88 (0.09)	0.90 (0.09)

Data are presented as mean (SD). RT = response time. Replacement and contralateral refers to images for the replaced knee and the opposite knee. Non dominant and dominant refers to the images for hand.

Table 3: Response time and accuracy for awkward and natural limb position images

	Pre rehabilitation		Post rehabilitation	
	Awkward	**Natural**	**Awkward**	**Natural**
Feet				
RT (ms)	2827 (1070)	2328 (699)	2734 (1017)	2137 (855)
Accuracy (%)	66 (24)	70 (22)	68 (24)	71 (22)
Hands				
RT (ms)	2274 (721)	1885 (697)	1993 (563)	1588 (432)
Accuracy (%)	86 (14)	89 (12)	88 (12)	95 (08)

Data are presented as mean (SD). RT = response time.

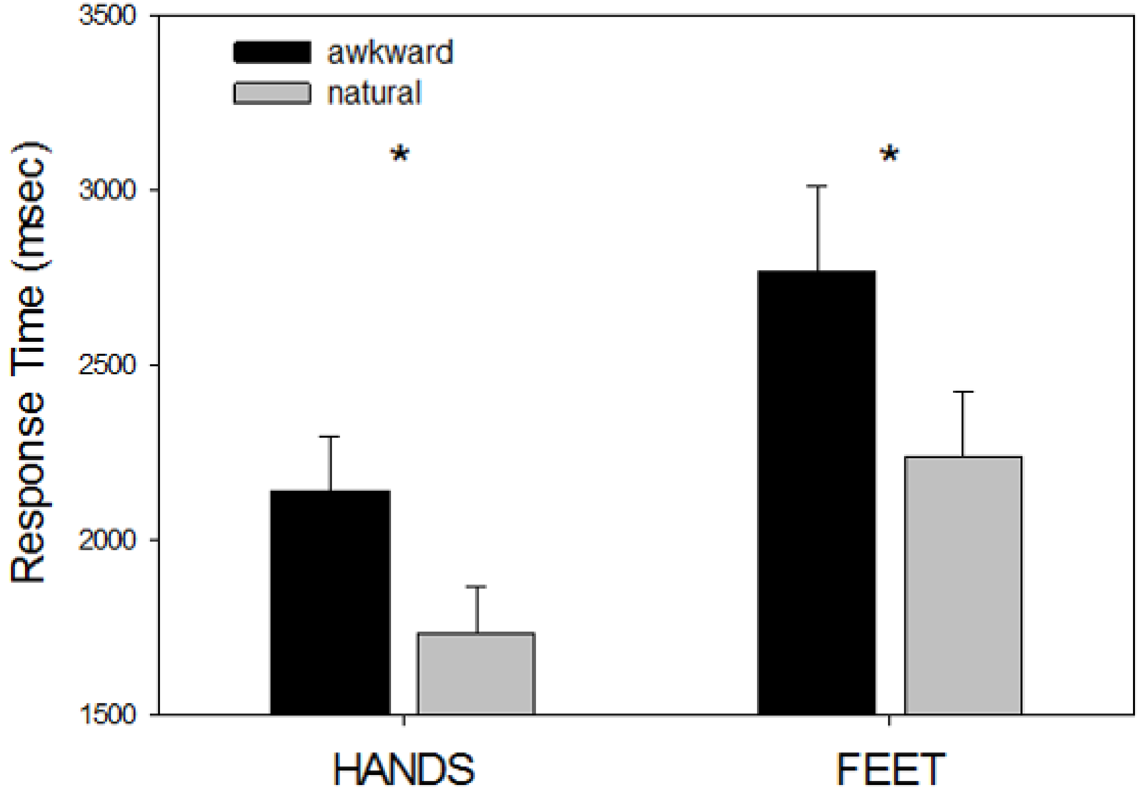

Figure 1: LRLJ task performance RT for awkward and natural images.

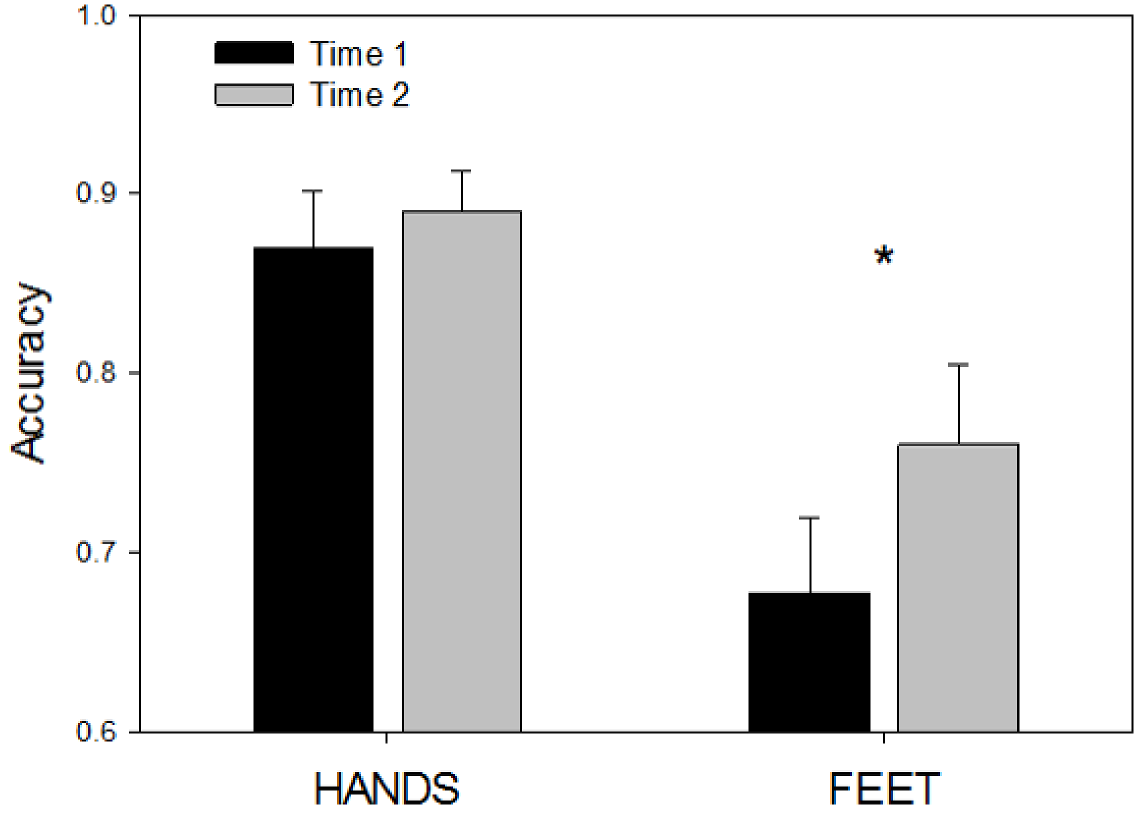

Figure 2: LRLJ task performance accuracy before (Time 1) and after (Time 2) rehabilitation.